EVOLUTION IN ENGINEERING DISPOSITIONS AND THINKING AMONG CULTURALLY DIVERSE STUDENTS IN AN UNDERGRADUATE ENGINEERING PROGRAMME

by

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Abstract

This study investigated the evolution in engineering dispositions and thinking among culturally diverse students through their enculturating experiences in team-based engineering design courses in second year electrical and computer engineering. Ethnographic methods (participant observation, semi-structured interviews) were employed to collect data in classrooms, labs, and project rooms over a seven-month period. Five culturally diverse students' trajectories illustrate the processes and products of the evolution of students' engineering dispositions and thinking. Five key conditions for students in navigating a shift from traditional to team-based project modes of study were identified: i) being willing to buy into working as part of a team, ii) being willing and able to claim a viable role as an engineer, iii) grappling with competing identities in becoming an engineer, iv) navigating different perspectives on engineering projects, and v) being able to self and co-regulate while under a complex, heavy workload. Cultural, language, and personal factors mediated culturally diverse students' capacities to satisfy these five conditions. The study offers the following implications for fostering the engineering dispositions and thinking of culturally diverse students: i) explicit and meaningful orientation of students towards team-based project modes of study; ii) fostering of metacognitive awareness and capacity with respect to teamwork processes; iii) harnessing cultural diversity for promoting intercultural skills; iv) focus on English language competencies for functioning in formal, informal, and non-formal academic contexts; v) formative and summative assessment to support this mode of study; vi) self-regulation and socially shared regulation skills for sustaining the success of individuals and teams. The study offers the following implications for employing the theoretical framework in future research: i) greater clarity on the evidence required to identify stages of change; ii) greater clarity on establishing the existence and nature of inner contradictions that drive change; iii) exploration of methodological opportunities and limitations on capturing change in students. This study offers an exemplar for researching evolution and change in students in complex educational contexts.

Preface

The research activities for this doctoral thesis were conducted with ethics approval (UBC BREB #H11-03181). This thesis is an original unpublished work created solely by myself, Christopher David Campbell, with the kind guidance and support of my supervisors: Drs. David Anderson, Samson Nashon, and Philippe Kruchten of The University of British Columbia. Funding for this doctorate research was generously provided by the Social Sciences and Humanities Research Council of Canada (Doctoral Fellowship Award #752-2012-2547) and the Killam Trusts (Doctoral Scholarship).

Table of Contents

List of Tables

List of Figures

Glossary

Acculturation
The dual process of cultural and psychological change that occurs as a result of contact between two or more cultural groups that, over the long term, cause change at the group and individual level (Grusec & Hastings, 2014).

Culturally diverse students
Non-native English speaking foreign students who required English language preparation prior to commencing their undergraduate studies in Canada. These students either came to Canada after finishing high school in their home countries or attended a Canadian high school for up to five years before their undergraduate studies.

Dispositions
The sum total of an individual's characteristic tendencies, such as basic temperament, attitudes, inclinations, and drives (Corsini, 2002, p. 288).

Enculturation
The shaping of values and behavior through the immersion of an individual in a culture (Herskovits, 1948).

Enculturation processes
Those forces, deliberate or not, in a given network of influences (e.g., adults, peers, school) that limit, direct, and shape an individual. These result in the individual having greater competence in the language, rituals, and values of the culture in which they are immersed (Grusec & Hastings, 2014).

Engineering Graduate Attributes
Twelve attributes (a knowledge base for engineering, problem analysis, investigation, design, use of engineering tools, individual and teamwork, communication skills, professionalism, impact of engineering on society and the environment, ethics and equity, economics and project management, and life-long learning) required of engineering graduates and required for program accreditation in Canada (Engineers Canada, 2014).

Engineering dispositions
Following from Corsini (2002) in the foregoing definition of *dispositions*, this is defined for the purposes of this study to be "an individual's characteristic tendencies, such as basic temperament, attitudes, inclinations, and drives" (p. 288) as they relate to engineering work.

Engineering thinking
Patterns of intellectual behaviour or habits of mind with respect to engineering work. Engineering thinking entails a composite of skills, attitudes, past experiences, and proclivities and includes such things as systems thinking, creative problem solving, persistence, and collaboration.

Generalized agency
Leont'ev's (1978) concept of the human capacity to gain, through participation in activity with others, some degree of control over societal conditions so as to improve one's life conditions and maximize one's capacity to act.

Generalized possibilities to act
Expressions of what a particular culture or activity system enables or constrains in individuals, which exist at a societal level (Holzkamp, 2013).

Inner/internal contradictions
Tensions that emerge between elements of an activity system (i.e., subject, tools and signs, object/motive, rules, division of labour, community) that drive evolution and change in the activity system itself and in the individuals, who are an integral part of activity (Leont′ev, 1978)

Irreducible unit of analysis
Activity theory takes activity itself as a unit of analysis, meaning that the individual and the other elements of activity together form an integral, indivisible whole. The elements of activity are dialectically related in that they pre-suppose each other (i.e., are mutually constitutive), have the potential to influence and transform one another, and so cannot be disentangled from each other in analysis (Leont′ev, 1978).

Learning as enculturation
Entailing that a person's development occurs through their immersion in a culture – a professional disciplinary culture, in this case - rather than through the transmission and acquisition of information and skills by a person (Hodson & Hodson, 1998a, 1998b).

Object/motive
A collective societal need that exists within an activity system which holds an orienting and organizing function for the activity and can exist as a material entity in the world or as how people envision it once created (Roth, 2014).

Psychic reflection
The process by which subjective images of objective reality are patterned in particular ways and on different levels in the mind of a person. Similarly, the person's mind also patterns practical activity in the real world, of which she or he is a constitutive part (Leont′ev, 1978).

Subjective reasons for action
A mediating layer between the structure of activities and the agency of individuals, in which societal conditions, available as "constellations of meaning" (Holzkamp, 2013) to an individual, become potential premises for an individual's reasons for their actions.

Symmetry
This term from Actor Network Theory (Latour, 1987) describes how human and non-human entities "assemble collectives or 'networks' that produce force and other effects: knowledge, identities, routines, behaviours, policies, curricula, innovations, oppressions, reforms, illnesses, and on and on" (Fenwick & Edwards, 2011, p. 2).

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I would like to thank all who made this degree possible through their time, thoughts, guidance, and generosity. Thanks, Drs. Samson Nashon and David Anderson, for being wonderfully supportive through the whole PhD from the time I visited you in September 2009 with an idea until the end - and the beginning of a new path. David: 日本でいつかあいましょう！ Samson: I don't know how to thank you and am going to miss the talk. Thanks to Dr. Philippe Kruchten for Hofstede, which turned into GLOBE. Special thanks to Drs. Seonaigh MacPherson (I did it!), Andre Ivanov, Kadriye Ercikan, and Joanne Nackonechny. A very special thanks to Drs. Wolff-Michael Roth and Kamyar Keikhosravy.

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Dedication

To all the PhD students and candidates studying, researching, and writing out there: *Ad augusta per angusta*. You too can get through - take it to the tower!*

* The soon to be defunct Acadia Park high-rise penthouse (PH) floor between the Common's Block and (the defunct) Salmo Court. Best-kept study secret at UBC until May 2015. We have heard the chimes (for beer) at midnight, Master MacKenzie!

Chapter 1: Introduction

1.1 Problem Statement

Engaging with the complexity of the lived curriculum - as students experience or live it within the situation (Aoki, Pinar, & Irwin, 2005) - is a relatively new, promising, and yet challenging approach to researching and understanding how students change through their study. It would be interesting to closely track students' participation as they live engineering curricula so as to understand over time how they change through their enculturating experiences in and exposure to a school disciplinary culture (Hodson & Hodson, 1998a, 1998b). As will be discussed in the literature review (Chapter 2), engineering education studies oriented towards situated cognition (Greeno, 1998), as this study is, have tended to approach researching change in students as the product of an assimilative brand of enculturation into disciplinary cultural norms (e.g., Clark, Dodd, & Coll, 2008; Dryburgh, 1999) such as characterized in the literature (e.g., Donald, 2002; Godfrey & Parker, 2010). More contemporary studies in other science, technology, engineering, and mathematics (STEM) subjects have sought more nuanced approaches to researching change in student in lived curricula by attempting to capture it as it emerges and evolves over time. This is often perceived as a product of complex interactions (Esmonde, Takeuchi, & Radakovic, 2011; Roth, 2013).

This study investigates how the engineering dispositions and thinking of culturally diverse students evolve through their enculturating experiences in an undergraduate Electrical and Computer Engineering program. Specifically, this study focuses on culturally diverse students in the second year of their degree program as they shift from the predominantly textbook and lecture-based math and science mode of study of first year general engineering to a team-based engineering design project mode of study. *Culturally diverse students* are intentionally defined in this study as non-native English speaking foreign students who required English language preparation prior to commencing their undergraduate studies in Canada. These students either came to Canada after finishing high school in their home countries or attended a Canadian high school for up to five years before their undergraduate studies. Further, culturally diverse students in this study are considered as undergoing an enculturation experience through complex interactions occurring in and through their participation as a part of team-based design projects that produce change in their engineering dispositions and thinking. Hence, this study is about the processes of enculturation and its products in the form of change in students' engineering dispositions and thinking.

Interest in knowing how culturally diverse students change over time in lived curricula and how this might be different from expectations espoused in planned curricula comes from the researcher's background as a STEM and language educator as well as his training and experience as an engineer and his experience living and working internationally. Two trends make this study a fruitful line of inquiry. First, engineering has a distinctive disciplinary and professional culture and the internationalization of many engineering programs in Canada has led to greater diversity in undergraduate student populations, which raises interesting questions about what might be happening operationally in engineering programs. Second, there is a general movement in undergraduate engineering programs towards outcomes-based curricula that provide early degree experiences in team-based engineering design aimed at a broader range of skills and knowledge (e.g., communication, teamwork, ethics, professionalism) required both in professional practice and by accreditation bodies (Duderstadt, 2008; National Academy of Engineering, 2005; Sheppard, Macatangay, Colby, & Sullivan, 2009). As such, students study in increasingly complex and open-ended formal, informal, and non-formal environments and there is a lack of research on how such trends affect how students develop. Such understanding can be analyzed from studying engineering dispositions and thinking.

As identified earlier, this study focuses on the *engineering dispositions and thinking* that culturally diverse students develop in team-based design projects. The term *disposition* is defined "the sum total of an individual's characteristic tendencies, such as basic temperament, attitudes, inclinations, and drives" (Corsini, 2002, p. 288). *Engineering dispositions* refer to such characteristic tendencies as they relate to engineering work. *Engineering thinking* is defined as patterns of intellectual behaviour, or habits of mind, with respect to engineering work. Engineering thinking entails a composite of thinking processes, skills, and approaches, which may include such things as systems thinking, creative problem solving, task analysis, and collaboration. Dispositions and thinking in this study are seen as not mutually exclusive. Given the applied, contextual, and social nature of engineering work (Bucciarelli, 1994), whenever a disposition is manifest, thinking is implied. For example, when an electrical engineering student is troubleshooting an analog circuit she has built, it requires the thinking processes of inference and verification that manifests as a patient and self-reliant disposition (Donald, 2002). For this study, engineering dispositions and thinking are taken as presupposing each other and so are treated as one. They are not to be separated.

If engineering dispositions and thinking are the products of study; then *enculturation* is the process. This study focuses on both. Conceptualizing development as *enculturation* entails that it occurs through a person's immersion in a culture – a disciplinary school culture, in this case - rather than through the transmission and acquisition of information and skills by a person (Hodson & Hodson, 1998a, 1998b). *Enculturation processes,* as defined by Grusec and Hastings (2014) are those forces, deliberate or not, in a given network of influences that limit, direct, and shape an individual and result in them having greater competence in the language, rituals, and values of the culture. The term “forces” is used in this study to refer specifically to interactions among students, instructors, course documents, assessment tools, and the material projects, equipment, and tools that become significant within the environment where change is observed in real time. Therefore, this study aims to account holistically for such interactions for their effects on culturally diverse students - an approach which entails a dual focus on enculturation processes and the change in engineering thinking and dispositions they produce.

1.2 Study Context

This case study (Stake, 1995) employs ethnographic methods (Hammersley & Atkinson, 2007) informed by a hybrid of theoretical perspectives from cultural historical activity theory and German critical psychology (Roth, 2009) to understand how culturally diverse students’ engineering dispositions and thinking evolve through their enculturating experiences in two second year team-based electrical and computer engineering design courses. This hybrid theoretical perspective (Roth, 2009) derives from the cultural historical activity theory perspectives of Vygotsky (1978), Leont’ev (1978), and Engeström (1987) and German critical psychology perspectives of Holzkamp (2013). This study is a response to recent trends in higher education and an interest in understanding what culturally diverse students develop after they undergo academic English and foundational science and math preparation during and after their high school education in Canada or in their home countries.

The internationalization of Canadian universities and curriculum reform underway in Canadian engineering programs noted in Section 1.1 require further elaboration. First, the Association of University and Colleges of Canada (2009) examined the internationalization of curriculum in Canadian universities, concluding that “although the value of internationalization is recognized by Canadian universities, and this interest is increasingly backed with concrete measures and investments, integrating an international dimension into the curriculum has been a more challenging endeavour” (p. 7). The AUCC report identified these components of an internationalized university curriculum: partnerships, foreign language learning, faculty members’ initiatives, students’ international or intercultural experiences, and internationalization in learning outcomes and assessment. Conspicuously absent are the supports and a research agenda needed to accommodate diverse students in STEM programs at Canadian universities. There is a lack of literature examining what the internationalization of engineering programs means for these students in lived curriculum.

Second, Canadian engineering departments are now pursuing curriculum change motivated by the goals of program improvement and innovation and by accreditation requirements that graduates possess twelve attributes: a knowledge base for engineering, problem analysis, investigation, design, use of engineering tools, individual and teamwork, communication skills, professionalism, impact of engineering on society and the environment, ethics and equity, economics and project management, and life-long learning (Engineers Canada, 2014). The Canadian Engineering Accreditation Board (CEAB) requirements stem partially from the Washington Accord, an agreement, which, along with the Barcelona Process in the European Union, aims at some degree of international harmonization of engineering program accreditation criteria and quality.

Engineering curriculum reform has also been widely discussed at the post-secondary level (Borrego & Bernhard, 2011) and the integration of engineering content and skills called for at the K-12 level (Hudson, English, & Dawes, 2014; Katehi et al., 2009). Key academic and professional studies in the US (National Academy of Engineering, 2005; Sheppard, Macatangay, Colby, & Sullivan, 2009), the UK (Royal Academy of Engineering, 2006), Canada (The Canadian Academy of Engineering, 2005), and Australia (King, 2008) have identified numerous challenges posed to the profession by the knowledge economy, globalization, demographics, technological change and innovation, and environmental sustainability and have urged revisions to engineering education as a solution. Duderstadt (2008, p. 67) characterizes such change as a needed paradigm shift from a focus on "reductionism to complexity, from analysis to synthesis, from disciplinarity to multidisciplinarity, and from local to global." He recommends the need to "accommodate a far more holistic approach…in linking social, economic, environmental, legal and political considerations with technical design and innovation" (p. 67) and places a premium on diversity in engineering.

The broad trend of demographic change brought by the globalization of Canadian universities and reform in engineering education has meant a shift towards more integrated curricula, early-degree experiences in team-based engineering design projects, and increases in the diversity of the student body. A literature review has shown that very little research has been done on culturally diverse students in team-based engineering design courses, a site which is at the confluence of these changes and where hard and soft skills and knowledge meet. This study is an opportunity to understand and explain what engineering dispositions and thinking emerge in these students through their participation in the lived curriculum of team-based engineering design projects. Furthermore, this study is significant for teaching, curriculum, and research because it provides nuanced accounts of how culturally diverse students develop in surprising and multifarious ways within the same team working on the same project. This study provides insight into these engineering students' early professional development in complex contexts.

1.3 Study Aims and Research Questions

This study aims to account holistically for the effects of complex interactions among students, instructors, tools, and assessments in team-based design projects on culturally diverse students' engineering dispositions and thinking over time. Implicit in such an aim is that cognition is situated, emerges through interaction in the world, and is interpreted through observed actions (Greeno, 1998; Lave & Wenger, 1991). Accordingly, the main research question is: How do the engineering dispositions and thinking of culturally diverse students evolve through their experiences in the second year of an electrical and computer engineering program? Investigation of this main question is guided by the following questions:

- What is the nature of the student-instructor, student-student, student-tool, student-assessment interactions in engineering design courses? What knowledge do these interactions foster and hinder?
- How do students and instructors perceive the evolution of engineering dispositions and thinking in students over the duration of the engineering design courses?
- How do engineering dispositions and thinking in students in a team evolve over the duration of the courses?

1.4 Educational Context

Engaging in ethnographic research means immersing oneself in the context. Hence, in reporting ethnographic processes, researchers are compelled to provide fuller descriptions of the context than are usually provided in other kinds of research (Becker, Geer, Hughes, & Strauss, 1976; Hammersley & Atkinson, 2007). Hence, this section presents a very brief overview of the curriculum and students at the Electrical and Computer Engineering department of the Canadian University (herein CU) in which this research took place. More specific descriptions of context will also be presented as necessary in Chapter 4, which focuses on methodology.

1.4.1 Educational Context: Curriculum

This study focused students in the second year of CU's Electrical and Computer Engineering program. By the time they had arrived in second year at CU, students had taken a common suite of general lecture-based first year engineering courses either at CU or their equivalents at another institution (Table 1).

Table 1. List of CU Engineering Courses, 2012/13 Academic Year

First year general engineering courses

Introduction to Engineering
Engineering Case Studies
Introduction to Computation in Engineering Design
Chemistry for Engineering
Strategies for University Writing
Differential Calculus
Integral Calculus
Linear Systems
Elements of Physics
Mechanics I
Non-engineering elective

Second year Electrical and Computer Engineering courses (common core)

Technical Communication (F)
Data Structures and Algorithms for Computer Engineers (F)*
Circuit Analysis I (F)*
Multivariable Calculus (F)
Introduction to Microcomputers (F)*
Electrical and Computer Engineering Laboratory I (F)
Basics of Computer Systems (W)+
Circuit Analysis II (W)+
Electrical and Computer Engineering Laboratory II (W)
Linear Differential Equations (W)
Mathematical Methods for Electrical and Computer Engineering (W)

* Co-requisites for Design I; + Co-requisites for Design II; F = fall semester, W = winter semester

As noted in Section 1.1, the culturally diverse students of interest in this study had either spent a few years in high school before studying engineering at CU or had come to CU to study engineering after attending high school in their home countries. Some of the students who had arrived in Canada after their high school study fed into CU's second year after attending first year at one of many engineering transfer programs which articulate to CU's general first year and also cater to English academic preparation needs. Once admitted into second year, students took a common set of seven courses plus two additional courses (Table 1), as dictated by their stream (i.e., computer or electrical engineering) which were also co-requisites to the two design courses in Design I (fall 2012) and Design II (winter 2013). The Design I and Design II courses were the focus of this study.

1.4.2 Educational Context: People

The Electrical and Computer Engineering (ECE) department is the most culturally diverse department in CU Engineering. Twenty four point eight percent of ECE students were immigrants, meaning that they have permanent resident status and attended high school in Canada for one to five years. Fourteen percent of the ECE students were international students, meaning that they have international student visas and moved to Canada specifically to get a degree. In the 2012/2013 academic year, 286 and 270 mostly second year electrical and computer engineering students were enrolled in Design I and Design II, respectively. ECE students come from a variety of countries (from highest to lowest percentage): Canada, China, Iran, Taiwan, South Korea, India, and a number of other countries including Malaysia, the USA, Saudi Arabia and Hong Kong. Eighty-three percent of ECE students are male. The instructors, teaching assistants (TAs), and lab technicians supporting the courses were more diverse than the students: of the two instructors, eight teaching assistants, and the lab technician, only two were born in Canada with many coming from Iran.

1.5 Literature Review

Chapter 2 situates the study within the field of engineering and the relevant science and math education research. Specifically, the review of the literature focuses on how scholars have researched processes of student change (e.g., enculturation) in complex, lived engineering and science curricula and what they have found to be the products of this enculturation in terms of dispositions and thinking. This review provides a map of the engineering education research literature to orient the reader to the field (Section 2.2), discusses how engineering education has been researched as disciplinary culture (Section 2.3), and discusses key studies to illustrate how enculturation processes in engineering curricula have been conceptualized as assimilation, a pipeline, and pathways (Sections 2.4, 2.5). It then reviews research done on complex engineering education environments that focuses on disjunctures between the planned and the lived curriculum (Section 2.6), on learning as identity development (Section 2.7). It then takes a tighter focus on more recent activity theory studies to understand how recent scholars have captured both the processes and products of change holistically in real-time in complex environments (Section 2.8). Studies specifically focusing on culturally diverse students in engineering and science are overviewed briefly (Section 2.9). Finally, the key points from this literature review for this study's theoretical perspectives, methodology, findings, and implications are summarized for later discussion in the relevant chapters (Section 2.10).

1.6 Theoretical

Chapter 3 presents, discusses, and justifies the theoretical underpinnings of the study (i.e., constructionism, interpretivism, symbolic interactionism, activity theory) for this case study of student evolution in team-based design projects (Section 3.2). The theoretical and analytical framing of this study - Roth's (2009) hybrid activity theory framework – is also presented and justified as sound and commensurate with the study's research questions (Section 3.4). To that end, this chapter overviews the relevant foundational perspectives within activity theory (Engeström, 1987; Leont′ev, 1978; Vygotsky, 1978) in Section 3.3. However, the focus of the study requires eschewing the use of Engeström's second generation activity theory in favour of Roth's hybrid framework. Roth's framework draws from German critical psychology (Holzkamp, 1991, 2013) and allows for the tracking, emergence, turnover in dominance, and restructuring of new development resulting from inner contradictions in the student-in-activity over time. Key terms are drawn from the work of Leont'ev, Roth, and Holzkamp (i.e., irreducible units of analysis, orienting effects of object/motive, inner contradictions, focus on trajectories over time, generalized agency, generalized possibilities to act, subjective reasons for action) and used in later chapters for the purposes of interpretation and discussion (Section 3.4). Finally, this chapter also reviews relevant perspectives from cultural psychology, intercultural studies, and cultural analysis to anticipate what students bring from their cultures and their potential mediating effects on overall activity (e.g., team dynamics, perspective) and hence the evolution of engineering dispositions and thinking (Section 3.5).

1.7 Methodology

This chapter presents the research design for the study, which employed ethnographic methods (participant observation, semi-structured interviews) to gather most of the data. The chapter also explains how the researcher accessed the site, became embedded in a design team, collected and analyzed the data, and ensured that the findings of the study would be trustworthy.

Chapter 4 overviews how this research was planned and conducted according to ethnographic research principles in an ethical manner so as to produce trustworthy findings. The chapter begins by justifying the study's theoretical and methodological choices and staking out five key points that guided its application of ethnographic methods. The selection and context of the research setting, the overall research design, and the work in the field is then discussed. Next, data collection and analysis considerations and processes are detailed and illustrated. Finally, the representation of the findings and issues of trustworthiness and ethnics are discussed.

1.8 Findings

Chapters 5 and 6 present findings to address this study’s main research question: How do the engineering dispositions and thinking of culturally diverse students evolve through their experiences in the second year of an electrical and computer engineering program? Chapter 5 can be thought of as an ethnographic portrait (Lawrence-Lightfoot & Davis, 1997) of disciplinary engineering culture (c.f. Donald, 2002; Godfrey & Parker, 2010 in Section 2.3) at the research site that has the secondary role of contextualizing five students’ trajectories, which are the main findings of this study (Chapter 6). Chapter 5 partly answers the first guiding research question (i.e., the nature of student-instructor, student-student, student-tool, student-assessment interactions in an engineering design course; the knowledge these interactions foster and hinder). However, additional data collected of such interactions in team Z5 were necessarily subsumed into the student trajectories that appear in Chapter 6. The findings in Chapter 6 are framed and interpreted through the hybrid activity theory framework of Roth (2009) as discussed in Sections 1.2, 3.4.3 and 4.2.5. At the end of Chapter 6, an additional level of analysis of the student trajectories revealed five critically important conditions for culturally diverse students to satisfy in order to develop engineering dispositions and thinking in this team-based project work mode of study. These are fodder for discussion in Chapter 7.

1.9 Discussion

Chapter 7 discusses the findings reported in Chapter 6 by elaborating upon the interpretations and meanings ascribed to how engineering dispositions and thinking of culturally diverse student evolve in the team-based design courses. The emphasis in this chapter is on the five conditions (Section 6.7) that potentially manifest along these students' trajectories, whose effects are mediated by other factors (cultural, contextual, personal) in activity to shape their engineering dispositions and thinking. This chapter draws out key challenges for culturally diverse students running through the five accounts of students' trajectories and discusses how these challenges shape possibilities for them in developing their engineering dispositions and thinking in team-based engineering design courses.

1.10 Conclusions and Implications

Chapter 8 recaps the study's key findings and presents and briefly discusses its conclusions and implications for theory, practice and curriculum, and research. The eight conclusions are drawn directly from the discussion in Chapter 7. The first three conclusions are general, and concern the nature of enculturation processes, team perspectives, and how opportunities to develop engineering dispositions and thinking manifest in complex activity. The next five conclusions derive directly from the discussion chapter and concern the five conditions identified that potentially manifest along students' trajectories to shape culturally diverse students' engineering dispositions and thinking.

The implications of this study are also discussed in this chapter. First, the application of Roth’s (2009) hybrid activity theory framework (Chapter 3) to focus attention on the student rather than the activity system is discussed as a unique approach to understanding evolution in students engaged in practical collective activity in complex systems. There are several implications for curriculum and practice that specifically relate to culturally diverse students and the challenges they face in the shift from traditional math and science to team-based project modes of study. Finally, a number of implications are discussed for research, particularly methodological challenges and opportunities in employing Roth’s (2009) hybrid activity theory framework.

Chapter 2: Literature Review

2.1 Introduction

Given this study's aim is to account holistically for the effects of complex interactions in team-based engineering design projects on culturally diverse students' engineering dispositions and thinking over time, this chapter's purpose is to contextualize and inform this research through a review of the relevant engineering, science, and mathematics education literature. It must be made abundantly clear at the outset that the processes of enculturation and its products, in terms of students' engineering dispositions and thinking, are both of interest in this study and that dispositions and thinking in engineering intertwined (see Section 1.1). Careful examination of this study's main research question (i.e., How do the engineering dispositions and thinking of culturally diverse students evolve through their experiences in the second year of an electrical and computer engineering program?) suggests the "how" in the question be thought of as containing a dual focus on both enculturation processes and its products. The first meaning of "how" entails an interest in the nature and dynamics of the enculturation processes. The second meaning of "how" entails an interest in the changes in students' engineering dispositions and thinking that emerge as a result. Following Tolman's (1991) insight that "a thing is best understood as to what it is by examining how it got that way" (p. 10), how culturally diverse students' dispositions and thinking have changed through their participation in team-based engineering design project courses and the process by which these changes happened both have important implications.

This literature review contextualizes and informs this research by focusing on how scholars have researched processes of student change (e.g., enculturation) in complex, lived engineering and science curricula and what they have found to be the products of this enculturation in terms of dispositions and thinking. Both will be done in tandem and the significance of the review will be drawn out and summarized in the final section (Section 2.10). This review will begin with a map of the engineering education research literature so as to orient the reader to the field (Section 2.2). Second, it will discuss how engineering education has been researched as disciplinary culture (Section 2.3), which provides a general picture of the products or outcomes of engineering curricula, specifically engineering dispositions and thinking. Third, the review will discuss key studies to illustrate how enculturation processes in engineering curricula have been conceptualized as assimilation, a pipeline, and pathways (Sections 2.4, 2.5), which gives a sense of how scholars have approached researching change over time. Fourth, research done on complex engineering education environments that focus on disjunctures between the planned and the lived curriculum (Section 2.6) and on learning as identity development (Section 2.7) will be discussed for their approaches, useful terminology, and findings. Fifth, a tighter focus on more recent activity theory studies will demonstrate how recent scholars have captured both the processes and products of change holistically in real-time in complex environments (Section 2.8). This study sits within this particular constellation of activity theory studies. Sixth, studies specifically focusing on culturally diverse students in engineering and science will be overviewed briefly (Section 2.9). Finally, the key points from the review for this study's theoretical perspectives, concepts, and terminology; its methodology; and its findings and implications will be summarized for reference in later chapters (Section 2.10).

Studies in this literature review were sourced in multiple ways. First, a general search was made on licensed databases (e.g., Web of Science, Academic Research Complete, Education Research Complete) and Google Scholar terms such as: engineering, enculturation, acculturation, socialization, professional identity, learning, ESL, ELL, minorities, teamwork, project based learning. Second, a more targeted search was conducted in these databases to identify limited and systematic literature reviews and meta-analyses in relevant domains. Such reviews were valuable for establishing a map of the field, particularly that of the emergent engineering education research. Third, specific education-oriented research journals (e.g., Journal of Engineering Education, European Journal of Engineering Education, Cultural Studies of Science Education, Review of Higher Education) were hand searched using more targeted terms. Fourth, once 40+ key studies and papers were identified and sorted, references within key papers were followed back in time. Google Scholar was also used to identify other important related works that had referenced these key papers since publication. Finally, over 60 key works were identified, read, summarized, and synthesized. Not all studies that were selected and read are discussed in the review that follows.

2.2 A Map of the Engineering Education Research Field

This review begins in the engineering education research literature. Engineering education research is a relative latecomer to education research: indeed, only since 2003 has the field's premier publication, *The Journal of Engineering Education*, exclusively focused on engineering educational research (Borrego, Douglas, & Amelink, 2009). Koro-Ljungberg and Douglas (2008) note that, prior to 2006, there were very few qualitative research articles published in this key journal, of which few could be considered quality research. Borrego and Bernhard (2011), inspired by Fensham's (2004) work in science education, was a landmark contribution because it synthesized the existing quality academic works in engineering education so as to define it as an emerging and internationally connected field of inquiry. Drawing on targeted literature reviews, general systematic literature reviews, and meta-analyses of the engineering education research (Borrego, 2007; Borrego et al., 2009; Johri & Olds, 2011; Koro-Ljungberg & Douglas; Wankant, 1999, 2004; Whitin & Sheppard, 2004), Borrego and Bernhard (pp. 22-23) mapped its subdomains:

- Curriculum and instructional improvement, in which interventions are described and direct or indirect evidence of their results are presented
- Interventions targeting specific technical and professional skills following a similar pattern (e.g., design, problem solving, team work, communication, global competence)
- Skills and knowledge required by industry and accreditation
- Professional development of instructors, professors, and teaching assistants
- Assessment
- Engineering in K-12
- Lifelong learning for engineers
- Diversity, recruitment, and retention of engineering students
- Understanding student learning processes

This literature review focuses primarily on the last two subdomains on this list and related works in the STEM education literature, as these are most relevant to the focus of this study. This review indicates that engineering education research has become more nuanced in its approaches to understanding student learning processes and diversity, recruitment, and retention issues. Firstly, there has been a slow shift in the research towards reconciling cognitive science and situated learning perspectives in conducting research on student learning processes (Johri & Olds). Second, there has been a dramatic increase and acceptance of qualitative studies thanks to their capacity to inform important questions in the field (Case & Light, 2011).

2.3 Engineering Education as Disciplinary Culture

This section discusses how engineering learning communities have been researched and understood as disciplinary culture. Drawing on Becher and Trowler's (1989) notion of university disciplines as subcultures or “academic tribes”, Kreber (2009, p. 4) cannily notes that while disciplinary knowledge in higher education programs such as engineering can be thought of as “what is looked at” (i.e., what is studied), it can also be thought of as “what is looked through or with” (i.e., how the world is viewed through such study). Going further, Donald (1995, p. 6) observes: “the method by which knowledge is arrived at in a discipline, the process of knowledge validation, and the truth criteria employed in the process are essential to the definition of the discipline.” Based on her substantial body of ethnographic research across multiple disciplines and institutions in Canada and Becher’s earlier work, Donald (2008) argues that disciplinary cultures entail particular ways of knowing, invite their own validating questions, and have their own particular educational organization or “signature pedagogies”:

> Each discipline has its own organization, artifacts, assumptions and practices particular to learning and teaching. In engineering...the validation question is ‘Does it work?’ In law, principles and practices rest on the case method, argument, statute and precedent, negotiation, and the potential of multiple interpretations. The validation question is ‘Does it fit?’ In English literature the signature pedagogy is found in the rifts or dialects, in close reading and in literary criticism. The validation question is, paradoxically, given the framework of contention in this discipline, ‘Do you agree?’ (p. 47)

Donald (2002) conducted extensive research in engineering faculties of five universities in Australia, Canada, the UK, and the US from 1986 to 2002 using interviews, observations, and document analysis to understand and characterize engineering intellectual culture and what it means to become an engineer. She focused primarily on disciplinary knowledge; its structure, context, and focus; and the associated engineering thinking and dispositions from the perspective of what engineering professors reported and were observed doing as educators and of what students reported and were observed learning. Donald (2008) characterizes engineering knowledge as “hard thinking: applying structured knowledge to unstructured problems” (p. 37), noting that the nature of the work, the required knowledge, and dispositions and thinking (Table 2) are central to students’ experiences in ‘becoming an engineer’ (Donald, 2002).

Table 2. Characterization of Engineering Disciplinary Culture (Donald, 2002)

Characteristic	Description
Nature of engineering work	**A:*** The industrial-corporate world substantially orients teachers’ and students’ awareness and shapes learning (e.g., strong ties with industry, accreditation processes exert control over learning, focus on knowledge and skills relevant to industry). **B:** “Uncertainty is a defining characteristic of the arena in which engineers perform: they deal with unbounded problems with too little or too much information, and must set the limits of their problem space” (pp. 37-38).
Knowledge	**A:** Understanding comes from joining concepts to practical activity (i.e., problem solving, design, investigation) in which fundamentals are thoughtfully applied to new problems. **B:** “The knowledge and skills needed in engineering reflect both a high degree of theoretical structure and the procedures and skills for applying them” (p. 38). The curriculum is packed; students are very busy.
Engineering Dispositions and Thinking	**A:** Though diverse dispositions are noted in engineering professors across individuals and sub-disciplines, they see themselves as practical, pragmatic, hardworking, stable introverts whose creativity and inventiveness outstrip their communication skills. **A:** Students are expected to adopt engineering thinking processes (e.g., description, selection, representation, inference, synthesis, verification, and their attendant steps) and consolidate and integrate disciplinary content knowledge and concepts into such processes or relevant systems or frameworks. **B:** “Learning to be an engineer includes estimating risk and taking responsibility for their decisions…(they are) self-reliant, willing to take responsibility, act on logical advice, and keep to the point” (p. 38).

* A: Description; B: Illustrative Quote

Godfrey and Park (2010) complement Donald (2002) with their large ethnographic case from 1999, which mapped engineering learning culture in one institution in New Zealand. The authors collected data using questionnaires from faculty (28 people) and students (55 people), semi-structured interviews (52 students, 25 faculty), focus group discussions, observation (4 years of field notes), and document analysis. Whereas Donald (2002, 2008) focused on the intellectual culture and context of engineering education, Godfrey and Park drew from Schein's (2010) cultural framework (i.e., artifacts, practices, behaviours as analytic categories) and focused on values and norms. Schein defines culture as:

> A pattern of shared basic assumptions that the group learned as it solved its problems of external adaptation and internal integration, that has worked well enough to be considered valid, and therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems. (p. 1)

Godfrey and Park identified the values and norms of engineering culture at the institution as having six dimensions, four of which are relevant to this study (Table 3).

Donald (2002) and Godfrey and Parker's (2010) characterizations of engineering disciplinary culture were conducted over 15 years ago before North American engineering faculties began answering later calls for engineering curricular reform (Duderstadt, 2008; National Academy of Engineering, 2005; Sheppard et al., 2009; The Canadian Academy of Engineering, 2005). While these characterizations of engineering disciplinary culture and the dispositions and thinking that comprise them may be dated, they hold significance for this study. First, Donald and also Godfrey and Parker, through their choice of Schein's (2010) definition of culture, have effectively framed engineering dispositions and thinking, among other characteristics, as constitutive of engineering disciplinary culture. Hence, they have made a conceptual link between a generalized image of engineering disciplinary culture at schools in the

1990s and specific engineering dispositions and thinking that are responses to the practical work in which engineering students engage. Dispositions and thinking are constitutive of disciplinary culture, and disciplinary culture is partly comprised of dispositions and thinking.

Table 3. Map of Engineering Culture: Four of Six Dimensions (Godfrey & Parker, 2010)

Dimension	Description
An engineering way of thinking	Mathematical representation omnipresent Visual communication prevails Problem solving and design are critical skills 'Best' over 'right' answers Engineering knowledge is 'race and gender free'
An engineering way of doing	Anything worth doing is 'hard': "a meritocracy of difficulty" 'Soft' (e.g., professional development: teamwork, communication, ethics) is valued Learning entails shared hardship, which is a natural part of the learning process Co-operation, collaboration highly valued Instrumental views on learning: passing vs. understanding; time is a limited resource
Being an engineer	High academic achievers: 'can do' people Numerate, practical, pragmatic, tough, self-reliant, capable, conventional Not emotionally demonstrative or concerned with appearance, self-deprecatory Strong group identity and pride as engineers Work hard-play hard mentality, identity 'gendered' to some degree
Gradual acceptance of difference	Respect and inclusion for diverse ideas and people gradually increasing, fostered by evidence of technical competence, high achievement, and communication skills

Second, Donald (2002) and Godfrey and Parker's (2010) findings add to a broader understanding of engineering dispositions and thinking that informed the interpretation of data in this doctoral study. The engineering dispositions and thinking identified in these studies were not taken as a framework of indicators to drive this study; rather, they served to contextualize it. Hence, they are taken as general descriptions or reference points for what might be observed rather than as a framework or what becomes internalized by individual students from the disciplinary culture in an unmediated, uncomplicated fashion.

Third, Donald (2002) and Godfrey and Parker's (2010) findings add weight to how engineering dispositions and thinking have been defined for this study. Following from Section 1.1, engineering dispositions are taken as "the sum total of an individual's characteristic tendencies, such as basic temperament, attitudes, inclinations, and drives" (Corsini, 2002, p. 288) as they relate to engineering work. Engineering thinking is defined as patterns of intellectual behaviour, or habits of mind, with respect to engineering work, which entails a composite of thinking processes, skills, approaches, and attitudes which includes systems thinking, creative problem solving, task analysis, and collaboration. Also noted in Section 1.1 is that given the applied, contextual, and social nature of engineering work (Bucciarelli, 1994), whenever a disposition is manifest, thinking is implied - these cannot be disentangled from one another. Upon careful examination of Tables 2 and 3, it should not be difficult to see the interconnectivity of engineering dispositions and engineering thinking. In Donald's findings, for example, it should not be surprising that the nature of engineering work (e.g., dealing with unbounded problems), engineering thinking processes (e.g., selection, representation, inference), and a pragmatic and inventive disposition presuppose each other. Hence, these engineering dispositions and thinking from Donald and Godfrey and Parker's studies are drawn out as reference points in Section 2.10 and treated as one for the purposes of interpretation of this study's data and further discussion in later chapters. This review now moves from engineering disciplinary learning culture to examine how enculturation has been conceived and researched in engineering and science.

2.4 Enculturation in STEM Education: Assimilation and the “Leaky Pipeline”

The topics of diversity, recruitment, and retention in engineering and science education programs are key drivers of research into engineering culture and enculturation (Borrego & Bernhard, 2011). While the orientation of this body of STEM literature is towards retention, equity, and social justice issues, it is relevant to this study for what it has to say about how enculturation has been conceived and researched. As Godfrey and Parker (2010) points out, “until very recently, research specifically investigating the culture of engineering education has only arisen in the context of women’s lack of participation” (p. 5). Both engineering and science have had perennial and disproportionate difficulties recruiting and retaining women and minorities in North American and European programs (Seymour, 2002; Seymour & Hewitt, 1997; Ulriksen, Masden, & Holmegaard, 2010). Such concerns for retention have catalyzed research around diversity, engineering culture, enculturation, and engineering identity development and inspired the widely used metaphor of the “leaky pipeline” to characterize the problem (Stevens, O’Connor, Garrison, Jocuns, & Amos, 2008). Until recently, the “leaky pipeline” problem (i.e., of recruitment and retention) was the research focus of a raft of largely quantitative studies (Harvey, Drew, & Smith, 2006; Pascarella & Terenzini, 2005; Ulriksen et al.) aimed at characterizing the problem and offering solutions to stop the leakage.

The wide acceptance of Tinto’s (1987) model of student leaving in the “leaky pipeline” literature says much about the predominant thinking around the processes of enculturation in higher education. Tinto’s process-oriented model rejects psychological approaches to student leaving as they focus on the traits of the individual, leaving interactions between individuals and the institution untouched. Instead, he focuses on students leaving or staying as a process. Tinto draws on Van Gennep’s (1960) socio-anthropological theory of *rites of passage*, which characterizes the process of enculturation as a border crossing with distinct stages (separation, transition, integration) by which individuals leave one culture and become integrated into another. Tinto also draws on Durkheim's (1952) theory of suicide, which understands the phenomenon in relation to the lack of social and intellectual integration in society. While Tinto's model is credited with treating retention and attrition as a multi-faceted longitudinal process of social and intellectual integration or non-integration into subcultures on campus, it has also been criticized as implicitly assimilative (Tierney, 1999; Ulriksen et al., 2010). Tierney argues that this model and, through its wide acceptance, the predominant thinking on post-secondary education rests on assimilation where "the success of the initiates – that is, the students – (is) dependent upon the degree to which they are able to integrate into the social and academic life of postsecondary institutions" (p. 82). Ironically, Tierney instead uses Durkheim to argue that such assimilative perspectives amount to "cultural suicide" for minority students.

This notion of education as assimilation is evident in undergraduate engineering education in North America, the UK, Australia, and New Zealand (Donald, 2002; Godfrey & Parker, 2010). Van Gennep's (1960) rite of passage phrase and its variants are widely used to describe the process of becoming an engineer. A two-year study in New Zealand (Clark et al., 2008, p. 323), for example, collected data through questionnaires, semi-structured interviews with stakeholders, observations, and documents (numbers of participants unreported) in order to understand enculturation and professional identity development in undergraduate science and engineering learning communities at one institution. The study was guided by sociocultural theory and conceptualized learning in the sciences as a border crossing into a new culture (Aikenhead, 1996) in which students acquired a new identity as a legitimate peripheral practitioner in an engineering learning community (Lave & Wenger, 1991). The authors superficially conclude “students are rapidly enculturated into their higher education learning communities and quickly take on board the culture developed by lecturers and tutors” (p. 323). Similar in approach, Dryburgh (1999) investigated the key factors that influenced how female engineering students became professionalized at one Canadian institution. Dryburgh performed content analysis on observational, semi-structured interviews (15 people), focus groups (3 groups) data. Her findings identify key themes concerning how female students internalize engineering identities, including the need to adapt to the work-hard culture, demonstrate competence, be nonthreatening, and project a confident image. The researcher notes that female engineering students need to manage others’ impressions of them as they adapt to the professional culture. These and similar studies (e.g., Clark et al.; Matsukovich, Barry, Meyers, & Louis, 2011; Pierrakos, Beam, Constantz, Johri, & Anderson, 2009) serve as examples of how early sociocultural theoretical perspectives on enculturation were employed to arrive at uncomplicated views of enculturation in engineering as simple assimilation, an approach this study has sought to avoid.

Calls have been made in North America for more nuanced conceptions and approaches to researching student recruitment and retention and the larger questions of learning and enculturation in engineering and STEM (Seymour & Hewitt, 1997; Seymour, 2002; Ulriksen et al., 2010; Holmegaard, Madsen, & Ulriksen, 2014). Seymour and Hewitt (1997) and Seymour (2002) demonstrated that those who leave or stay in STEM are indistinguishable in terms of academic standing. They question the beliefs and practices evident in science and engineering faculties of weeding out students and suggest that the culture and context of STEM programs require more careful examination. Ulriksen et al. call for a more nuanced approach to understanding the problem, leading the same authors (Holmegaard et al.) to later write:

> Recent research has shifted the focus from perceiving success and retention as solely a question of students' adaptation to institutional requirements towards retention as a relation between the students and the culture of the program they enter and also an increasing concern for issues of identity. (p. 758)

While this study is not explicitly focused on retention issues, by association, it benefits from this body of literature, which has moved the conversation away from "leaky pipeline" metaphors and engineering education as assimilation. This is significant because it appears that the aims and approaches of contemporary studies to researching enculturation in science and engineering are shifting towards gaining more nuanced understandings. This is evidenced by several clusters of studies that moved the metaphor of enculturation and learning from the "leaky pipeline" to pathways and beyond. The next sections will discuss the planned versus the lived curriculum (Section 2.5), engineering identity (Section 2.6), enculturation in science and math (Section 2.7), and culturally diverse students in engineering (Section 2.8), which all hold significance for this study.

2.5 Enculturation in Engineering: Moving from Pipeline to Pathways

Stevens et al. (2008) conducted a longitudinal ethnographic case study employing surveys, interviews, and participant observation to capture change in 40 students over the four years of their program at one American engineering school, with intensive qualitative data collection on eight of the forty students. This study is the most relevant part of a larger academic pathways study (Sheppard et al., 2004) for this study. The authors explicitly rejected the pipeline for a pathways metaphor and used person-centered ethnography (Hollan & Wellenkamp, 1994; LeVine, 1982) so as to "recover the person" by focusing on individual students as they attempted to make themselves into or as they were made into engineers in formal and informal learning contexts. The researchers identified three critical and inter-related dimensions of becoming an engineer (developing accountable disciplinary knowledge, forming an identity of an engineer, navigating through engineering education) and illustrated them with two short narratives. The first dimension, developing accountable disciplinary knowledge, recognizes that what counts as disciplinary knowledge varies with time, situation, and place; something that students had to navigate. Stevens et al. challenge the notion of a stable body of engineering disciplinary knowledge, arguing for a far more dis-unified and contextually variable view of what it means to have and use it. This is significant because distributed cognition is a feature of engineering design teams (Pea, 1993; Bucciarelli, 1994) and the knowledge that becomes valued in team-based design has implications for the focus of collective practical activity and individual students' access to opportunities to learning through the delegation of tasks and roles. Stevens et al. (2008) also identified several shifts in knowledge over the duration of the programs they researched:

- Highly-structured → Open-ended problems in engineering science courses
- Perfect world → Real world contexts in problem framing and design
- Individual → Team-based work and assessment practices
- Origin of data: Data as given → Data as student-generated
- Learning activities: Content included → Supplementary content required
- Instructors: Lecturers → Coaches

These findings are significant because they indicate the shifting nature of expectations, experiences, and modes of study that culturally diverse students will be presented with as they move from traditional modes of study in first year to team-based design in second year. These findings are very similar to the shifts students in this doctoral research experienced by participating in the Design I and II courses, which were similarly characterized by a shift to open-ended problems, real world contexts, team based modes of work, and student-centered learning.

The second of Stevens et al.'s (2008) dimensions (i.e., forming an identity of an engineer) has a dual nature: students need to *identify with engineering* and also need to be *identified as engineers*, as seen in other studies on learning as identity development (e.g., Tonso, 2006a, 2006b), to be discussed in Section 2.7. Such issues of identification with engineering, as observed in teamwork in this doctoral study, were important with respect to roles and access to learning opportunities. The third dimension, navigating through engineering education, describes the routes by which students move through the program and their consequences of their navigations. The researchers observed two students' official and unofficial routes into and through an engineering program and characterized how they "stayed on" or "fell off the flowchart" depending on their approach, resources, and the program's navigational flexibility.

In terms of theoretical focus and methodology, Stevens et al. (2008) is similar in focus to this doctoral study because it is a person-centered ethnography that attempts to capture how students develop along their pathways or trajectories over time. It draws attention to several key points in lived curricula that affect students' access to opportunities to develop engineering dispositions and thinking: the value ascribed to knowledge, shifts in the lived curriculum over time, and issues of identification and navigation. These findings complement Donald (2002) and Godfrey and Parker (2010) by providing a sense of the curriculum-as-lived by students (Aoki et al., 2005) over time. However, while the researchers claim to take a nuanced focus on pathways and "recovering the person", they appeared to strike a balance between a focus on the general program (i.e., identifying the three dimensions) and a nuanced focus on particular students (i.e., person-centered accounts). It appears that the researchers remained close to the pipeline metaphor by retaining a whole program focus over four years, drawing out three dimensions to characterize the programs, and providing accounts of how two students who “stayed on” or “went off the flowchart” as a secondary focus. The two students’ dilemmas of navigation are interesting because they bring hidden phenomenon into relief, allowing for the researchers to interpret the outcomes their study. Yet, Stevens et al. remained somewhat close to the pipeline metaphor in how they selected and represented their data: they focused on an overall account of the program and placed the students’ stories in a secondary, illustrative role. As reported, they did not fully explain the dynamics of students’ enculturation or truly “recover the person” in all their complexity.

2.6 The Planned Versus the Lived Curriculum

Stevens et al.’s (2008) identification of dilemmas as driving students’ individual navigations of their programs opens the door to a body of research relevant to this study’s focus on lived engineering curricula. Newstetter (1998) employed ethnographic methods to investigate how four students in a third year mechanical engineering class of 30 students at an American engineering school understood and participated in their first team-based design experience, where and why difficulties were encountered, and how students made use of social and material affordances, intended by professors to support their learning, in often unexpected ways. Newstetter employed sociocultural and activity theory (Lave & Wenger, 1991; Leont′ev, 1978) and distributed cognition (Pea, 1993) perspectives in her student engineering design case study. She found a mismatch between the perspectives on engineering study that professors espoused and enacted through their course design and teaching and the tacit assumptions students had of their study, which shaped how they responded to the team-based design project tasks (Table 4).

Table 4. Professor and Student Conceptions of Study (Newstetter, 1998)

Focus	Professor conception	Student conception	Illustrative Quotes (p. 122-125)
Goal of course	Conceptual understanding	Procedures, methods	"Conceptual understanding is to be glossed over as just another set of methods and procedures to be mastered or cleverly faked to pass the course."
Meaning of activities	Vehicles for learning	Tasks to complete	"Opportunities for learning about the design process are represented as tasks to be completed and handed in."
Function of assignments	Development of know-how	Create busy work	"The observed team dutifully plotted out the problem space using these graphic tools as required by the assignment, but it was clear from discussions that the team members never appreciated the affordances of these tools for exploring a problem domain."
Function of tools	Distribute cognition	Impede task completion	"The numerous cognitive tools…to manage planning and software packages are not tools, but impediments to speedy task completion."
Role of collaboration	Promote learning	Divide and conquer	"Different forms of expertise failed to get passed around. Apprenticeship opportunities were ignored…tasks were processed in parallel so as to reach completion as soon as possible"

The gaps Newstetter (1998) identifies between professors' conceptions and intentions and students' conceptions and practices in the lived curriculum delves deeper than Stevens et al. (2008) with respect to how students navigate pathways through engineering. Newstetter makes a number of interesting observations. The first relates to the educational value of *soft-prototyping* (i.e., representing: ideation, paper work, model building) and *hard-prototyping* (i.e., building the physical project) in design. While hard-prototyping is more traditionally thought of as design, she argues the value is really in the soft-prototyping because it is knowledge rather than production oriented. Newstetter also notes that since the students have been trained from kindergarten to complete teacher-initiated tasks, they persist in *doing schooling* rather than studying engineering: “old ontologies die hard” (p.126), particularly given the workload and time pressures in the lived curriculum. Second, she notes that “less is more” (p. 127), in that less complex design projects, more support on how to collaborate, and earlier introduction of key design tools can help students from defaulting to their old study patterns due to the pressures of workload, marks, and time. Third, she notes that “teacher-orchestrated reflection on learning is necessary but not sufficient” (p. 127) to promote reflective design practice and that teachers need to find ways of encouraging students to extract important understandings from their design experiences.

Newstetter (1998) offers a rare and nuanced example in the engineering education literature into tensions and contradictions between espoused and lived curriculum in team-based engineering design courses that has important implications for this study. She identifies a key contradiction between professor (i.e., teaching team-based engineering design) and student (i.e., doing schooling) conceptions of study, which makes visible what students potentially experience and how they develop in the lived curriculum. So, while it might be tempting to assume students approach project tasks in predictable ways, they may respond to them in ways that run counter to the intended outcomes. The brands of task division and distributed cognition observed in a team-based project mode of study by Newstetter similarly have consequences for the actual change that occurs, a point that is significant for this doctoral study. The study also coins some useful concepts in engineering design: hard versus soft prototyping and divide-and-conquer task division and completion. This terminology will be employed in Chapters 7 and 8 in interpreting the findings and discussing implications in this study.

Holland and Reeves (1996) is another interesting activity theory study on teamwork in software engineering. Their study employed ethnographic methods to investigate how the cognitive tasks of designing programs and writing code in a software engineering course were embedded within the socially organized activities of three teams. In particular, the research focused on each team's use and reuse of the intellectual resources they produced (e.g., drawings, charts, meeting minutes) and the technology at hand. In their words, their task was to explicate "the intellectual work of programming as it is situated within a set of historically emergent activities and technologies" (p. 258). The aim of the software engineering course was to prepare students for careers working on large-scale programming projects. Instructors became bosses, so to speak, and integrated real world projects, industry and business oriented content, practices, and conduct into the course. The researchers found that although the institution, the instructors, and the course set some conditions that directed students' attention, they could not dictate the focus of the study that actually occurred in teams. Teams construed their work in different ways, resulting in highly variable and disparate work practices and outcomes of study. The manner in which the teams organized their activities had the effect of circumventing the intended outcomes of the course to varying degrees (Holland & Reeves):

> Team A saw its project as an opportunity to develop an elegant, efficient program; Team B focused on satisfying institutional demands in exchange for institutional rewards (a good grade); and Team C became so enmeshed in internal and external struggles that the relationships among its members frequently became the object of its work. (p. 258)

Their findings confound common assumptions that the work of teams proceeds from a rational and goal-oriented perspective and that there is some consistency to the collective goals and organization of work across teams. Holland and Reeves (1996) draw on sociocultural theory (Lave & Wenger, 1991) and activity theory (Engeström, 1987; Leont′ev, 1978) to explain how different groups create different intellectual tasks and develop different “takes” or “perspectives” on doing the project because they have some degree of freedom in controlling and directing their work. As an example, a task intended by instructors to support the goal of completing the project became the goal itself. Teams completed the task as such without much discussion, suggesting that an unspoken consensus existed - a perspective on doing the project - that equated to doing schooling, but did not make much sense in relation to workplace practices.

Going beyond Newstetter (1998), Holland and Reeves (1996) show in their data how a given team jointly and discursively constructed a perspective on the project through a collective process of sharing informal histories and rationales that congealed into an emergent team culture, history, rationale, and ethos. As they note from Carroll et al. (1992),“they (the students) ‘make’ a history and rationale for their project by telling stories among themselves” (p. 59). The concepts of *team perspective* and *emergent team culture* in projects are important for this doctoral study because they trouble simplistic ideas inherent in other studies (e.g., Clark et al., 2008; Dryburgh, 1999) about the nature of enculturation as being an unmediated and unproblematic conditioning and assimilation of individuals into a professional disciplinary learning culture. A final implication from this study is the concept of inner contradictions, an activity theory term (Leont′ev, 1978) used to describe what drives evolution and change in humans participating in collective activity (see Chapter 3). The researchers observed systemic contradictions between doing schooling and conducting a large scale programming project that drove the teams in disparate ways. This resonates with contradictions reported in Newstetter and the dilemmas, tensions, and disjunctures in Stevens et al. Although a lot has changed technologically since the 1990s when these studies were conducted, the particular dynamics and context – of team-based engineering design in a complex environment – are relevant and informative today. Though dated, these present model contexts where similar dynamics became manifest, as were observed in this PhD study. In these studies, the complex dynamics at work in design teams and the resulting focus of study yield useful reference points, concepts, and terminology that will be discussed in later chapters. Contemporary studies adopting more nuanced approaches to researching such dynamics are discussed in Section 2.8.

2.7 Engineering Identity

Early studies focusing on engineering identity such as Tonso (1996) and Ambrose, Lazarus, and Nair (1998) never entertained the engineering education as assimilation and "leaky pipeline" metaphors around diversity in engineering. At a time when qualitative studies were rare in the engineering education literature, Ambrose et al. (1998) noted that "statistics can give us the warning, or encouraging signs, but it is the individual story that provides the context … we need the ecology of the data and the stories that go with each of the individuals who make up that data" (p. 363). Ambrose et al. provided the ecology of the data through narrative analysis and accounts of individual women, often minorities, in engineering and science. In a similar vein, others studies (e.g., Carlone & Johnson, 2007; Hughes, 2001; Tate & Linn, 2005) also offer rich insights. While these examples of narrative inquiry are interesting and address engineering identity relevant to culturally diverse students in engineering, they mostly do not focus on the complex milieu of engineering design teamwork and so are noted but not discussed.

Four studies (Kittleson & Southerland, 2004; Tonso, 2006a; Tonso, 2006b; Walker, 2001) research engineering identity in teams with a particular focus on gender, offering relevant insights into identity development in mixed gender groups. Tonso (2006a; 2006b) report on insightful ethnographic research on culture, identity, and gender in engineering teamwork. Tonso (2006b) investigated how mixed male and female teams do design work and the ways in which campus culture reaches into social interactions between teammates via "engineering identities produced on campus". Such identities are represented as localized cultural knowledge that students employ to present themselves as engineers and to recognize others' identification or performances as engineers. Interestingly, Tonso (2006a) details the complex pre-professional engineering identities on one campus (e.g., high status: leader, geek, hacker, nerd; low status: loner, squid, curve-breaker, frat boy, sorority chick) and investigates how people performed such engineering identities and whether these garnered them recognition as engineers. She argued that, unlike men, women may identify themselves through effective performances as engineers (i.e., show/have the abilities, bearing, appearance, behaviour etc. of engineers) but may not be identified by others as engineers. As such, she argues it is harder for women to garner a valid engineering student identity and, hence, belonging among their peers, a claim that has been substantiated since by more recent studies (e.g., Phipps, 2007; Powell, Bagilhole, & Dainty, 2009; Powell, Dainty, & Bagilhole, 2012). These studies do not address these issues within the context of design teamwork.

Tonso (2006b) reported findings on two mixed gender project design teams in an educational context in which instruction in teamwork, communication, and professional skills was left largely unaddressed by the lecturers. Tonso argued that belonging as an engineer entailed both identifying and being identified as having a viable, locally produced engineering identity (e.g., nerdboy, hacker, sorority chick, curve breaker, squid). She also observed that people with different ways of belonging (i.e., different engineering identities) brought the associated position and status into the social order into teamwork interactions. In the first team, three students with high status engineering identities actively exploited two highly capable students (one male, one female) with low or no engineering identity status. The female student was known as the workhorse of the team, yet her impressive contributions did nothing to garner her recognition and belonging as an engineer. In the second team, three students with identities as nerds and high-achievers were the de facto leaders of the team that included two Greeks (a frat boy, sorority woman) who did very little. In contrast to the first team, the second team achieved excellent results and had respectful interactions: the loafers were tolerated. Tonso's key contribution is her summary description of the complex team dynamics and how the status of the engineering identities shaped team interactions, work practices, and roles, all below the instructors' radar. She recommended structuring team-based design projects by making teamwork expectations explicit, balancing gender composition, incorporating formative feedback, monitoring, and training faculty how to facilitate effective and equitable teamwork practices in student teams.

A merit of Tonso's (2006b) study is its attempt to grapple with the complexity of the context by focusing on how culture at the macro level (i.e., engineering identities on campus, curricular structures, campus routines, practices) affected interactions, roles, and ultimately individual and team experiences at the micro level of the team to produce certain practices. However, a more nuanced and satisfying reckoning of the space between the macro and micro level is missing. Tonso seems to suggest that local engineering identities and institutional structures flow in an unmediated fashion to shape individuals and teams. The study also appears to essentialize identity to a great degree with its use of engineering identity terms and to present teams and individuals as static and unevolving. Admittedly, perhaps this was not her goal. Yet, Tonso (2006a; 2006b, 1996) were groundbreaking as more nuanced approaches to researching how the complex milieu affects engineering identity development in design projects. Though dated, Tonso's studies present model contexts and important reference points for how gender, identity, and roles in team-based projects become manifest and shape students' development.

Walker (2001) focused on gendered enculturation in engineering through narrative inquiry. She asked why women's participation in engineering programs remains low when shifts in British society and institutional policy and programs have promoted gender balance for some time. Employing identity theory perspectives, she focused on how the contemporary identities and constructions of self - of belonging and not belonging - are shaped in and through an engineering program characterized by asymmetrical gender power relations. Walker's narrative inquiry yields nuanced accounts of how women's engineering identities are constituted. Quoting Castells (1997), Walker identified how female students in the design team reported projected *legitimate identities* (i.e., identities sustained by the dominant institutions in society), *resistance identities* (i.e., identities generated on the margins in opposition by the excluded), and *project identities* (i.e., new identities aimed at redefining, transforming societal structure). Students were reported to *identify*, *counter-identify*, or *dis-identify* with the dominant discourse in their engineering learning environment (Pesheux, 1982, in Walker). For example, one narrative account shows how one female student emphasized differences between them and their non-engineering female peers and projected legitimate identities that were aligned with those of their male classmates. In doing so, their identity construction did not destabilize the dominant gendered structure of engineering identities.

As seen in Tonso (2006b), female students encountered more difficulty being seen as engineers compared to their male counterparts. For example, they were perceived as more organized and hardworking than their male peers, but this did not afford them a status as an academically talented engineering student. Walker's (2001) narrative analysis revealed how men and women alike re-inscribe dominant notions of masculinity and femininity onto engineering identities in a way that is restrictive to both, suggesting that access is not enough: as long as this dynamic remains in place, few women will pursue engineering careers. This claim is substantiated in many other more recent studies (e.g., Phipps, 2007; Powell, Bagilhole, & Dainty, 2009; Powell, Dainty, & Bagilhole, 2012). Tonso and Walker provide important insights and useful terminology for this study around issues of engineering identity construction, which will be employed in this study: identifying, being identified, and dis-identifying as an engineer.

Kittleson and Southerland's (2004) in-depth case study in one mechanical engineering team over two terms of design projects provides similar findings through their investigation into how students in teams negotiate concepts and the factors that afford and constrain the process. Their study follows a cluster of studies in science education (e.g., Bianchini, 1997; Hughes, 2001; Kelly & Crawford, 1997; Moje & Shepardson, 1998; Richmond & Striley, 1996) which reveal how identity and meaning are constructed in teams and how issues of gender, knowledge, status, and leadership condition who participate and who is excluded from roles. As an example of such studies, chosen for its focus on knowledge and concept negotiation in design projects, Kittleson and Southerland revealed several themes relevant to this study with respect to status, roles, and the development of engineering dispositions and thinking:

- Pulling off 'being an engineer' requires participants to enact particular discourses associated with ways of thinking, acting, valuing, and using tools and technologies that help other people recognize them as engineers

- Having and being recognized as someone who has shared engineering knowledge was important to the communication and work flow of the team.

- An academically stratified hierarchy did not emerge: status within the team was defined by participation (i.e., time spent on project) and access to resources, technical authority

- Roles and the division of labour were based on a person's abilities, experience, or strengths; work was delegated and completed in parallel using a divide and conquer strategy, thus limiting the collaborative learning the instructors sought to foster

- Students professed their goal to construct understanding of the project's underlying phenomenon, whereas the team's culture of efficiency precluded much of this kind of learning in preference for completing the project tasks in a timely manner

- Discourse was characterized by an objectivist/realist and utilitarian orientation towards tool use and the application of scientific concepts

Many of these findings resonate with the contradictions identified in Newstetter (1998) between instructors' intentions and actual student learning. This study also adds balance to Tonso (2006b) and Walker (2001) through its findings that students' capacity to be recognized as engineers, and hence have technical authority, depends on factors oriented around knowledge, thinking, and effort that are actually relevant to being an engineer (i.e., ways of thinking; possessing, sharing knowledge/its application, hard work). This suggests a limit to the capacity of factors irrelevant to being an engineer (e.g., gender, privileged campus identities) in conferring identity and status on students. They actually have to be able to know and do engineering in order to be recognized as engineers.

Tonso (2006a; 2006b), Walker (2001), Kittleson and Southerland (2004), and Stevens et al. (2008) provide far more nuanced and subject-oriented accounts than the "leaky pipeline" studies. While they focus on the dynamics of engineering identity development and teamwork practices, they also take the environment, the team, and the individuals to be relatively static over time. These studies offer valuable insight and terminology, which will be summarized in Section

2.10. Additional studies that were reviewed have called for research that addresses change in complex contexts: Ingram and Parker's (2002) micro-ethnography; Foor, Walden, and Trytten's (2007) ethnography of the particular; and Malone and Barbarion's (2009) real-time science. Several activity theory studies that answer such calls are now discussed.

2.8 Enculturation in Science and Math: Towards a Holistic View for Engineering

Studies employing a broad range of activity theory frameworks occupy a unique position in STEM education research because they hold potential for capturing change - real-time science - emerging in students in complex contexts without being reductive or overly simplistic. While several studies based on the theoretical and analytical perspectives of activity theory are discussed in this section, a complete overview of activity theory as a theoretical framework will be provided in Chapter 3.

Barab et al. (2002) is discussed here because it is an early study which attempted to observe the emergence of new science conceptions on short time scales and track their evolution over longer ones. They examined how scientific understanding emerged in the complex dynamics of students, technology, rules, and classroom micro-culture in a technology rich introductory astronomy course. Multiple data sources (participant observation, pre-/post-course interviews, retrospective recall interviews, document/artifact analysis) were collected in this work-intensive ethnography. Audiovisual recordings of student-student and student-technology interactions allowed researchers to capture what they called *action-relevant episodes* involving the negotiation of meaning over minute time scales. Researchers pieced multiple networks of such episodes together so as to explicate how understanding developed real-time and to link it over longer time scales of lessons and the course. The authors used the trajectories revealed by the networks of action-relevant episodes to bring tensions or contradictions in the course into relief. First, the researchers found that students building astronomical models did not interfere with their learning of the content knowledge: skills and understandings were observed to co-evolve. Second, a contradiction was identified between teacher-directed instruction and the student-directed study: the local rules, micro-culture, and teamwork that emerged around building and sharing models took precedence over the outcomes intended by the teacher. The study's focus on contradictions as drivers of learning resonates with Newstetter (1998) and Holland and Reeves (1996) and is a point of focus that was employed in this doctoral study. Third, Barab et al. proposed a method of tracking discrete events on short time scales and showing how they accumulate to produce conceptual change over longer time scales. They found it difficult to connect incremental action-relevant episodes over long time scales in ways that were convincing, which raises a methodological conundrum for the study in deciding what on short time scales is significant on longer ones. This conundrum will be discussed in Chapter 4.

Esmonde, Takeuchi, and Radakovic (2011) conducted an ethnographic study on collaborative work in three high school mathematics classrooms over the duration of a year in the United States. The study was focusing on the collaborative task types/activities and group interactions that could best support learning. Drawing on activity theory, they focused on the details of individual social interactions in team problem solving on short time scales (i.e., microgenesis) to understand how people change over time in solving recurring problem types (i.e., ontogenesis), and in turn to understand how teams change over time as they build on each others' successes and disseminate new and old ways of solving problems (sociogenesis). Sociogenesis is another way of saying emergent culture, small-scale culture/history, or micro-history/culture. These terms mean that members participating in collective activity jointly construct meanings about the group. The researchers identified over a hundred “difficulty episodes” or conflicts in interaction around mathematical inscriptions (i.e., in posters, notebooks, textbooks), which served as analytically significant moments for understanding the evolving history and culture of the teams. Analysis of these episodes, specifically the use and evolution of inscriptions revealed that:

- Small-scale culture and history exists at the heart of any classroom interaction
- Schooling contains within it dual motives: learning math and doing school
- Students black boxed[1] concepts and did not routinely describe their thinking
- Non-task relevant talk in teams might promote academic risk taking

The researchers concluded that multiple histories and motives afford and constrain student learning in teams and student success cannot be discussed without considering these. In a clear methodological implication for this study, Esmonde et al. exemplifies an activity theory approach to making observations on short time scales in complex learning environments so as to make sense of evolution and change over longer time scales.

Two other activity theory studies in science education took into account complex learning environments along with the formation of identity in a holistic way so as to capture and explain change. Roth et al. (2004) demonstrated how the identities of a science student and a science teacher were continuously made and remade in a complex school setting. In their approach, the authors stipulated that “an individual, a tool, or a community cannot be theorized in an independent manner but must be understood in terms of the historically changing, mediated relations in which they are integral and constitutive parts” (p. 48). Drawing from Penuel and

[1] To black-box concepts means to deal with something complex by simply dealing with its inputs and outputs, sometimes without a deep understanding.

Wertsch (1995), the authors focused on the following: the student in settings where the formation of identities is at stake by virtue of participation in activity through contradictions; the identification of cultural and historical resources as enabling and constraining tools in identity formation; and mediated action as the basic unit of analysis. Through what can be described as a tight weaving of theory and narrative, the authors provide a nuanced explanatory account of how a student evolved from being a street fighter to being an A-student and how a teacher changed from being someone unable to control a class to being a respected teacher. This study accounts for identity formation in a way that is neither reductive nor simplistic.

A second later study by Roth (2013) tracked a young woman across contexts and time in pursuing her goals of graduating from high school, studying science, and becoming a doctor. Taking identity as multiple, contingent, and contextual in the manner of Mead rather than Erikson, Roth (2013) drew on the activity theory perspectives of Leont'ev (1978) to formulate a theoretical and analytical approach to explain how, through a person's participation in many activities within their life, they inhabit a hierarchical web of life activities, each with their associated motives and identities. Roth showed in careful detail how, over years, a young woman's primary motive of getting into medical school drives her engagement in science in formal and informal contexts of study and work. He demonstrated how her multifaceted identity is driven by the dominant motive of attending medical school until her experiences cause a shift in the hierarchy and she goes off the flowchart, drops the idea and, predictably, her engagement in science. This exemplar shows how becoming an engineer might be conceptualized in terms of competing identities and activities across the spheres of a person's life so as to yield a nuanced explanatory account of their evolution and change.

2.9 Culturally Diverse Students in Engineering and Science

This section briefly overviews the limited literature on culturally diverse students in engineering and science and then identifies three factors that potentially affect their development in this mode of study. While a rich body of research has been evaluated, synthesized, and discussed through this review, very few studies were found of culturally diverse students in team-based project modes of study. The studies on minorities in STEM (Section 2.4) are important; however, they are framed in the cultural, historical, and socio-economic conditions of the US. A major review of the research on English Language Learners in science education by Lee (2005) identifies a lack of studies on this topic:

> Future research need to conceptualize the interrelated effects of language and culture on students' science learning in more nuanced ways. Furthermore, there is a need for studies that combine multiple theoretical perspectives on science learning, rather than focusing on one to the exclusion of others. (p. 513)

Focusing mainly on K-12, Lee added "a major future area of research should be the linguistic and cultural experiences that ELLs bring to the science classroom and the articulation of these experiences with science disciplines" (p. 153). Given the prominence and pedigree of K-12 science education research, her identification of ELLs in K-12 science as an emerging field in 2005 suggests that research on culturally diverse students in post-secondary engineering education contexts is even less common. This literature review confirmed this to be the case.

One important body of research on culturally diverse students in post-secondary contexts from a language perspective focuses on immigrant and international students and language socialization. Duff (2010) systematically reviewed the literature on how international and immigrant students are socialized into the language communities of their disciplines: doctoral students in physics, law students (Mertz, 2007), first year undergraduate students in the US

(Leki, 1995), medical students (Hobbs, 2004), and Japanese studies in undergraduate degrees (Morita, 2004). However, these studies focused mainly on genres and language practices in these various speech communities and tend not to address teamwork. One exception is a study by Vickers (2007), which examined language socialization in a student engineering team working on design projects in electrical and computer engineering.

Vickers (2007) researched how interactional processes in a student design team socialized an Indonesian immigrant ESL student into the team's speech norms. Vickers used communities of practice (Lave & Wenger, 1991) and language socialization (Watson-Gegeo, 2004) perspectives and ethnographic methods to capture and examine naturalistic language socialization processes in project meetings over two terms. She characterized the norms and valued knowledge in the general context and the speech communities and participant structure at the team level. Vickers found that the ability to effectively linguistically display technical content knowledge was an important way in which engineering students gained status, controlled topics, and ensured their ideas were incorporated into designs. By analyzing participation in the form of demonstrated linguistic and technical expertise during design meetings, Vickers observed how students adopted locally constructed roles as core, novice, peripheral, and non-participant members. The only non-native English-speaking student in the team began as a novice. Through experience, observation, control of content knowledge, and the scaffolding, confidence building, ridicule, and opportunities provided by expert members, he earned an identity of competence, becoming a core member by the end of the course in a punctuated fashion. This shift from novice to expert began with the student demonstrating competence in solving design problems and then improving his control of language so he could explain the viability of his solutions.

Vickers' (2007) study is interesting for several reasons. First, it focuses tightly and deeply on socialization through interaction and language use to the exclusion of other cultural, historical, and material factors in the learning context. Second, all except one of the students were native English speakers, which differs from this doctoral study in which all are from different East Asian countries. While it is easy for Vickers (2007) to assume that socialization occurs to a norm, in this doctoral study, participants are from different linguistic and cultural groups. There is no normal - the team can be thought of as a hybrid or third-space (Gutiérrez, Baquedano-López, & Tejeda, 1999). Vickers (2007) is an excellent example of how interactions can be captured and analyzed real-time and their effects accounted for and explained over longer time scales. It also reveals how mastery of language and disciplinary knowledge as an indivisible whole is a critical engineering competence. Finally, it emphasizes the need for researchers to attend to team participatory structures and the links between the claiming of roles and the outcomes of enculturation.

This section now goes on to identify three factors that potentially influence the development of engineering dispositions and thinking among culturally diverse students in team-based projects in this study. Biggs and Tang (2011) note that a host of factors mediate culturally diverse students' learning in higher education, some of which are unique to them (i.e., learning in English; cultural, social isolation) and others that mediate all students' development. These include the level of engagement a given student has with respect to tasks, the degree to which lecturers and classes stimulate them, and their academic orientation. While this does not deny the unique challenges of culturally diverse students, it also does not mean that all of their challenges are unique to them.

In the context of this study, students are transitioning from traditional to team-based project modes of study where activities come to be organized around projects and social interaction. Thomas (2000) defines project-based learning as having these characteristics: projects are central, not peripheral to the curriculum; they are realistic (i.e., not school-like) and focus on problems in which students encounter the discipline's central concepts and principles; and they are student driven to a significant degree and involve students in a constructive investigation. Transitioning successfully to this mode of study requires students to be receptive to project work, value applied knowledge, have a capacity for self-directing study, and have a capacity for collaborating and jointly constructing technical understanding. Such a transition potentially introduces a dissonance between the academic expectations, knowledge, and skills students bring from previous experiences and those required in this new mode of study. For culturally diverse students, this amounts to at least three interconnected factors that potentially shape the development: i) expectations, beliefs, and practices in relation to engineering study; ii) English language competence within engineering disciplinary contexts; and iii) intercultural and interpersonal skills.

On the question of expectations, beliefs, and practices, team-based projects represents a transition for many students from teacher-centered to student-centered pedagogy, which requires a greater, or perhaps a different, capacity to be self-directed in classrooms. Any individual student's capacity to do so will depend on complex factors that are difficult to generalize. Yet, for those students who have come from academic backgrounds largely characterized by traditional lecture, textbook, and exam oriented modes of study, being self-directed in team-based project modes of study may be a challenge. Students' expectations of their roles, their beliefs about the nature of knowledge, and their study practices may all influence how they adapt to this new mode of study.

While the danger of stereotyping culturally diverse students from specific countries or cultural groups is recognized, so too are attempts made to research challenges of students from Asian countries in higher education. A large body of literature exists on Confucian Heritage Culture (CHC) students with "the Chinese learner" being a frequent topic of papers over the last 30 years (Ryan, 2010). Cross and Hitchcock (2007) note how these students have been portrayed from a deficit perspective as passive, reluctant to express opinions, reliant on rote memorization, respectful of hierarchy, and lacking a capacity for self-directed learning. While ascribing many of these perceptions as outdated stereotypes, as do other authors (Biggs, 1996; Ryan, 2010), Cross and Hitchcock did a comparative study of 68 students from China, Chinese Hong Kong, and Taiwan as they neared the end of their degree programs at a UK university. They found that students perceived a mismatch in expectations between themselves and their teachers in the UK with respect to teachers' roles (e.g., hierarchical, students dependent), assessment (e.g., varied assessments used in the UK, almost exclusive use of exams in their home countries), and knowledge (e.g., rote memorization). Scholars rejecting persistent stereotypical views of CHC students have sought nuanced approaches to understanding these students' challenges (e.g., Mathia, Bruce, & Newton, 2013; Ha & Li, 2014). While these debates are recognized, a plausible proposition is that any student bringing vastly different expectations, beliefs, and practices to team-based projects may find challenges benefitting from this mode of study.

Second, with respect to English language competence within STEM disciplinary contexts, Lee (2005) notes that may English Language Learners "confront the demands of academic learning through a yet-unmastered language" and "to keep from falling behind their

English-speaking peers in academic content areas, such as science…need to develop English language and literacy skills in the context of subject area instruction" (p. 492). For culturally diverse students, their English competence is one identifiable factor likely to mediate their capacity to function in team-based design projects. It is impossible to generalize a priori about culturally diverse students' discipline-specific English language competence; however, it may mediate their capacity to jointly construct technical understanding in teams and engage in team processes.

Third, intercultural competence and interpersonal skills potentially mediate culturally diverse students in how they respond to a team-based project mode of study. Native and non-native English speakers alike require intercultural and interpersonal skills, also known as sociolinguistic and strategic language competence (Bachman & Palmer, 2010). Arkoudis, Richardson, and Baik (2012) note in the Australian context that "interpersonal communication skills are considered important attributes for graduates to have, especially as many will work with people from diverse cultural and linguistic backgrounds … this is true for all graduates, not only for EAL (i.e., ESL) students" (p. 94). Highly diverse teams, such as at this study's site, can be thought of as "hybrid cultural spaces" (Gutiérrez et al., 1999), meaning that in order to have successful projects, participants from diverse backgrounds need to engage in creating shared meanings across cultural, linguistic, and personal differences that serve as a basis for future collaboration that make for successful outcomes. Culturally diverse students who have attended high school outside of Canada may struggle with the dual task of coping with language challenges and negotiating team relationships across cultural divides. Competence in intercultural and interpersonal skills potentially mediates the nature of these students' engagement with and capacity to succeed in team-based project work.

2.10 Literature Review: Summary and Significance

This section identifies the significance of this review of the literature, which aimed to contextualize and inform this thesis. This review set out to understand how scholars have approached the challenges of researching enculturation in complex, lived curricula and what they have found to be its effect on engineering dispositions and thinking. The first implication is for this study's overall orientation towards research. This study eschews an approach to researching the evolution of culturally diverse students' engineering dispositions and thinking as the product of an assimilative brand of enculturation into an engineering disciplinary cultural norm (e.g., Clark et al., 2008; Dryburgh, 1999) such as characterizations noted in the literature (i.e., Donald, 2002; Godfrey & Parker, 2010; Stevens et al., 2008). Rather, this study embraces an approach to researching enculturation by capturing evolution and change as it emerges over time as a product of complex interactions in the lived curriculum (e.g., Esmonde et al., 2011; Roth, 2013).

Second, the engineering dispositions and thinking that Donald (1995, 2002, 2008) and Godfrey and Parker (2010) identify as engineering disciplinary culture are summarized in Table 5. These are taken as orienting features that may exist at this study's data research and, if so, may shape culturally diverse students' engineering dispositions and thinking. Hence, they are taken as reference points for what might be present in the environment and what might emerge in the engineering dispositions and thinking of the culturally diverse students in this doctoral study. They are not taken as indicators that will dictate this study's data collection and analysis and drive its findings. A related implication with respect to engineering dispositions and thinking comes from Stevens et al. (2008) in Section 2.5, who identified shifts in the curriculum as students begin to engage in open-ended real-world problems, team-based work, and student-centered study which they are challenged to navigate. The students in this doctoral study are precisely at the point where they will no longer be de facto math and science students. Hence, the tensions and contradictions this shift engenders are likely to drive the nature of the enculturation and the engineering dispositions and thinking that emerge.

Table 5. Engineering Dispositions and Thinking as Points of Reference

Relevant Disposition/Thinking	Source
Take risks/responsibilities for decisions Be self-reliant Act on logical advice Keep to the point Practical, pragmatic, hard-working, stable, introverted, Creative and inventive rather than communicative Join concepts to practical activity Deal with unbounded problems; too little/much information Cope with uncertainty Set limits on problem space Be adept at thinking processes (e.g., description, selection, representation, inference, synthesis, verification) Consolidate/integrate disciplinary content knowledge into thinking processes or relevant systems or frameworks	Donald (2002)
Work-hard, play hard Best over right answers Anything worth doing is hard: a natural part of learning/working Cooperation, collaboration, professionalism highly valued Time is a limited resource Achievement oriented: ‘can do’ people Tough, capable, conventional, self-deprecating Not emotionally demonstrative or concerned with appearance Proud, strong group identity as engineers Work gendered to some degree Respect for diversity if technically, communicatively competent Orientation towards solving problems Capacity for visual, mathematical representation/communication Instrumental views on learning: passing vs. understanding	Godfrey & Parker (2010)
Access to technical knowledge, hard work confers authority Rewards, roles judged by effort, ability, experience, strengths Utilitarian orientation towards knowledge and its use	Kittleson & Southerland (2004)

Third, the review offers a cluster of rich concepts and terminology for the data analysis, findings, and implications discussed in later chapters. These are: identify with engineering, be identified as an engineer, and disidentify with engineering (Pesheux, 1982; Stevens et al., 2008; Tonso, 2006a; Walker, 2001); the centrality of disciplinary knowledge, thinking, behaviour, and hard work in "pulling off being an engineer" (Kittleson & Southerland, 2004); doing school versus learning, hard versus soft prototyping, and divide-and-conquer approach to tasks (Newstetter, 1998); and emergent team perspectives, emergent team culture, and contradictions (Esmonde et al., 2011; Holland & Reeves, 1996; Stevens et al., 2008).

Fourth, this literature review has also emphasized the paucity of research on how culturally diverse students evolve in team-based engineering design STEM programs. Consideration of the characteristics of the shift to team-based project modes of study from the literature and the requirements it places on students allowed three major factors likely to affect the development of culturally diverse students' engineering dispositions and thinking to be identified. These are: expectations, beliefs, and practices in relation to engineering study; English language competence within engineering disciplinary contexts; and intercultural and interpersonal skills.

Owing to the gap in the literature on culturally diverse students in engineering, there is clearly a need for more research with the theoretical and analytical capacity to reveal how and in what way these students develop at the level of the lived curricula. This chapter's discussion emphasizes the need for innovative studies that employ the theoretical and analytical capacity of activity theory to understand the process and products of enculturation for these students as they participate in team-based engineering design projects. This thesis now discusses relevant perspectives from activity theory that situated and guided this study.

Chapter 3: Theoretical

3.1 Introduction and Overview

This chapter presents and discusses the theoretical framing of this case study which investigates how the engineering dispositions and thinking of culturally diverse students evolve through their enculturating experiences in an undergraduate Electrical and Computer Engineering program. This study conceptualizes becoming an engineer as *enculturation*, which entails that a person's development occurs through immersion in a culture – a disciplinary school culture, in this case - rather than through the transmission and acquisition of information and skills by a person (Hodson & Hodson, 1998a, 1998b). As discussed briefly in Section 1.1, enculturation, first articulated in anthropology by Heskovits (1948), refers to the shaping of values and behavior through the immersion of an individual in a culture. *Processes of enculturation*, as defined by Grusec and Hastings (2014), are those forces, deliberate or not, in a given network of influences that limit, direct, and shape an individual. These result in the individual having greater competence in the language, rituals, and values of the culture in which they are immersed. The term "forces" is used in this study to refer specifically to interactions among students, instructors, tools, and assessment that become significant within the environment for students' enculturation.

Acculturation is a similar term coined earlier in anthropology (Redfield, Linton, & Herskovits, 1936) to describe "the dual process of cultural and psychological change that occurs as a result of contact between two or more cultural groups" that, over the long term, causes change at the group and individual level (Grusec & Hastings, 2014, pp. 520–521). While both enculturation and acculturation can be used to talk about change through processes of cultural transmission (Grusec & Hastings), the terms *enculturation* and *enculturation processes* were chosen for this study for two reasons. First, enculturation is a more appropriate term with which to frame processes of change in individuals immersed in disciplinary cultures such as engineering study as they begin to develop as early professionals. Acculturation entails a juxtaposition of different cultures writ large and the mutual changes that result from such differences, which is less fitting to this study's focus. Second, the terms enculturation and processes of enculturation have greater currency in the science and engineering literature (e.g., Hodson & Hodson, 1998b; Godfrey & Parker, 2010). In their framing of learning in the sciences, for example, (Hodson & Hodson, 1998a, 1998b) draw on sociocultural theory (Vygotsky, 1978; Lave & Wenger, 1991), to describe becoming a scientist as enculturation: students participate in the social, cultural, and material context and acquire a disciplinary mind-set and culture by appropriating the cultural tools of science (Driver, Asoko, Leach, Scott, & Mortimer, 1994). As noted in Section 1.1, this study aims to account holistically for interactions in the context for their effects on culturally diverse students, an approach which entails a dual focus on processes (i.e., enculturation processes) and products (i.e., engineering thinking and dispositions). Hence the main research question is: How do the engineering dispositions and thinking of culturally diverse students evolve through their experiences in the second year of an electrical and computer engineering program?

This case study is informed by a hybrid of theoretical perspectives from cultural historical activity theory and German critical psychology (Roth, 2009) to understand how culturally diverse engineering students evolve through their enculturating experiences. This hybrid has been derived by Roth from the cultural historical activity theory[2] (herein referred to

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[2] The term activity theory is used as shorthand for Cultural-Historical Activity Theory: Engeström (1987) employs both terms interchangeably in his seminal book.

as activity theory) perspectives of Vygotsky (1978), Leont’ev (1978), and Engeström (1987) and the German critical psychology perspectives of Holzkamp (Holzkamp, 1991, 2013). As such, although this chapter derives and explains the origin of what is often referred to as first and second generation activity theory (Vygotsky, Leont′ev, Engeström), this study employs a hybrid theoretical framework (Roth) which credits but bypasses Engeström’s second generation activity theory through a new lineage of activity theory which takes the standpoint of the subject within activity rather than the activity system (Vygotsky, Leont′ev, Roth, Holzkamp). This chapter’s purpose is to locate this study within a constellation of educational research epistemologies, theoretical frameworks, and theories; to overview activity theory; and to define this study’s perspective on culture so as to provide reasoned and justifiable theoretical and analytical focus for this research. This chapter will do the following:

- Justify the theoretical choices (constructionism, interpretivism, symbolic interactionism, activity theory) for researching enculturating effects of social, cultural, historical, and material factors in a team-based engineering design course. (Sections 3.2, 3.3)

- Trace activity theory’s origins in Vygotsky (1978), who theorized development as a person’s sign-tool mediated practical activity in the world that results in transform for both. This is theoretically relevant to later sections. (Section 3.3.1)

- Trace Leon’tev’s (1978; 1981) incorporation of societal, cultural, and historical dimensions into Vygotsky’s ideas, expressed as Engeström’s (1987) second generation activity theory. (Section 3.3.2)

- Shift away from Engeström’s (1987) second generation activity theory, which emphasizes the structure of activities in preference to the hybrid theoretical perspective of Roth (2009), which takes the standpoint of the subject in activity (Section 3.4.1)

- Discuss units of analysis (activity, consciousness, personality) for research (Leont′ev, 1978; 1981). Key terms adopted include: *irreducible units of analysis*, orienting effects of *object/motive, inner contradictions*, focus on *learning trajectories* over time. (Section 3.4.2)

- Overview the five-stage hybrid theoretical framework (Roth, 2009) for tracking emergence, turnover in dominance, and restructuring of new development resulting from inner contradictions in the student-in-activity over time. This is the primary theoretical framework employed in this research (Section 3.4.3)

- Discuss Holzkamp's (2013) key concepts (key terms: *generalized agency*, *generalized possibilities to act*, *subjective reasons for action*) as ways of understanding mediating layers between societal conditions and individuals engaged in practical activity. (Section 3.4.4)

- Overview theoretical perspectives and findings from cultural analysis to anticipate what students bring from their cultures and their potential mediating effects on overall activity (e.g., team dynamics, perspective) and hence the evolution of engineering dispositions and thinking. (Section 3.5)

3.2 General Theoretical Framing

Research into evolution and change in students through their participation in team-based design projects could be conducted from a number of standpoints about what it means to know (e.g., objectivism, constructionism, subjectivism) and their loosely coupled theoretical perspectives (e.g., positivism, interpretivism, post-modernism, critical inquiry) and theories (e.g., symbolic interactionism, phenomenology, hermeneutics). The complex social, cultural, historical, material, and cognitive influences on students that exist in the context of this study present a set of choices of how to best frame and conduct research. As an example, Greeno (1998) contrasts how applying a cognitive science (i.e., stemming from an objectivist epistemology) versus a sociocultural (i.e., stemming from a constructionist epistemology) lens alters the focus of research:

> Cognitive science analyzes structures of the informational contents of activity, but has little to say about the mutual interactions that people have with each other and with the material and technological resources of their environments. Interactional studies analyze patterns of coordinated activity but have little to say about the informational contents of interaction that are involved in achieving tasks, goals and functions. (p. 6)

In terms of researching development, Greeno suggests that a cognitive science approach entails a product ontology (i.e., their change) whereas a sociocultural approach entails a process ontology (i.e., how they got there). While the researcher recognizes the value of an objectivist lens and a focus on cognition, applying a traditional cognitive approach would not serve this study's focus because of what it would tend to exclude. Simply put, it would run the danger of "conceiving the person as existing in a cultural, historical, institutional, and micro-social vacuum" (Trowler, 2008, p. 19). The researcher remains interested in the processes of enculturation in complex contexts – "those forces, deliberate or not, in a given network of influences (e.g., adults, peers, school) that limit, direct, and shape an individual" (Grusec & Hastings, 2014) - and how these might be accounted for in order to understand evolution in students. Hence, this research is oriented towards the epistemology of constructionism, a theory of knowledge, which sees meaning as emerging only when consciousness engages with objects that exist in the world and that "knowledge, and therefore all meaningful reality as such, is contingent upon human practices, being constructed in and out of interaction between human beings and their world, and developed and transmitted within an essentially social context" (Crotty, 1998, p. 42). Accordingly, interpretivism is an appropriate philosophical stance or theoretical perspective with respect to research activities because it "looks for culturally derived and historically situated interpretations of the social life-world" (Crotty, p. 67).

Careful consideration of the theoretical perspectives associated with interpretivism led the author to conclude that a theoretical and methodological orientation towards symbolic interactionism is appropriate for this study of how engineering students' dispositions and thinking evolve through their participation in team-based engineering design projects. This is so because of this perspective's focus on language and other symbolic tools in dialogue and interaction as the carrier of perceptions, feelings, and attitudes of the participants and as a pathway to interpreting their meanings and intents. According to Blumer (1986), symbolic interactionism's basic assumptions are that:

- Human beings act towards things on the basis of the meanings that these things have for them
- The meaning of such things is derived from, and arises out of, the social interactions that one has with one's fellows
- These things are handled in, and modified through, an interpretive process used by the person in dealing with the things he encounters (p. 2)

The purpose of this study is to tune into these acts, meanings, and interpretive processes over time so as to explain how students evolve, something echoed in the central notion of symbolic interactionism, or, in the words of Denzin (1974): "symbolic interactionism directs the investigator to take, to the best of his ability, the standpoint of those studied" (p. 269). It is the students' standpoint from which evolution in their dispositions and thinking might be best understood and explained.

Phenomenology, another interpretivist theoretical perspective, seeks to suspend received notions or predispositions and to identify, understand, and describe subjective lived experience. In contrast to symbolic interactionism, which sees culture as a rich web of meaning in subjects' lives as fodder for understanding, phenomenology regards culture with caution. As Merleau-Ponty (1996) notes, "in order to see the world and grasp it as paradoxical, we must break with our familiar acceptance with it" (p. xiv). For phenomenological researchers, laying aside prevailing understandings to focus on what is experienced in a direct and unmediated manner allows for new meanings and understandings to emerge. However, three principle rationales led to a choice of symbolic interactionism as the study's dominant interpretivist perspective. First, phenomenological studies have tended to result in meanings and accounts which are largely thematic and descriptive in nature and so are mismatched to this study's purpose of understanding and, importantly, explaining individual students' evolution and change through their participation in team-based design. Second, while the phenomenological directive to "bracket" oneself as a researcher is a notable caution against over-interpretation, making a full break with familiar acceptance runs the risk of disallowing the researcher's experience for arriving at new meanings. Third, activity theory, described herein, provides theoretical and analytic guidance to the basic assumptions and approach of symbolic interactionism, which will allow for a richer understanding of how students evolve beyond what a phenomenological perspective might afford. Together, these rationales justify adopting symbolic interactionism as the most fitting theoretical and methodological orientation for this study's research questions.

3.3 Activity Theory: Foundations

Careful consideration of a number of theories (i.e., cultural-historical activity theory, sociocultural theory, actor-network theory, language socialization theory) commensurate with this study's theoretical orientation to constructionism, interpretivism, and symbolic interactionism led to a choice of activity theory and the main framework for guiding this research. Cole (1998) eloquently summarizes activity theory's key characteristics. First, "it emphasizes mediated action in a context (and) seeks to ground its analysis in everyday events" (p. 104). Importantly, he notes that activity theory is not reductive as it "rejects cause-effect, stimulus-response, explanatory science in favour of science that emphasizes the emergent nature of mind in activity and that acknowledges a central role for interpretation in its explanatory framework" (p. 104). Cole also emphasized the social nature of cognition: "(activity theory) assumes the mind engages in the *joint* mediated activity of people … mind, then, is in an important sense, "co-constructed" and distributed" (p. 104). Finally, Cole notes that activity theory privileges neither structure nor agency in that "it assumes that individuals are active agents in their own development, but do not act in settings entirely of their own choosing" (p. 104). Activity theory has the capacity to theoretically ground and analytically guide this study because it allows researchers to conceptualize and define what is important in complex environments; to avoid naïve unidirectional accounts of development that mainly privilege either individual agency or structural factors students' development; and to attend to the particular societal, cultural, and individual factors relevant to students' enculturation.

This section overviews activity theory, beginning with the original work of Vygotsky (1978), whose foundational theories of development drew on dialectical and historical materialism to place the mind in the world and the world in the mind (Section 3.3.1). It then discusses Leont'ev (1978) and Engeström's (1987) activity theory perspectives, so as to explain the theoretical and analytical framework known widely as second-generation activity theory (Section 3.3.2). Hence, Section 3.3 provides the theoretical basis for the hybrid activity theory framework of Roth (2009), which is employed in this thesis. Engeström's second generation of activity theory is not employed in this thesis. Section 3.4 introduces this study's hybrid theoretical framework from Roth, which joins important concepts from German critical psychology (Holzkamp, 1991, 2013) to refocus activity theory on the standpoint of the students as they evolve through their enculturating experiences as a constitutive part of collective activity.

3.3.1 Vygotsky and First Generation Activity Theory

Activity theory is a way of understanding human activity and development as a dynamic evolving process constituted by a complex and mutually defining array of social, cultural, historical, material, and subjective elements. Activity theory finds its roots in Vygotsky (1978), who formulated a model of human development by drawing on historical and dialectical materialism. These philosophical perspectives derive from the teachings of Marx and Engels and focus on how new qualities of being and society emerge and evolve out of historical and material conditions. As Tolman (1991) notes, historical materialism ”derives from the maxim that a thing is best understood as to what it is by examining how it got that way” (p. 10). Dialectical materialism attempts to move beyond binaries and simplistic unidirectional cause-effect or stimulus-response approaches to understanding development. Vygotsky extended these perspectives so as to be relevant and applicable to psychology by articulating a way of studying the development of human behaviour and consciousness by accounting for its origins and tracing the dynamics and nature of its change. By so rooting individual development in society and culture and articulating mechanisms for change and evolution, Vygotsky offered a way of investigating the development of higher psychological functions.

Two concepts from Vygotsky's work - *mediation* and *internalization* - are important for this overview. These concepts are explained using Vygostky's (1978) own examples of development in children with the understanding that they are for illustrative purposes only. In *Mind in Society*, Vygotsky discusses the unique aspects of early human development and how children use instrumental or *mediated* (i.e., indirect) methods - tool use and speech - when interacting with the world in order to fulfill their goals. He notes how, in early childhood, the use of tools and signs develops along separate lines but converges at what becomes a significant point in a child's development. Vygotsky cites his study of problem solving in children, in which participants had to obtain a piece of candy that had been placed out of reach. The children availed themselves of both tools (a stool and a stick) and language, which changes from initially descriptive speech to what he calls increasingly "planful" (p. 25) speech, in order to get the candy. His point is that by this stage in a child's development "their speech and action are part of one and the same complex psychological function, directed toward the solution to the problem at hand" (p. 25). In more complex tasks as well, speech becomes critical for planning or engaging adults in talk to solve problems. Hence, tools and signs (aka artifacts) *mediate* the child's interaction with the world. Vygotsky also refers to a second development when language becomes *internalized*, "when socialized speech (which has previously been used to address an adult) is turned inward." When this happens, "instead of appealing to the adult, children appeal to themselves; language thus takes on an intrapersonal function in addition to its interpersonal use" (p. 27). Yet when speech turns inwards and takes on an intrapersonal function, the child also begins to internalize social relations and cultural forms of behaviour. As Vygotsky notes: "The history of the process of the internalization of social speech is also the history of the socialization of children's practical intellect" (p. 27).

In summary, humans learn to avail themselves of mediating artifacts (tools, signs) during practical activity to affect the world in order to fulfill their goals and later begin to internalize social speech and problem solving capacity. Vygotsky (1978) further notes that the respective nature of tools and signs as mediating artifacts differ in the way they orient human behaviour:

> The tool's function is to serve as the conductor of human influence on the object of activity; it is externally oriented; it must lead to changes in objects. (…) The sign, on the other hand, changes nothing in the object of a psychological operation. It is a means of internal activity aimed at mastering oneself; the sign is internally oriented. (p. 55)

As such, a dialectical relationship exists between mind and world that is mediated by tools and signs: the person, engaging in tool- and sign-mediated practical activity, at once transforms and is transformed by the world. Accordingly, Vygotsky eschewed the idea of a direct link between stimulus in the environment (i.e. the object of cognition) and the response of the organism (i.e. an organism's cognition) in favour of a dialectical relationship (Figure 1):

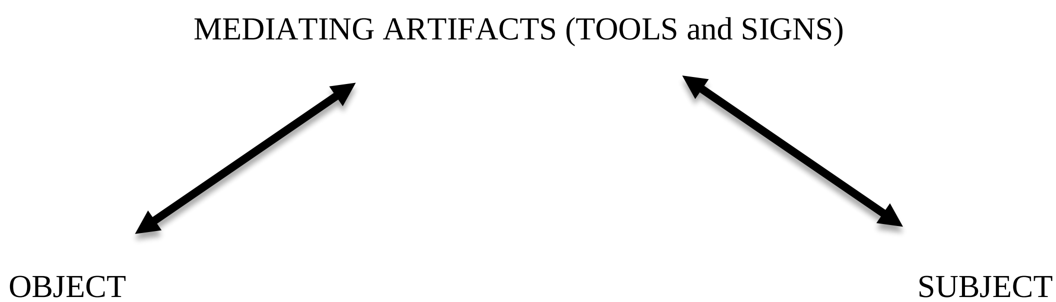

Figure 1. Vygotsky's (1978) Concept of Mediation

The bidirectional arrows indicate the dialectical relationship between mind and world in human activity, in which mind and world are mutual constitutive and have the potential to transform each other. Engeström (1987) rendered this relationship as a triangular schematic (Figure 2).

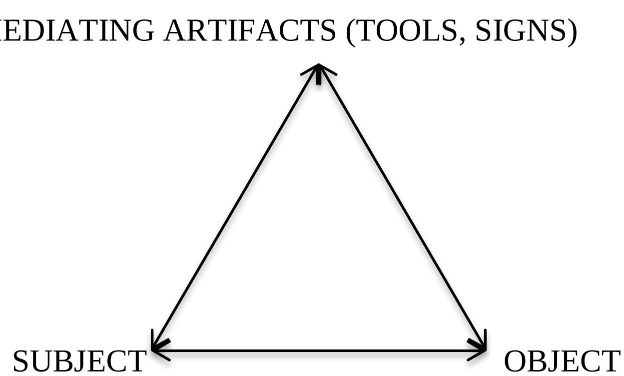

Figure 2. Vygotsky's (1978) Concept of Mediation as Represented by Engeström (1987)

Engeström (2009) dubbed Figure 2 first-generation activity theory, noting that this "basic unit of analysis (of cognition) now overcame the split between the Cartesian individual and the untouchable societal structure" because subject and object (individual and society/environment) are recognized as mutually shaping and transforming each other. Hence, "the individual could no longer be understood without his or her cultural means (i.e. mediating tools/signs or artifacts), and society could no longer be understood without the agency of individuals who use and produce artifacts (i.e., tools and signs)" (Engeström, 2009, p. 94). In this way, Vygotsky, following Engels, argued against the limitations of naturalism and behaviourism in the early 20th century, in what he called "the crisis of psychology" (Vygotsky, 1997). Vygotsky (1978) notes:

> Naturalism in historical analysis, according to Engels, manifests itself in the assumption that only nature affects human beings and only natural conditions determine historical development. The dialectical approach, while admitting the influence of nature, asserts that man, in turn, affects nature and creates through his changes in nature new natural conditions for his existence. (…) All stimulus-response methods share the inadequacy that Engels ascribes to naturalistic approaches to history. Both see the relation between human behaviour and nature as unidirectionally reactive. (p. 60)

Through his conception of human development, Vygotsky (1978) points to a way forward out of the crisis of psychology based on the scientific concepts of evolution: "the internalization of socially rooted and historically developed activities is the distinguishing feature of human psychology, the basis of the qualitative leap from animal to human psychology. As yet, the barest outline of this process is known" (p.57). The dynamics and mechanisms of the process have great theoretical and methodological relevance for how new dispositions and thinking in students will be tracked as it emerges and evolves through their participation in complex tool and sign mediated activity in team-based engineering design projects.

The next section discusses second-generation activity theory because it helps conceptualize the structure of collective human activity and the emergence of new dispositions and thinking that results from it. Although Engeström's (1987) second generation activity theory will not be employed in this research, discussing it provides a basis for illustrating key concepts. It is Roth's (2009) hybrid activity theory framework (Section 3.4) which is employed in this research as a far more appropriate approach to achieving a focus on individual students' enculturation.

3.3.2 Leont'ev and Engeström: Second Generation Activity Theory

This section discusses how Leont'ev (1981) situated Vygotsky's theoretical perspectives of development within a context of joint, collective activity and how the relations and tensions among its elements (i.e., subject, tools/signs, object, rules, community, division of labour) were usefully extended and represented by Engeström (1987). As noted in Section 3.3.1, Vygotsky (1978) framed the development of individual higher psychological processes as a product of dialectical tool and sign mediated practical activity of the individual in the real world. He also recognized that tools and signs and the knowledge required for their continued use and modification are passed between generations; yet it was Leon'tev (1978; 1981) who explicitly incorporated societal, cultural, and historical dimensions into his ideas. Drawing from Marx and Engels, Leont'ev (1981) used an example of a primeval hunt to illustrate how individual activity is altered when individuals engage in collective labour directed at an object/motive and how the elements of activity function together:

> Human labour is social activity from the beginning, based on the co-operation of individuals, assuming a technical division, even though rudimentary, of labour functions; labour consequently is a process of action on nature linking together its participants, and mediating their contact. (pp. 185-186)

Leont’ev (1981) notes that a given individual within the hunting group is motivated by the need for food and serves a particular role within the group to achieve this ultimate goal. For example, a beater within the group, who frightens animals from the bushes for others to catch, engages in actions (beating the bushes) to realize the object or motive of the activity (getting food). The object/motive of the action and activity differ, yet the product of the actions of individuals within the group is the accomplishment of the goal of the activity (Leont’ev, 1981). Leont’ev identified the division of labour, society, and rules as additional mediators of an individual’s development within a collective. Extending Leont’ev’s primeval hunt example, Holland and Reeves (1996) note this culture and history (i.e., division of labour, society, rules) potentially has local manifestations, which they coined as an emergent team perspective (see Section 2.6):

> The hunting groups develop different ‘takes’ or ‘views’ of hunting, so that the activity ends up differing from team to team. Perhaps one team focuses on hunting as a masculine competition, to the point that the hunters relentlessly pursue the prey that best symbolized virility, disdaining all others. Perhaps another elaborates a second opportunity offered by hunting, namely, an escape from other domestic duties. This team begins to pursue whatever prey takes them farthest away for the longest time. (p. 260)

Hence, the emergence of collective human activity is synonymous with the genesis of culture and history, of which development is but one manifestation. Engeström (1987) drew on Leont’ev (1981) and on the evolutionary concept of morphogenesis (i.e., the emergence of structure, function in organisms through organism-environmental pressure) to represent such co-emergence of collective tool/sign mediated labour, culture, and history (i.e., anthropogenesis) as the dominant driver of change in humans (Figure 3). By definition, this meant engaging in elements of human activity that mediate collective activity (Figure 3b: rites, rituals, population, division of labour). In doing so, Engeström arrived at a heuristic for collective human activity, which he dubbed the second generation of activity theory (Figure 3c, 4). The object/motive in

Figure 4 can be an outward goal, concrete purpose, or conceptual understanding “at which the activity is directed and which is molded or transformed into *outcomes* with the help of physical and symbolic, external and internal tools” (Engeström, 2009, p. 67) by an individual or group (*subject*). This triangle sits atop a superstructure of *rules*, *community/society*, and *division of labour* that accounts for the historically and culturally contextualized nature of human activity. The community/society of an activity system is the individuals or groups that share the mediating artifacts and whose agency is constrained or afforded through the division of labour or formal, informal and technical rules (i.e. norms, conventions).

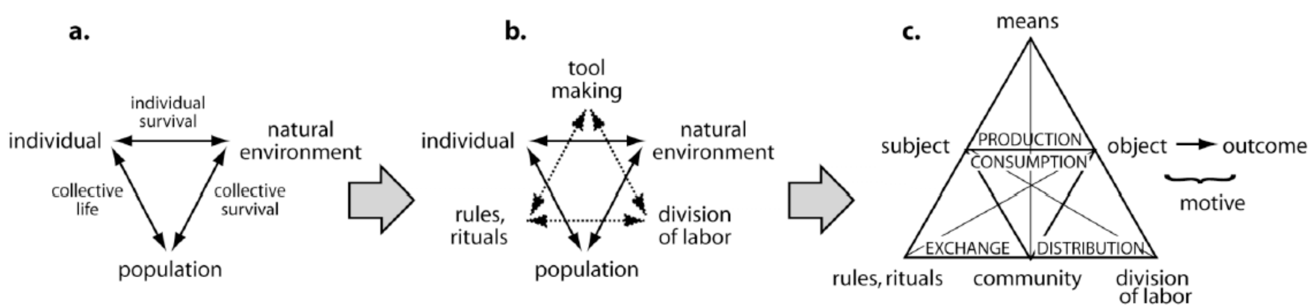

Figure 3. Anthropogenesis

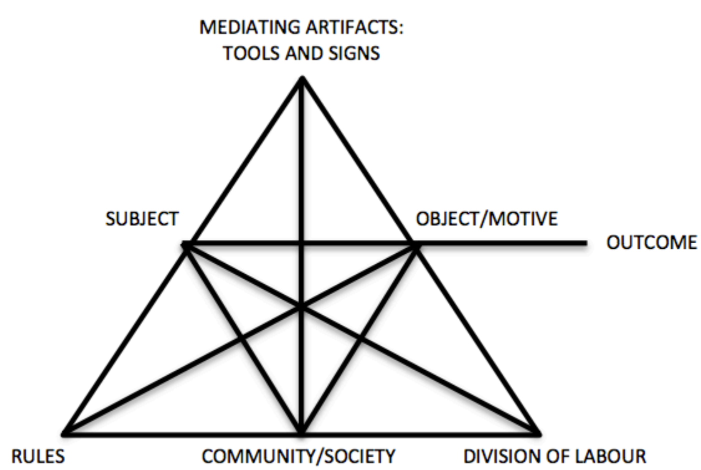

Figure 4. Second Generation Activity Theory (Engeström, 1987)

The theoretical perspectives of Vygotsky (1978), Leon'tev (1978), and Engeström (1987) are foundational for this study, although Engeström's second-generation activity theory is not employed in this study. First, Vygotsky offered the perspective that a person's engagement in purposeful activity in the world through the mediating effects of artifacts (tools and signs) results in mutual transformation in individuals and their environment in ways that are neither simplistic nor unidirectional. Second, Leont'ev enhanced the explanatory power of Vygotsky's ideas by shifting the focus from a subject's tool-sign mediated development of higher psychological functions to object/motive centered activity within a cultural-historical milieu. Third, Engeström captured the mutually defining interactions among elements in an activity system in a useful heuristic (Figures 3c, 4) and more clearly articulated the mechanism of anthropogenesis, or emergent culture, as the dominant driver of change in humans. This discussion of activity theory will now shift from a focus on the structure of activity (e.g., Figure 4) to a focus on the student in activity and on the hybrid theoretical framework employed in this study (Roth, 2009)

3.4 Activity Theory: Focusing on the Subject/Student

The previous section described activity theory's basic development, the conceptual structure of activity and its mutually defining elements (Figures 3c, 4), and articulated how culture and history emerge from collective activity. This study focuses on the enculturating effects of complex interactions in the environment (i.e., conceptualized as activity) on students. Hence, this study is intent upon the analysis of change that emerges in students through activity rather than an analysis of the activity system itself, which the second generation activity theory of Engeström (1987) tends to emphasize (Langemeyer & Roth, 2006). As such, this section presents Roth's (2009) hybrid theoretical framework, which provides this study with the theoretical and analytical capacity to follow students as they participate in complex activity. This section refocuses attention on the student within the activity, discusses how Leont'ev's (1978) conceptualized holistic units of analysis to understand development, and draws out important theoretical and analytical concepts and terminology that allow evolution in students' engineering dispositions and thinking to be tracked over time as they participate as a constitutive part of activity.

3.4.1 Finding the Learner and the Learning in Activity

This study employs a hybrid activity theory framework (Roth, 2009) to focus on students engaging in collective practical activity rather than on the whole activity system itself. Leont'ev (1981) and Roth (2013) provide a way forward for how to employ activity theory to look at development over time. Leont'ev described activity as a cluster of social, rule-bound, and embodied actions hierarchically structured into three levels (Figure 5).

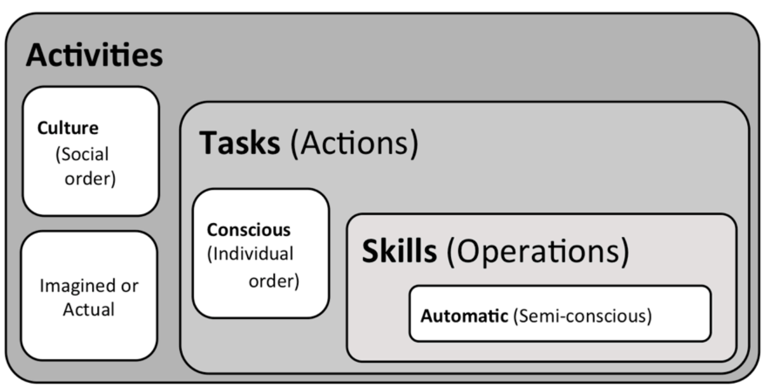

Figure 5. The Structure of Activities

As embodiments of culture, human activity (activity level) is formed through discrete, consciously enacted tasks (action level) that are constituted by automatic or semi-conscious skills (operations level). In other words, although a person might experience an overall activity (e.g., hunting) in terms of multiple conscious or intentional actions or events (e.g., shaking bushes to flush out animals), these actions are constituted by knowledge and sequences and levels or skills with component micro-skills that are often performed in a semi- or un-conscious manner (e.g., judging which bushes to shake, approaching the bush quietly out of sight, timing actions such that other hunters can catch the animals).

Understanding the foregoing description of activities, actions, and operations from the point of view of what the student does, and hence becomes, is one way of refocusing on the student, as does Roth (2013) with his description of the concept of *subjectification* or, at the risk of oversimplifying, students *becoming what they do* as a constitutive part of the activity:

> First, the subject expends energy and therefore is materially transformed. Second, as a result of repeatedly producing the same form of movements (that realize actions), the body or bodies of the subject are transformed, becoming increasingly practically competent. Third, in praxis, the comprehension of the subject is changed, as it increasingly comes to understand praxis on the ideal level. Fourth, with increasing practical and ideal competence, the changes of the subject are recognized within the collective (community) writ large (i.e., not only within a specific groups that might constitute the collective subject of activity, but also within all those who are the subjects in other concretizations of the activity). (pp. 45-46)

Subjectification is similar to Lave and Wenger’s (1991) concept of learners as legitimate peripheral practitioners who garner viable identities-in-practice through participation in a community of practice: they are inexorably changed and come to be recognized as full members. These two key concepts are important for this study and will be discussed in later chapters.

3.4.2 Units of Analysis: Activity, Consciousness, and Personality

This section discusses how Leont'ev (1981) more clearly articulated the structure of activities and the units of analysis in ways that are fruitful for this research. Leont'ev (1978) posited activity itself as a unit of analysis for understanding human development in a way that was neither reductive, deterministic, nor naïve (italics mine):

> *Activity is a molar, not an additive, unit of the life* of the physical, material subject. In a narrower sense, that is, *at the psychological level, it is a unit of life, mediated by psychic reflection*, the real function of which is that *it orients the subject in the objective world*. In other words, activity is not a reaction and not a totality of reactions, but a system that has structure, *its own internal transitions and transformations, its own development*. (p. 84, *italics* mine)

This quote is rich in meaning and is an opportunity to introduce key concepts for this study: units of analysis in activity theory, the relationship of the mind and activity (i.e., mind-world dialectic/ psychic reflection), the orienting effects for the person of activity (i.e., object-motive), and inner contradictions that drive change in the person and the activity system.

First, activity is an irreducible unit of analysis, meaning that the individual and the elements of activity together form an integral, indivisible whole (i.e., *activity is a molar, not an additive, unit of life*; molar: as in pertaining to the whole). The components of an activity system (Figures 3c, 4) are dialectically related in that they pre-suppose each other (i.e., are mutually constitutive) and have the potential to influence and transform one another. Hence, they cannot be disentangled from each other in analysis. Leont'ev (1978) had arrived at what Vygotsky (2001) had foreshadowed: a unit of analysis that "does not lose any of the properties that are characteristic of the whole, but manage(s) to retain, in the most elementary form, the properties inherent in the whole" (p. 76) – or, in other words, an *irreducible unit of analysis* that preserves the characteristics of the whole (Roth, 2014).

Second, an activity system in the real world exists in a dialectic relationship with the higher order psychological functions of students participating in the activity (i.e., *at the psychological level, it is a unit of life, mediated by psychic reflection*). Through the process of *psychic reflection*, subjective images of objective reality are patterned in particular ways and on different levels in the mind of the person, just as a person has a role in patterning the practical activity in the real world of which she or he is a constitutive part.

Third, activity contains within it an object/motive, which holds an orienting function for the elements of the system, including people engaged in activity (i.e., *it orients the subject in the objective world*). As clarified by Roth (2014), "the subject actively and consciously orients in the world and toward its transformation for the purpose of meeting a generalized, collective (societal) need" (p. 9). The collective societal need is also known as the *object/motive*: "the moving force that governs the processes of activity at the collective level; its image is a subjective product of activity that fixes, stabilizes, and contains it on the ideal plane (collective consciousness)" (Roth, 2014, p. 10). Hence, the object/motive holds an orienting function for the activity and can exist as a material entity in the world or as how people envision it once created.

Fourth, an activity system, rather than being static, is an evolving dynamic entity (i.e., *its own internal transitions and transformations, its own development*). As such, rather than development being driven predominantly by forces that exist outside the unit of analysis (e.g., an enculturating society, community, or structure) or by forces innate to the person whose effects are somehow delimited even in the face of societal structures (e.g., delimited agency), activity as a unit of analysis contains change within itself that is driven by persistent *inner contradictions* that emerge between its elements. One example of an inner contradiction in this context of engineering design is that which arises between the outer, material activity of building the project (i.e., the object/motive as it is currently) and the project as it is imagined by individual team members in different ways (i.e., the object/motive on the ideal plane); between what it is and what it could be. Another example of an inner contradiction in an activity system is when the object/motive for an action (i.e., shaking the bushes to flush out game) becomes the main event, displacing the object/motive of the original activity (i.e., capturing animals for food; Figure 5). Alex (1992) gives the example of the hunter who "gets caught up in the action of beating the bushes … over time he 'elevates' it from an action to an activity". In education, this can be thought of as the contradiction identified in studies discussed earlier (Esmonde et al., 2011; Holland & Reeves, 1996; Newstetter, 1998) between doing schooling and studying engineering.

As Roth and Lee (2007, p. 189) explain, adopting activity as a unit of analysis "leads to changes in the location of representing what is educationally relevant (in that) its inherently dialectical unit of analysis allows for an embodied mind, itself an aspect of the material world, stretching across social and material environments". While Leont'ev's (1978) title *Activity, Consciousness, and Personality* identifies three units of analysis, Engeström's (1987) representation (Figure 3c) gives pre-eminence to the structural elements of activity in analysis. Langemeyer and Roth (2006) note that most activity theory applications stem from Engeström's system-eye perspective and take activity as effectively static, hence precluding researchers from accounting for the activity system's evolution or self-movement and from taking the standpoint of students, who are a constitutive part of activity. This criticism is relevant because this study is researching evolution and change in individual students as they participate in multifarious ways in team-based design projects. As such, Leont'ev's categories of consciousness and personality are overviewed for insights into how to maintain focus on students.

3.4.2.1 Consciousness

After activity in Leont’ev’s book title *Activity, Consciousness, and Personality* (1978), the second developmental category (aka unit of analysis) of consciousness is a way of understanding development as involving the process of psychic reflection identified in Section 3.4.2: “individual consciousness as a specifically human form of subjective reflection of objective reality can be understood as a product of those relations and mediations that arise during the formation and development of society” (p. 12). Leont’ev (1978) describes the role of psychic reflection in mediating inner and outer activity:

> The activity of the subject, external and internal, is mediated and regulated by a psychic reflection of reality. What the subject sees in the object world are motives and goals, and conditions of his activity must be received by him in one way or another, presented, understood, retained, and reproduced in his memory; this applies to processes of his activity and to the subject himself – to his condition, characteristics, and idiosyncrasies. (p. 114)

Here, real world activity and consciousness exist in a dialectic relationship with psychic reflection mediating the two fundamental planes of inner (i.e., mind) and outer activity (i.e., society), which exist side by side as an organic whole. So “consciousness gives rise to activity, but activity gives rise to consciousness” (Roth, 2014, p. 16). Accordingly, Leont’ev (1978) notes:

> The analysis of activity (comprises) the decisive point and principle method of (studying) consciousness. In the study of the forms of societal consciousness it is the analysis of social life, characteristic means of production, and systems of social relationship; in the study of the individual psyche (consciousness), it is the analysis of the activity of individuals in given social conditions and concrete circumstances that are the lot of each of them. (p. 43)

Such an approach would seem to involve tracking how relevant mediating elements of an activity system (Figure 3c, 4) play out for students in their particular concrete circumstances within the activity so as to arrive at an account of their evolution and change as trajectories. This entails identifying students' particular circumstances and inner contradiction(s); observing and interpreting events, interactions, and reports through their participation in activity over time; tracking how their contradictions resolve, ease, persist, or heighten; and then interpreting what this means for their development over longer time scales.

3.4.2.2 Personality

Personality is the third developmental category proposed by Leont'ev (1978) and is particularly useful for understanding the multifaceted nature of personality and identity of students as they traverse different activities, contexts, and stages of life. This approach informed one of the cases in this study. Marx and Engels draw a clear line regarding the nature of personality (translated by Roth, 2013): "The human essence is not an abstractum inherent in the singular individual. In its reality, it is the ensemble of societal relations" (Marx & Engels, 1958, p. 6). This is interesting in light of a parallel distinction in how identity has been conceptualized in the work of Erik Erikson and George Herbert Mead. Erikson (1968) described identity as "a process 'located' in the core of the individual and yet also in the core of his communal culture" (p. 22). Erikson recognized the contextual circumstances of culture, history, and community in identity formation, but emphasized an individual's need to achieve coherence and community validation of a unified personal and cultural identity. Hence, he saw identity as inexorably driven towards integration (Holland & Lachiotte, 2007). In contrast, Mead saw identity as multiple and contingent more in the manner of how Marx, Engels, and Vygotsky conceived personality: "a sense in oneself as a participant in the social roles and positions defined by a specific, historically constituted set of social activities" (Holland & Lachiotte, p. 104). Mead echoed Vygotsky's concepts of mediation by elaborating on his own the dialectic around identity formation, which he coined as the “I-me” dynamic. “I” simultaneously describes the actor and the observer involved in participation, who evaluates and infers “mes” from its own acts (Mead). Holland and Lachiotte usefully paraphrases this mediated process of knowing who one is through participation in activity:

> As we develop maturity in society’s activity systems, we, as individuals, begin to experience our own behaviour as signs of who we are. We become objects of our own gaze, and we experience our own behaviour - and by association ourselves - in relation to the meanings of the group and so become liable to receive admiration and respect or disapproval and condemnation, according to the values practiced by the group. (p. 108)

Similarly, Leont’ev (1982) saw personality as multiple and contingent: “the real basis of human personality is the totality of the, by nature societal relations man entertains with the world, precisely those relations that are realized. This occurs in/through his activity, more precisely, in/through the totality of his manifold activities” (pp. 175-176, translated Roth, 2013).

A key challenge, then, of conceptualizing the category of personality is accounting for the multifaceted nature of students’ personalities as they move between different contexts and activity systems. As in his developmental category of consciousness, Leont’ev (1981, p. 152) proposes researching personality by examining the activities in which individuals are engaged. Leont’ev considered these multiple activity system as consisting of a hierarchical network of nodes or *knot-works* of activities. These knot-works “are tied not by the action of biological or spiritual forces of the subject which lie within him but by that system of relationships into which the subject enters” (p. 159); they represent the substrate of personality. Roth (2014) extends this idea in a useful way for investigating evolution of identity:

> Within the unique individual, the object/motives, all of which are socially determined, exist in some hierarchical order that determine their relative priorities for the person as a whole…the study of personality cannot be conducted by looking at the individual itself, but one has to investigate the development of the systems in which the individual is part and which it, through its own development, develops in turn. (p. 18)

This approach was employed in Roth (2013), as described in Section 2.8, to understand the evolution of a young woman who was initially determined to enter medical school and so engaged in science-oriented study and work opportunities until a turnover in this hierarchical order (of knot-work of object/motives) took her off the flowchart (Section 2.8). In this doctoral study, a source of one student's inner contradiction was precisely between her competing identities within their knot-work hierarchy of object/motives and activities as she entered second year. Pressures she encountered through the program's workload and her lack of investment effected a shift in what was to sit at the topic of the hierarchy of object/motives, identities, and activities. By definition, this entailed evolution and change in her identity and, hence, how her engineering dispositions and thinking evolved.

3.4.3 Mapping Learning Trajectories: Five Stage Hybrid Activity Theory Framework

This section introduces the hybrid analytic framework from Roth (2009) that provides an approach for tracking the evolution of culturally diverse students' engineering dispositions and thinking in team-based design projects. The foregoing sections suggest that researching evolution and change in culturally diverse students' engineering dispositions and thinking is possible by focusing on individual students' inner contradictions that emerge for them in their particular circumstances and play out over time as they participate as a constitutive part of activity. Scholars drawing on the German critical psychology tradition (Holzkamp, 1991, 2013; Roth, 2009) detailed how this might be achieved in the form of trajectories of evolution over time through their articulation of the process and mechanism for "the qualitative leap from animal to human psychology" noted in Section 3.3.2 and represented in Figure 4 (Vygotsky, 1978, p. 57).

In reference to the concept of anthropogenesis represented in Figure 3, Roth (2009) credited Engeström's (1987) summary, but noted that it fell short: "what Engeström does not provide are the reasons and mechanisms for such a turnover from a system regulated by evolutionary pressures to one that develops because of cultural-historical principles" (pp. 8-9). Leont'ev, as Roth notes, proposed developmental trajectories based on evolutionary principles that were "brought about by the accumulation of incremental quantitative changes and inner contradictions that led to qualitative changes (i.e., turnover) where new characteristics and functions came to predominate" (p. 10). Holzkamp (1991) articulates this buildup and turnover from evolutionary to anthropogenic change. Summarized handily by Roth, these stages provide a way for this study to frame, analyze, and report learners' evolution and change:

1) **Stage 1** There has to be a demonstration of the real-historical conditions of the preceding level within and upon which the quantitative functional change develops

2) **Stage 2** It has to be shown that there were objective changes in the external conditions that allow the inner contradictions, which will give rise to the qualitatively new function, to have its equivalent in the external environment.

3) **Stage 3** It behooves the analyst to articulate a functional turnover that related the pre-existing dimensions in a new way, and thereby the evolution of the first qualitative change of the specific nature of the new function that makes the organism better adapted.

4) **Stage 4** A change in dominance must be demonstrated, whereby the previously dominant function is negated and the co-existing new function becomes the dominant one.

5) **Stage 5** The analyst must demonstrated the restructuring process that gives the evolutionary trajectory of the system as a whole a new direction following the becoming dominant function becoming the system-sustaining determinant function. (p. 12)

While these stages are derived to explain the turnover that occurred to make higher functioning in humans possible, the very same stages can be applied to any developmental turnover in humans when a change in dominance of dispositions or thinking, for example, is observed through participation of a student in activity. This approach is a corollary to Cole’s (1998) recommendation to employ three levels of analysis: the microgenetic or event scale, mesogenetic (i.e., extended activity or project) scale, and the ontogenetic (developmental-biographical) scale to research change over time. As noted in Section 2.8, Esmonde et al. (2011) uses such an approach in high school math class group work to focus on: 1) individual interactions around problems on short time scales, 2) change in students over time in solving recurring problem types, 3) change in teams over time as they built on each others’ successes and disseminated new and old ways of solving problems.

This doctoral study will similarly apply Roth’s (2009) work to track change in students’ engineering dispositions and thinking as it emerges and becomes dominant over time because it provides a theoretically and analytically sound approach for operationalizing the research questions. The first two of these five stages were set through the choice of data site and participants, wherein individuals with their own histories prior to second year (i.e., Stage 1: real-life conditions of the preceding level) moved from lecture-based math and science courses to team-based design projects in a more integrated curriculum (i.e., Stage 2: objective changes in external conditions). The trajectories of five students, as driven by their inner contradictions as identified through intense observation, were tracked and accounted for over time using this five-stage framework.

3.4.4 Holzkamp: Mediation Between Societal Structure and the Individual

The concepts of subjectification, psychic reflection, consciousness and personality as units of analysis, and inner contradictions described in the foregoing sections have drawn activity theory away from Engeström's (1987) systems-eye view of second-generation activity theory (i.e., not employed in this study) towards a person-eye view in a way that attends to individual students and their particular circumstances. Holzkamp (2013) went further by recognizing that individuals are never confronted by society face-to-face without mediation (e.g., Clark et al., 2008, Section 2.4). He took on the project to "adequately elaborate the mediation between the societal structure and the individual or … more exactly, between the societal structure and each single subject as an actor within the locality of the particular scene of life conduct (i.e., a given scene in a sequence of life scenes) addressed at a specific time" (p. 277). In proposing mediating factors between the individual and societal structure, he contributed several important concepts for this study: *generalized agency*, *generalized possibilities to act*, and *subjective reasons for action*.

Generalized agency refers to Leont'ev's (1978) concept of the human capacity to gain, through participation in activity with others, some degree of control over societal conditions so as to improve one's life conditions and maximize one's capacity to act (e.g., the primordial hunt). He also refers to *generalized agency* as "the subjective need for individual control over societal life-conditions" (Holzkamp, 2013, p. 41). Yet, as Holzkamp (2013) notes, individuals do not experience an unmediated societal structure directly:

> The (societal) conditions which, in their environmental specificity, face the individuals (are) conceptualized as 'constellations of meaning' – that is generalized possibilities to act – which the individual can consciously relate to by accepting or rejecting them as "premises" for her/his subjectively grounded actions. (p. 41)

Generalized possibilities to act exist at the societal level and can be viewed as expressions of what a particular culture or activity system enables or constrains. Yet, as Holzkamp (2013) notes, individuals can choose to accept or reject these and do so consciously or unconsciously according to their *subjective reasons for action*, which represents another mediating layer between societal structure and individuals:

> In this perspective, the individuals actions are not conditioned by societal structures but - however mediated - are grounded in them, whereby the relations between the experienced life conditions and the individual's life interests constitute the essential premises for their reasons to act. (p. 42)

These concepts were useful in grappling with the large amount of qualitative data in this study, specifically for making sense of the grounds for subjects' actions and attitudes. They help the researcher attend to what the context looks like to the person; what information is available to them; what affordances and constraints affect them; and, accordingly, what the person does, how they do it, and why they do it. These concepts also suggest that in an engineering design team, while it may seem as if there is one problem or object/motive for the team (i.e., designing and building the project), individuals in the team are, in fact, all working on their own problems as defined by the generalized possibilities to act available to them, their individual capacity for generalized agency, and their individual subjective reasons for action. This chapter now moves closer to the students and what they might bring from their cultures into activity.

3.5 Culture

The reader will note that while this study's research questions (Section 1.3) employ the word enculturation, they do not explicitly use the word culture. Rather than being embedded in the research questions, culture and cultural diversity are recognized as residing in the choice of the context and in the participants, who are all culturally diverse. Yet, while questions of culture will naturally emerge, this theoretical chapter demands a reasoned appreciation of the potential influences of culture on engineering dispositions and thinking. It is timely at this point to reveal that this study's main participants are six students from China, Chinese Hong Kong, South Korea, Malaysia, and the Philippines and to ask what they might be bringing from their cultural backgrounds that potentially shapes activity in their team-based engineering design project and hence, the evolution of their engineering dispositions and thinking. This section takes stock of the relevant perspectives on culture that inform this question; settles upon a relevant definition of culture; and provides direction for attending to the effects of cultural factors students might bring to the research context.

3.5.1 Culture Defined

Culture has been discussed so far in this study in terms of enculturation (Herskovits, 1948; Grusec & Hastings, 2014), mechanisms of anthropogenesis or emergent culture within teams (Leont'ev, 1981; Engeström, 1987; Holzkamp, 1991; Roth, 2009; Holland & Reeves, 1996, this chapter), and broad descriptions of engineering disciplinary culture (Donald, 2002; Godfrey & Parker, 2010, Section 2.3). Culture is challenging to define and discuss because experts and scholars have employed it in different disciplines, at different times, and in different contexts for different purposes: indeed, over 250 distinct definitions have been identified for the term (Gallego, Cole, & The Laboratory of Comparative Human Cognition, 2001). Culture also sits within a cluster of related labels, concepts, and constructions (i.e., ethnicity, nationality, race, identity, personality, gender). Hence, a clear definition of culture for this study's context, purpose, and theoretical framework is necessary to clarify what students might bring to activity from their own cultures and histories. This study takes the view that students and the collective activity they engage in mutually shape each other, being as they are, indivisible parts of the same whole and over time. New culture, history, and development emerge in activity, but have their origins in the pre-existing culture at the societal level and pre-existing culture in people. Engineering disciplinary culture (e.g., Donald, Godfrey & Parker) has been discussed in Section 2.3 and so it is the latter that requires elaboration.

Keeping the focus on the person, this study settles on Hong's (2009) definition of culture "as networks of (shared) knowledge, consisting of learned routines of thinking, feeling, and interacting with other people, as well as a corpus of substantive assertions and ideas about aspects of the world…activated in a probabilistic (vs. discrete or categorical) manner within certain ethnic or national groups in certain social contexts" (p. 4). Hong differentiates culture from something that resides in a particular group of people and so avoids conflating culture with race, ethnicity, or national groups. Hong (2009) adds that the "causal potential of culture resides in the activation of the shared cultural knowledge, which brings about affective, cognitive, and behavioural consequences" (p. 4). This definition was chosen because it strikes a balance between what Otten and Geppert (2009) coin in intercultural communication as *being culture* definitions (i.e., human action is deeply rooted in one antecedent cultural knowledge system) and *doing culture* definitions (i.e., contingent, evolving, hybrid, revealed in practical action). The latter aligns with the process orientation of activity theory, while the former says something about what 'pre-exists' before people gather to begin engaging in collective activity.

Culture sits among a cluster of related concepts (i.e., ethnicity, nationality, race, identity, gender), which are seen, for the purposes of this study, as subsets of culture. Starting with ethnicity, rather than being related to objective stand-alone cultural differences between peoples, Eriksen (1995) argues that ethnicity is a construct that springs from the co-existence of minority and majority groups who are culturally close and have contacts with each other: "ethnicity occurs when cultural differences are made relevant through interaction" (p. 250-251). As such, ethnicity results from the general recognition and consciousness of cultural distinctiveness and is often characterized by symbolic, social, economic, and political elements. Fenton (1999) extends Eriksen by incorporating a common core of ideas around cultural communities and descent, all touched by culture, in her definitions ethnicity, race, and nation:

> *Ethnic group* refers to descent and cultural communities with three specific additions:
>
> - That the group is a kind of sub-set within a nation-state
> - That the point of reference of difference is typically cultural rather than physical appearance
> - Often that the group referred to is ‘other’ (foreign, exotic, minority) to some majority who are presumed not to be ‘ethnic’
>
> *Race* refers to descent and cultural communities with two specific additions:
>
> - The idea that ‘local’ groups are instances of abstractly conceived divisions of humankind
> - The idea that race makes explicit reference to physical or ‘visible’ differences as the primary marker of difference and inequality
>
> *Nation* refers to descent and cultural communities with on specific addition:
>
> - The assumption that nations are or should be associated with a state or state-like political form (p. 23)

Ting-Toomey’s (2012) definitions of gender identity and personality identity also bear out the position of culture (and personal history) as running through the core of these concepts (Weber, 2006, p. 90):

> *Gender identity* is a dynamic construct, which is learned and unlearned through gender role expectations within a culture:
>
> - Refers to the meanings and interpretations an individual has concerning her/his self-images and expected other images of “femaleness” and “maleness”
>
> *Personal identities* are the ensemble of distinctive characteristics within and enacted by a person due to their unique life histories, experiences, personality traits, drives, goals, and values

Interestingly, Ting-Toomey (2012) Mindful Identity Negotiation model provides a way forward in grappling with the complexity of personal culture and history in interaction. She understands this discussion of culture in terms of identity negotiation in intercultural contexts: students have primary (e.g., cultural, ethnic, gender, personal) and situational identities (e.g., role, relational, facework, symbolic interaction). Her identity focus is synonymous in this study with personal culture, yet her treatment of the intersectionality of identity and complexity of interactions emphasizes that nothing in the human interactional milieu is simple.

In this study, ethnicity, race, nation, gender, and personality are seen as subsets of personal culture and history which will be attended to in the observational and interview data insofar as they have "causal potential…which brings about affective, cognitive, and behavioural consequences" (Hong, 2009, p. 4). The remaining question is how to anticipate what particular networks of knowledge; routines of thinking, feeling, and interacting; and assertions and ideas about aspects of the world (Hong, 2009) students in this study are likely to bring to activity.

3.5.2 Cultural Schema and Cultural Repertoires

Drawing on the fields of cultural psychology, cultural anthropology, and intercultural communication, Hong's (2009) "networks of knowledge and learned routines of thinking, feeling, and interacting" (p. 4) are conceptualized as cultural schema and cultural repertoires that comprise a student's 'pre-existing' culture and history. These are seen as potentially enacted in collective activity so as to have consequences for learning:

- *Schema* is a term used to refer to knowledge structures in which the parts relate to one another and the whole in a patterned fashion…selection mechanisms specify(ing) how certain essential elements relate to one another while leaving other, less essential elements to be filled in as needed according to the circumstances (Cole, 1998, p. 125)

- *Cultural schema* (are) patterns of elementary schemas that make up the meaning system characteristic of any cultural group (Cole, 1998, p. 126)
- *Cultural repertoires* are 'cultural tool kits' of habits, skills, and styles which people may use in varying configurations to solve different kinds of problems (Swidler, 1986)

In schema theory, these are interpreted as being inside the head; yet, Cole posits that they exist both as mental structures and materialized practices "on both sides of the skin line" (p. 128). Cultural schema theory (D'Andrade, 1995) has been applied in intercultural studies of cross-cultural adaptation (Nishida, 1999) and meaning making (Garro, 2000). Cultural repertoires, as Long (2001) notes, "point to the ways in which various cultural elements (values, notions, types and fragments of discourses, organizational ideas, symbols, ritualized procedures) are used and recombined in social practice, consciously or otherwise" (p. 51). Cultural repertoires have been employed to research the language practices of culturally diverse students in intercultural (aka "hybrid cultural space") contexts in which hybridized language and practices emerge (e.g., Gutierrez & Rogoff, 2003).

3.5.3 Putting the Culture into Enculturation: First Wave Cultural Analysis Research

Attending to cultural schema and repertoires of Chinese, Hong Kong Chinese, South Korean, Malaysian, and Filipino students in this study requires that the particular schemas and repertoires of their home cultures be known, observed in interaction, and interpreted for how they might affect the evolution of their engineering dispositions and thinking. This section discusses the theoretical grounding for identifying the kinds of cultural schema or repertoires these culturally diverse students are likely to enact, with the hope that interactions in team life can be interpreted for how they affect the development of engineering dispositions and thinking.

Scholars in cultural psychology (Cole, 1998), organizational science (Weber & Dacin, 2011), and intercultural communication (Friedman, 2014) mark the year 2000 as a shift in the focus of cultural analysis. Weber and Dacin note that the first wave of cultural analysis began in the 1980s and focused on the "collective meaning systems at the level of groups, organizations, industries, fields, or countries" (p. 287) such that ethnic groups, nations, organizations, and professions could be thought of as cultures, or having cultures. The second wave "focused more broadly on processes of cultural construction and the strategic use of culture rather than on cultures as being distinct objects of study" (Weber & Dacin, p. 287). The first wave of cultural analysis holds important points of reference for understanding what students may bring to the context. As noted by Friedman, first wave cultural analysis has the following take on culture, which is very different from Hong (2009):

- Culture is an overarching framework of values, meanings, norms that shapes behaviour
- Culture is created in groups and transmitted to individuals through socialization
- Individuals can be seen as belonging to a distinct culture
- Individuals are embedded in national or organizational cultural contexts that powerfully determine behaviour through explicit/implicit rules, models, and templates for behaviour that constrain action, define opportunities, and facilitate patters of interaction
- Large scale, international comparative quantitative research is capable of identifying and classifying the dimensions of national cultures so as to anticipate, avoid, and resolve potential conflicts in cross-cultural settings

Hofstede's Cultural Dimensions framework (Hofstede, 1991) is the best-known body of first wave cultural analysis research. Though a giant in the field, Hofstede's work has been critiqued on theoretical and methodological grounds (Frame, 2014; McSweeney, 2002; Warner-Søderholm, 2014). This study will draw from a major international research program known as the Global Leadership and Organizational Behaviour Effectiveness (GLOBE) project, which has had appreciable success addressing critiques leveled at Hofstede (Warner-Søderholm). The GLOBE Cultural Competencies' nine dimensions (Table 6) will be used ad hoc in this doctoral study as points of reference for analysis and discussion (House et al., p. 30).

Table 6. GLOBE's Cultural Construct Definitions

Cultural Construct	**Definition**
Power distance	The degree to which members of a collective expect power to be distributed equally
Uncertainty avoidance	The extent to which a society, organization, or group relies on social norms, rules, and procedures to alleviate unpredictability of future events
Humane orientation	The degree to which a collective encourages and rewards individuals for being fair, altruistic, generous, caring, and kind to others
Collectivism I: Institutional collectivism	The degree to which organizational and societal institutional practices encourage and reward collective distribution of resources and collective action
Collectivism II: In-group collectivism	The degree to which individuals express pride, loyalty, and cohesiveness in their organizations or families
Assertiveness	The degree to which individuals are assertive, confrontational, and aggressive in their relationships with others.
Gender egalitarianism	The degree to which a collective minimizes gender inequality.
Future orientation	The extent to which individuals engage in future-oriented behaviours
Performance orientation	The degree to which a collective encourages and rewards group members for performance improvement and excellence.

In doing so, the researcher remains mindful of the dangers of essentializing individual students based on measures of central tendency of samples of people from their country of origin. Indeed, Hofstede (2011) warned about applying findings at a macro-social level analysis in a simplistic manner to micro-social interactions. These findings will be used with other data and perspectives to form a plausible, composite picture of the mediating influences of cultural on the evolution of culturally diverse learners' engineering dispositions and thinking. As Frame notes "behaviour in a given situation is influenced by a wide variety of factors, including individuals' experience, the roles being played in the situation, external pressures, interpersonal relationships, and the ability to take into account foreign identities" (p. 22). Caution will be taken in using this information.

3.5.4 Putting the Culture into Enculturation: Second Wave Cultural Analysis Research

The second wave of cultural analysis has only appeared in the last 15 years as a cross-disciplinary enterprise and so there is no body of generalizable qualitative empirical findings to match the scale of what GLOBE Cultural Competencies (House et al., 2004) has accomplished (see reviews by Otten & Geppert, 2009; Jensen & Andreasen, 2014). There appears to be no qualitative corpus that documents cultural patterns (i.e., cultural schema, event schema, cultural repertoires) across dozens of countries for several reasons (Otten & Geppert):

- Qualitative research is scattered among many fields: cognitive anthropology, cultural psychology, sociolinguistics, ethnography of communication, cultural and intercultural discourse analysis, critical cultural studies, social practice theory
- The wide acceptance of qualitative research has only occurred in the last decade
- Cultural as shared knowledge and identifiable patterns are hard to capture by their very nature: they are transitory and contingent, varying over space, time, and sociocultural context
- Qualitative studies are time consuming, not well funded, tend to focus on small groups
- Empirical findings of qualitative studies usually do not strive for statistical representation but for theoretical representation

The lack of a comprehensive answer to the first wave from second wave cultural analysis is understandable, considering what this new approach is striving do. The second wave is attempting to employ a micro-interactional understanding of culture through the use of qualitative research methodologies rather than attain macro-scale understandings of broad trends. As such, relevant and targeted use of second wave studies, such as ethnographies investigating specific cultural repertoires (e.g., Puzar, 2011; on Korean gender issues) and cross-cultural research studies (e.g., Sechiyama, 2013; on patriarchy in East Asia) will be drawn into discussion.

3.5.5 Putting the Culture into Enculturation: Tapping Indigenous Cultural Concepts

One source of insight into cultural patterns of students in this study is indigenous knowledge from students' countries of origin by cross-cultural scholars focusing on cultural study rather than empirical research. One example that will become important for this study is the concept of face (*mian zi* or *lian*) in Chinese culture. While the concept of face arguably exists in all cultures, face in Chinese culture has been described as an important part of self-construal, or self-definition, in the culture, meaning the extent to which the self is defined independently of others or interdependently with others. Gao and Ting-Toomey (1998) write that "the concern for *mian zi* (面子) is an integral part of Chinese self-construal, Chinese personal relationship development, Chinese discourse, and Chinese communication strategies…the prominence of *mian zi* in Chinese culture is unsurmountable" (p. 53). The phenomenon of face as being embarrassed, or losing integrity in the eyes of others, is universal to humans. However, the manifestation of Chinese face arguably has particular manifestations in social interactions. As will later be discussed in Chapter 6, one student from Shanghai was beginning to grow into a central technical role in the team but failed at one point to produce a functioning circuit he had designed. He hid his failure, albeit not every effectively. When queried lightly about it, he denied that it had failed but could not produce it. The topic was quickly dropped and never mentioned again. In this sense, he kept his face by denying that it had failed and the other team members helped preserve the silence. This example of indigenous knowledge and others, in the form of cultural concepts and repertoires, will be employed to interpret and discuss the findings in Chapters 6 and 7.

3.6 Summary

This theoretical overview has provided the epistemological, theoretical, analytical, and methodological grounding required for guiding this research: In Section 3.2, constructionism, interpretivism, symbolic interactionism, and activity theory were established as the key epistemological, theoretical, analytic, and methodological orientations of this study. Section 3.3 then overviewed the fundamental aspects of activity theory from Vygotsky (1978) to Leon'tev (1978; 1981), and Engeström (1987). Activity theory provides a conception of human development as an emergent process constituted by a mutually defining array of social, cultural, historical, material, and subjective elements. Conceptually, an activity system is an evolving dynamic entity, which contains change within itself: the presence of inner contradictions between its elements drives its transitions, transformations, and development.

Section 3.4 established Roth's (2009) hybrid activity theory framework in this study as the most fruitful way of focusing on the students rather than the activity itself. This study focuses on the enculturating effects of complex interactions in the environment (i.e., conceptualized as activity) on students. Hence, this study is intent upon analysis of change that emerges in students through activity rather than an analysis of the activity system itself. Students' daily interactions with other elements in the activity system over time were the prime location for understanding what they were doing, how they were doing it, why, and how it shaped them. Researching student's trajectories involved focusing on inner contradictions that emerged in activity, specifically for them in their particular circumstances, and played out over time so as to effect change. This section also described Roth's hybrid five-stage framework used in this study to track the emergence of students' dispositions and thinking over time that derive from inner contradictions. This is a justified and reasoned choice because it provides a theoretically and analytically sound approach for operationalizing the research questions.

Although a topic for the next chapter, the data site was been chosen so that a shift from a traditional math and science to a team based design project mode of study was implicit. Changes were observed over time to determine are whether a turnover in students' dispositions and thinking had occurred. Section 3.4 also identified key analytical concepts that served as reference points and sensitizing concepts in the research: subjectification, irreducible units of analysis (activity, consciousness, personality), orienting effects of object/motive, inner contradictions, focus on trajectories over time, generalized agency, generalized possibilities to act, and subjective reasons for action.

Finally, Section 3.5 overviewed theoretical perspectives/findings from cultural analysis so as to inform what students brought from their culture and its potential mediating effects on their enculturation and the evolution of their dispositions and thinking. Cultural schema, cultural repertoires, patterns and tacit indigenous knowledge from the students' home countries were considered so as to identify sources of cultural mediation in team life that to inform the findings and discussion in Chapter 6 and 7.

Chapter 4 now presents the research design for this study, which employed ethnographic methods (participant observation, semi-structured interviews) to gather most of the data to address the main research question: How do the engineering dispositions and thinking of culturally diverse students evolve through their experiences in the second year of an electrical and computer engineering program? The chapter explains how the researcher accessed the site, became embedded in a design team, and collected and analyzed the data so as to ensure that the findings of the study would be trustworthy. Finally, it discusses how the researcher ensured that the study was conducted in an ethical manner.

Chapter 4: Methodology

4.1 Introduction

This chapter explains the methodology and methods this study employed to investigate the main research question: How do the engineering dispositions and thinking of culturally diverse students evolve through their experiences in the second year of an electrical and computer engineering program? Crotty (1998) defines methodology as “the strategy, plan of action, process or design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcome” (p. 3). The planning of this study’s methodology was guided by principles espoused in its epistemological perspective of constructionism, which sees meaning as “being constructed in and out of interaction between human beings and their world, and developed and transmitted within an essentially social context” (Crotty, p. 42). Further to this constructionist view of knowledge, a hybrid activity theory framework (Roth, 2009) based on the work of Vygotsky (1978), Leont’ev (1978), and perspectives from German critical psychology (Holzkamp, 1991, 2013) was employed to understand how culturally diverse students evolved over time and the change that resulted in terms of engineering dispositions and thinking (Chapter 3). Three guiding research questions placed a tighter focus on the interactions in the environment and the perceived evolution of students’ engineering dispositions and thinking over the duration of the course:

- What is the nature of the student-instructor, student-student, student-tool, and student-assessment interactions in engineering design courses? What knowledge do these interactions foster and hinder?

- How do students and instructors perceive the evolution of engineering dispositions and thinking in students over the duration of the engineering design courses?

- How do engineering dispositions and thinking in students in a team evolve over the duration of the courses?

The methodological challenge in this study was how to sufficiently capture and make sense of the interactions in the research site and of the perceptions of the participants in this complex environment over time so as to make plausible explanatory accounts of students' development. As discussed in Chapter 3, the focus of these research questions necessarily implied the choice of qualitative research methodology residing within an interpretivist paradigm orientated to symbolic interactionism. This study draws primarily from ethnographic methods - participant observation and semi-structured interviews - as the most fruitful approach for capturing the evolution of culturally diverse students' engineering thinking and dispositions. Further to the research questions, which focus on interactions within a complex environment, their enculturating effects over time, and their requirement for careful observation to get thick descriptions of the norms, values, practices, and perceptions of the study's participants, the use of ethnographic methods is entirely justified.

This chapter overviews how this research was planned and conducted according to ethnographic research principles in an ethical manner so as to produce trustworthy findings. Drawing from the ethnographic approach, Section 4.2 stakes out five key standpoints that characterize this study's research activities. Sections 4.3, 4.4, and 4.5 describe the selection and context of the research setting and the study's overall research design. Sections 4.6 and 4.7 discuss initial access to the research site and how the researcher became embedded in a culturally diverse team. Section 4.8 describes how data collection and analysis procedures commensurate with an ethnographic methodology were conducted in the field as an integrated whole and summarizes the data collected. Section 4.9 describes how interview and observational data in the form of field notes, post-observational write-ups, documents, and audio-visual recordings were analyzed for two separate but related purposes: to provide a portrait of the educational context

(Chapter 5) and to make accounts of the evolution of five culturally diverse students' engineering dispositions and thinking. Sections 4.10 and 4.11 then respectively discuss the trustworthiness of the data and the ethical considerations of the study.

4.2 Ethnography

This section takes a stand with respect to how ethnographic methods were employed in this study, beginning with a general discussion of ethnography. Ethnography is a qualitative research methodology which encompasses a range of research activities and modes of data collection that depend on the balance of participation and observation deemed appropriate for the research aims (Hammersley & Atkinson, 2007). Researchers may spend extended periods of time observing and participating in the daily lives of people in a specific community or culture in order to document, interpret, and write accounts of specific aspects of their social life (e.g., way of life, beliefs, values, learning). Early ethnography, as it emerged alongside 19th century Western anthropology, had embedded within it the perspective of naturalism: the notion that the social world of groups, communities, or cultures should be studied in their natural state, undisturbed by the researcher (Hammersley & Atkinson). Naturalistic ethnography eschewed features of positivistic research such as standardized research processes, isolation and manipulation of variables, alignment with the laws of natural science. However, it shared with positivism a view that phenomenon have an objective reality – they exist independently in the world and are to be captured – and a concern for eliminating or minimizing the effects of the researcher on the data (Hammersley & Atkinson). Early ethnography aimed to accomplish this through extended participation with, and observation of, people in the target culture, subculture, or community, which enabled the researcher to see and interpret their social world as they do. By going native, the researcher became “a neutral vessel of cultural experience” (Hammersley & Atkinson, 2007, p. 15) and captured social and cultural phenomenon so as to “tell it like it is” (p. 160). Five standpoints are presented herein with respect to how ethnography was employed in this study: the nature of ethnographic understandings (Section 4.2.1), the general ethnographic approach used (Section 4.2.2), the primary focus on interactions (Section 4.2.3), data collection and analysis (Section 4.2.4), and the representation of findings (Section 4.2.5).

4.2.1 Ethnographic Understandings

The first standpoint relates to how this study is oriented with respect to the project of understanding social worlds and its relation to the trustworthiness of the findings. As noted in this section’s introduction, early naturalistic approaches to ethnography posited “going native” as beneficial to capturing social and cultural phenomenon so as to “tell it like it is” (Hammersley & Atkinson, 2007, p. 15). However, later thinking contested such approaches to understanding social and cultural worlds. Kuhn’s (1962) argument that knowledge is mediated by paradigmatic presuppositions gained currency in social science and educational research and stood in contrast to ethnography’s initial epistemological orientation to naturalism. In tandem with Kuhn, Hanson (1958) argued that all data involve presuppositions and Hodson (1986) that no observations are innocent or unbiased, being that they are theory-dependent and made my people. Such thinking translated to a concern for how factors influencing researchers and their contexts (i.e., biological, personal, social, cultural, historical) affect the motivation, purpose, grounding, processes, and products of research. In response, qualitative researchers of various stripes came to adopt the concept of *reflexivity* in multifarious ways in order to frame and guide qualitative research, collect and analyze data, report results, and make claims (Lynch, 2000). Having reflexivity as a researcher entails being aware of oneself as a constitutive part of the activity of research and, indeed, of one's role in constructing the research situation itself (Glesne, 2011).

This study's use of ethnographic methods eschews the perspective of naturalism and the notion that the researcher's job is to "tell it like it is". It embraces the notion that no observations are innocent or unbiased and that all data involve presuppositions. Reflexivity was adopted as a working principle to frame this study, collect and analyze data, and report results as a minimum requirement for producing knowledge that can be considered trustworthy. The researcher understands reflexivity as a research attitude and approach, embedded in theoretical and methodological aspects and activities of the study, that enhances the possibility for plausible inferences to be made about the evolution and change of these students. This requires an acceptance that interpretations are inherently flawed because humans cannot fully bracket themselves from the processes of observation or what is observed. Yet, if done in a principled and mindful way, research can lead to increased understanding (Hammersley & Atkinson, 2007):

> We can work with what we currently take to be knowledge, while recognizing that it may be erroneous; and engaging in systematic inquiry where doubt seems justified. And in doing this we can still make the reasonable assumption that we are able to describe phenomenon as they are, and not merely how we perceive them or how we would like them to be. (p. 16)

The researcher understands theoretical reflexivity as being knowledgeable and explicit about epistemological and theoretical perspectives that frame and guide the research and how it strengthens, limits, and colours the findings. The researcher understands methodological reflexivity as entailing a specific and extended awareness of how the researcher's actions in data collection and analysis shape the findings. Such reflexivity was embedded in the planning and process of this study through specific practical measures (i.e., planning research design, data collection tools and processes, analysis, reporting) and adjustments in the research process aimed at minimizing bias and enhancing trustworthiness.

4.2.2 Ethnographic Approach

The second key standpoint relates to how ethnography has been used in this study. Ethnography's long and complex history since its emergence around 1830 means that it does not have a standard, well-defined meaning (Hammersley & Atkinson, 2007). Ethnography's use over time and across disciplines and contexts means "its sense has been reinterpreted and recontextualized in various ways, in order to deal with particular circumstances" (p. 2). Ethnography has been applied in combination with a number of perspectives both inside (e.g., symbolic interactionism, phenomenology, hermeneutics) and outside (e.g., critical inquiry, feminism, post-structuralism, post-modernism) the interpretivist paradigm chosen for this research. Yet, a consensus does exist on the universal characteristics of ethnography, regardless of the theoretical perspective that underpins its particular application. These guidelines were adhered to as much as possible in this study (Hammersley & Atkinson):

1) People's actions and accounts are studied in everyday contexts rather than under conditions created by the researcher – such as in experimental setups or in highly structured interview situations. In other words, research takes place in the field.

2) Data are gathered from a range of sources, including documentary evidence of various kinds, but participant observation and/or relatively informal conversations are usually the main ones.

3) Data collection is, for the most part, relatively unstructured, in two senses. First, it does not involve following through a fixed and detailed research design specified at the start. Second, the categories that are used for interpreting what people say or do are not built into the data collection process through the use of observation schedules or questionnaires. Instead, they are generated out of the process of data analysis.

4) The focus is usually on a few cases, generally fairly small-scale, perhaps a single setting or group of people. This is to facilitate in-depth study.

5) The analysis of data involves interpretation of the meanings, functions, and consequences of human actions and institutional practices, and how these are implicated in local and, perhaps also, wider contexts. What are produced, for the most part, are verbal descriptions, explanations, and theories; quantification and statistical analysis play a subordinate role at most. (p. 3)

These key features provided important guidance for framing and conducting this study. Yet, this study is perhaps best characterized as *employing ethnographic methods* to understand the enculturation processes at work in an engineering disciplinary school context and the engineering dispositions and thinking students develop rather than *being an ethnography* on general engineering disciplinary learning culture in a Canadian engineering department. This distinction is important because it defines this study's use of the ethnographic approach as geared towards the specific end of producing accounts of students' enculturation and the dispositions and thinking that resulted. Rather than *being an ethnography*, this study *employs ethnographic methods* to arrive at these understandings.

4.2.3 A Focus on Interactions

The third standpoint concerns this study's focus on interactions. As discussed in Section 3.3, careful consideration led the author to conclude that a theoretical and methodological orientation towards symbolic interactionism was appropriate for this study. This is so because of symbolic interactionism's focus on language and other symbolic tools in dialogue and interaction as the carrier of perceptions, feelings, and attitudes of the participants and as a pathway to interpreting their meanings and intents. Blumer (1986), articulates symbolic interactionism's basic assumptions as: human beings act towards things on the basis of the meanings that these things have for them; the meaning of such things is derived from, and arises out of, the social interactions that humans have with each other; and that things are handled in, and modified through, an interpretive process used by the person in dealing with the things he or she encounters. As such, interactions between and among the elements in learning context (i.e., student-student, student-instructor, student-tool, student-assessment) are potential sites where meaning emerges and can be observed and interpreted.

This study tuned into these acts, meanings, and interpretive processes over time so as to understand how individual students evolve, the personal element of which is echoed in the central notion of symbolic interactionism (Denzin, 1974): “symbolic interactionism directs the investigator to take, to the best of his ability, the standpoint of those studied” (p. 269). Yet, missing from many static ethnographic accounts of students in engineering disciplinary culture (Newstetter, 1998; Tonso, 2006a; Tonso, 2006b; Godfrey & Parker, 2010) is the evolution of the individuals (and, indeed, their activity: Roth, 2009) over time. As Emerson, Fretz, and Shaw (2011) write, “the social worlds (are) created and sustained in and through interactions with others, when interpretations of meaning are central processes” (p. 2). Pollner and Emerson (2001) add the dimension of time when they note that social worlds and the elements that comprise them are in a state of change: “society consists of the ceaseless, ever unfolding transactions (i.e., interactions in this study) through which members engage one another and the objects, topics, and concerns that they find relevant” (p. 122). It is the students’ standpoint, observed over time through their interactions from which the researcher might understand and represent the nature of their enculturation and how it shapes them.

Two caveats are noted in this study’s focus on interactions. Of the multiple pairs of interactions identified, the student-assessment interactions identified in the first guiding research question require clarification. This study did not evaluate change in engineering dispositions and thinking through the use of assessment tools. The word assessment in this interactional pair can be thought of as assessment information (e.g., rubrics, feedback from instructors, descriptions of project requirements which serve as de facto criteria, sharing/discussion of this information between students) that emerges in the context and have a potential role in directing students' attention and effort. As such, this study is not in the realm of assessment studies. Rather, it holds a minor focus on how student-assessment interactions, as one of many kinds of interactions unfolding in the environment, potentially direct students' practical activity on the projects and hence, shape students' engineering thinking and dispositions. As such, reference to assessment is to be understood in the context of enculturation and how the task that students work towards is explicated. Additionally, it should be noted that the word culture itself is not specifically mentioned in the main or guiding research questions. This is because these questions have been defined relative to the context that has already been characterized as culturally diverse through the choice of the context and the participants. Hence, their analysis will necessarily be culturally framed.

4.2.4 Data Collection and Analysis in Ethnography

The fourth standpoint relates to the nature of data collection and analysis and hence, the way they are reported in this chapter. In ethnography, analysis begins as soon as the researcher steps into the field. It is widely recognized that data collection and analysis is an intimately intertwined iterative process rather than one that proceeds linearly in sequential stages. Hence, researchers must commit themselves to maintaining the dialectical interaction between data collection and analysis (Hammersley & Atkinson, 2007). It is important to recognize that there is no formula or recipe for the analysis of ethnographic data and that data collection and analysis involves a progressive focusing on interactions and phenomena of interest that occurs through the researcher's close and persistent interaction with the data. Hammersley and Atkinson note that the researching and theorizing "ought to involve an iterative process in which ideas are used to make sense of data, and data are used to change our ideas…there should be movement back and forth between ideas and data…so analysis is not just a matter of managing and manipulating data" (p. 159). Accordingly, accounts of the data collection and analysis while the researcher was in the field will be described as the same process (i.e., in field data collection and analysis in Section 4.8). However, data analysis that occurred after leaving the field (i.e., post-field data collection and analysis), of which writing is an important part, will be described in Section 4.10.

4.2.5 Representation

The fifth standpoint relates to the representation of the research process and the findings from this study. While ethnographic methods have been employed in both phenomenological research (e.g., Stevens, O'Connor, Garrison, Jocuns, & Amos, 2008), phenomenographic research (e.g., Booth, 2001), and critical inquiry (e.g., Tonso, 2006b) in engineering education, such studies have tended to focus on producing generalized categories of description, which describe students' experience, knowledge, or developing engineering identities. As discussed in Chapter 3, this study attempts to follow Vygotsky's (1978) advice to analyze processes provide and explanations. Vygotsky (1978) called for a methodological and analytical approach that gets at the causal dynamic elements underlying development (i.e., a genotypic, explanatory focus) as in activity theory, rather than one that focuses on external features (i.e., a phenotypic, descriptive focus) as in phenomenology. A genotypic, explanatory approach entails not washing out the particulars of each case through the research design and data analysis. Rather, it means realizing that each student is, as Bachelard (1949) notes, "a particular instance of the possible" (in

Bourdieu & Wacquant, 1992, p. 223), meaning in the context of this study that individual cases serve as examples of what the environment affords or constrains.

This study's findings are presented in two forms. First is a portrait of the context of team-based project work at the research site. Second are accounts of five student trajectories, based on the hybrid activity theory framework of Roth (2009), discussed in Chapter 3, that represent the evolution of dispositions and thinking over time in a way that attempts to preserve the dynamic and complex nature of each student's evolution. The context and trajectories offer readers portraits of the context of team-based projects at the research site and five culturally diverse students' trajectories over time. Portraiture (Lawrence-Lightfoot & Davis, 1997), as used in this study, is an approach towards inquiry and the documentation of findings in the social sciences that combines systematic, empirical description with aesthetic representation. Portraits, then, are "designed to capture the richness, complexity, and dimensionality of human experience in social and cultural context, conveying the perspectives of the people who are negotiating those experiences" (Lawrence-Lightfoot & Davis, 1997, p. 3).

A brief discussion of the importance of social context in reporting the findings is useful in understanding the structure of the chapters that following this one. Engaging in an ethnographic study as a researcher or reader means immersing oneself in context. Hence, researchers are compelled to provide fuller descriptions of the context than is usual in other kinds of research (Becker, Geer, Hughes, & Strauss, 1976). Context is presented in two parts in this thesis. First, the research context is described in this chapter so as to orient the reader (Section 4.4). Second, findings about the overall context are presented in Chapter 5 to address the first guiding research question (i.e., the nature of student-instructor, student-student, student-tool, student-assessment interactions in an engineering design course; the knowledge these interactions foster and hinder). Chapter 5 can be thought of as a small portrait of disciplinary engineering culture (c.f. Donald, 2002; Godfrey & Parker, 2010 in Section 2.3) at the research site that has a secondary role of contextualizing five students' trajectories, which are the main findings of this study (Chapter 6). The findings in Chapter 6 are framed and interpreted through the hybrid activity theory framework of Roth (2009). At the end of Chapter 6, an additional level of analysis of the student trajectories revealed five conditions that are critically important for culturally diverse students to satisfy in order to develop engineering dispositions and thinking and capitalize on the benefits of team-based project work modes of study. These are fodder for the discussion in Chapter 7. In summary, representation of the findings of this multi-subject case study (Stake, 1995), through the application of ethnographic methods has produced an overall portrait of the general interactions at the research site (Chapter 5); five explanatory accounts of five students over two design courses which include the learning that was observed (Chapter 6); five critical conditions for culturally diverse students to develop engineering dispositions and thinking in team-based projects (Chapter 6), and a discussion of the conditions' significance (Chapter 7).

A point of representation related to the use of voice in the rest of this thesis is clarified here. Typical scientific research reports demand the researcher's absence from the write-up, which is consistent with the positivist epistemology that reality is independent of the observer but confers a tacit authority on the author in "telling it like it is". This convention is noted in more traditional ethnography as a device to claim what Van Mannen (2011) calls the writer's "interpretive omnipotence" (p. 51) - a quiet or invisible claim of the authority of the researcher and/or the theories that they invoke through the use of grammatical structures (i.e., passive voice; impersonal nouns, pronouns) the passive tense and impersonal nouns and pronouns. Geertz

(1973) argued for jettisoning “experience-distant” in favour of “experience-near” representations in ethnographic writing so as to be commensurate with its epistemological and theoretically underpinnings. Until this point in the thesis, the author has written in the third person, but herein, first person will be employed when it contributes to the coherence, tone, and flow of the writing (e.g., in Section 4.6).

4.3 Selecting the Research Setting

This section discusses the selection of Electrical and Computer Engineering’s second year team-based design project courses (Design I, Design II) as the research setting. Hammersley and Atkinson (2007) describe the process of visiting and collecting information about potential research settings in order to assess issues of suitability, feasibility, and access and make informed choices in colloquial language as “casing the joint”. The researcher was active prior to his doctoral program in conceptualizing this study and investigating opportunities in the Faculty of Science and engineering departments within the Faculty of Applied Science. In doing so, the research setting and the research focus co-emerged. From September 2009, informal meetings began with about 15 professors or department heads (faculties of science, engineering, education), educational specialists, and institutional researchers through CU’s Science Centre for Teaching and Learning over a two year period to explore fruitful avenues of research into the challenges and opportunities associated with culturally diverse students in science and engineering. By September 2011, the Department of Electrical and Computer Engineering (ECE) was selected for three reasons. First, the researcher was familiar with engineering through his training and work experience as a chemical engineer. Second, ECE was the most culturally diverse department in the Faculty of Applied Science. Third, and importantly, ECE’s Department

Head and National Sciences and Engineering Research Council (NSERC) Design Chair were both keenly interest in promoting educational research and generously supported this research.

The researcher's connection to ECE yielded important information about the department's evolving undergraduate curriculum and the educational facilities through curriculum documents, informal facility visits, conversations with faculty members, and attendance at curriculum committee meetings. The department also hired him, once the research was underway, to collaborate on developing a survey instrument for collecting data on undergraduate student perceptions of engineering competence for the upcoming department accreditation process. The second year program was identified as the most fruitful place in the curriculum for the research because it is a key transition for students. At this point in the program, students move from a general first-year engineering curriculum, comprised mainly of individual lecture-based science and math courses, to a more integrated curriculum in which students work in teams on design projects and take related lecture-based courses. The two team-based engineering design project courses (Design I, Design II) were at the centre of this shift in second year, being that they involved teamwork across electrical and computer engineering, took place in a variety of sites (lecture halls, project rooms, electronic labs, machine shops), and were integrated with co-requisites such as Data Structures and Algorithms for Computer Engineers and Circuit Analysis I for Electrical Engineers. Over the three years leading up to the choice of ECE, the researcher's familiarity with various departments in engineering resulted in a good grasp of the context, research focus, and issues and allowed potential challenges to be identified that would shape the research design, data collection processes, and data analysis.

4.4 Research Setting: Educational Context

Engaging in ethnographic research means immersing oneself in context. Hence, in reporting ethnographic processes, researchers are compelled to provide fuller descriptions of the context than are usually provided in other kinds of research (Hammersley & Atkinson, 2007; see Becker, Geer, Hughes, & Strauss, 1976, pp. 49-63). Section 1.4 provided a brief description of the curriculum and students. This section presents a more complete overview of the physical setting, people, curriculum, and design projects at the research site.

4.4.1 Physical Setting

The research site at Canadian University (CU), where the majority of this study's observational data was collected, was in CU's old Electrical and Computer Engineering (ECE) building, which dates back to 1963. This building was on the main CU promenade and had a direct connection on each floor with a more modern airy building which was home to the Faculty of Applied Science and ECE Department and housed faculty and administrative offices, state-of-the-art labs, and general study spaces. In contrast, the spaces in the old ECE building, where undergraduates spent much of their time, consisted mostly of labs, workshops, project rooms, and classrooms that were old and well-used. The old ECE building was where second year students did most of their work on the design projects during this study and so became its key site.

The two electrical labs, where most of the observations were done, were functional rooms packed full of equipment, parts, materials, and furniture with people during the fall and winter terms. These rooms were narrow with large windows along one side, measuring 20 by 8 metres (room 322: Figure 6) and 20 by 4 metres (room 303). These dimensions are given because these two labs served upwards of 280 students every week, which emphasizes how crowded the labs became at peak times. Room 322 had a 4-metre long locked glass-faced equipment storage cabinet on the back wall by the entrance containing labeled equipment boxes: variable resistance, inductors, decade resistance boxes, and pulse generators. There were also all kinds of parts and plastic drawers: alligator clips, LEDs, headers, buzzers, socket pins, keys, motors, and lots of wire. A table against the wall past the cabinet was usually covered in wire, equipment, and students' personal effects. Between the cabinet and the table was an entrance to a Technical Services Room, which contained more equipment, parts, storage space, and workbenches. This adjoined to a second lab beyond it, which was occasionally opened up during times of high demand before project demonstration days.

Figure 6. Electrical Lab 322

Students worked in the lab on benches arranged back to back on either side of the aisle running down the middle of the room. Each bench had two tiers of solid shelves: a solid top shelf and a wire bottom shelf packed with equipment. The shelves and the equipment acted as a divider between groups of students working on either side of the benches, although a glimpse through the equipment and shelving to the other side was possible. Groups tended to sit in a line on the bench in groups or pairs in chairs or mill about in standing position between benches or in the aisles. The equipment on each bench included: two Xantrex XPH35-4T triple power supplies ($800), a Fluke 45 dual display multimeter ($1500), a Tektronix TDS 2012 two-channel digital storage oscilloscope ($1000), a GW Instek GFG-8219A signal generator ($460), a mounted magnifying glass, a solder iron with holder, a vice, and a computer (Figure 7 – note sleeping bag on the shelf). A sign on every bench read “NO FOOD OR BEVERAGE ALLOWED IN THIS ROOM!” The labs were consistently packed with very little room to spare.

Figure 7. Lab 322 Work Bench

There were many natural gathering points inside and outside these labs. When working, students gathered at the workbenches, by the technical room near the cabinets, and by the blackboard, which took up most of the wall on the opposite side of the room. The blackboard was a place for students to hang out and sketch diagrams, work out problems, draw rude pictures, graffiti, and humour. The hallway was another natural gathering place for students to stand around, eat, and talk. Down the hall and around the corner from the labs were ten project rooms, roughly three-by five metres in size, for project meetings and study sessions. They were the second major sites for observation. These rooms had tables and chairs and sat up to eight people. Students had around-the-clock access to these project rooms and the labs. Students spent a lot of time there doing homework, working on projects and modules, eating, sleeping, and socializing. The weekly lectures were held in a modern lecture hall, a minor data collection site.

4.4.2 People: Second Year Student Demographic Information

The Electrical and Computer Engineering (ECE) department is the largest and most culturally diverse department in CU Engineering. In the 2012 academic year, twenty four point eight percent of ECE students were immigrants, meaning that they gave permanent resident status and attended high school in Canada for one to five years. Fourteen percent of ECE's students were international students, meaning that they had international student visas and had moved to Canada specifically to get a degree. In 2012, 286 and 270 mostly second year electrical and computer engineering students were enrolled in the design courses Design I and Design II, respectively. ECE students came from a variety of countries (from highest to lowest percentage): Canada, China, Iran, Taiwan, South Korea, India, and a number of other countries including Malaysia, the USA, Saudi Arabia and Hong Kong. Eighty-three percent of ECE students that year were male. The instructors, teaching assistants (TAs), and lab technicians supporting the courses were more diverse than the students: of the two instructors, eight teaching assistants, and the lab technician, only two were born in Canada with many coming from Iran.

4.4.3 People: Introducing Team Z5

Team Z5 was the culturally diverse team in which the researcher became embedded for 6 months during the study. It consisted of five to six students whose four core members remained together for most of the second academic year of electrical and computer engineering. When the researcher became embedded in the team, it consisted of five culturally diverse students: Hyuna, Tia, Jay, Tony, and Lee. Hyuna and Tia were the only immigrant students with permanent residence status in Canada, meaning that their whole families had moved to Canada in the last five years. The background information for these participants appears in Table 7.

Team members changed frequently in team Z5, with only Hyuna, Lee, and Tony remaining for the academic year from September 2012 to April 2013. The first change occurred when ECE's curriculum committee made a late decision to link Design I's project report requirement to that of the technical communication course for a fifth of the students in Design I's project teams. This amounted to a substantial reorganization of teams two weeks into term. Jay replaced Jim, another international student from China, in mid-September. In early November, a conflict broke up team Z13, resulting in Yao, an immigrant Chinese Hong Kong student, joining Hyuna, Lee, Tony, Tia, and Jay to make a team of six. Jay, who lacked a key Design II pre-requisite, was replaced by Li, a female international student from Hong Kong in January 2013. Finally, Tia's health concerns caused her to leave the program at the end of February after Design I project 1. She was not replaced.

Besides the team projects, individuals or pairs had seven modules of electrical lab work each term and were free to form their own working pairs with any students in their course section. Team Z5 all elected to work with their teammates on the modules with the exception of Jay, who, being the fifth member at the time, paired up with a student outside the team.

Table 7. Background Information on Team Z5 Study Participants

Category	Jay	Lee	Hyuna	Tia	Yao	Tony
Origin	China	Malaysia	South Korea	Philippines	HK, China	Malaysia
Age	21	20	20	21	20	21
Gender	M	M	F	F	M	M
Visa status	international	international	immigrant	immigrant	immigrant	international
Arrived in Canada	Jan. 2010	Sept. 2011	Sept. 2007	Sept. 2009	Jul. 2005	Sept. 2011
Arrived at CU	Sept. 2012	Sept. 2011	Sept. 2011	Sept. 2012	Sept. 2012	Sept. 2011
Specialty ECE	Electrical	Computer	Computer	Electrical	Computer	Computer
High school	Shanghai Advanced math, science	KL Malaysia	Canada public from grade 9	Philippines, math, science study in English	Canada public from grade 7	Kota Bharu Malaysia
Joined team Z5	mid-September 2012	Original member	Original member	Original member	early November	Original member
Prior hands-on experience	Eight years electronics	None	Limited	Limited	Three years machine shop	Limited mechanical home repair
English for Academic Purposes preparation?	Yes Canada	Yes Malaysia	Yes Canada grades 10-11	Yes Canada	Yes Canada grades 7-9	Yes Malaysia
Other	Engineering transfer school in first year	Chinese Malaysian, elite scholarship	Mostly Asian peer group since immigrating	Engineering transfer school in first year	NA	Indian/ Chinese Malaysia

At the end of Design I in December 2012, when teams were free to break up and reform with different members, team Z5 unanimously decided to stay together. These choices by the members of team Z5 to work and stay together suggest that overall they were satisfied with their team members.

4.4.4 Curriculum

A brief description of the first and second years of the Electrical and Computer Engineering program at CU and a sample of technical detail on a project is presented here to orient the reader. The general first and second year curriculum have already been discussed in Section 1.4.1, which also included a list of courses in Table 8. Three points are important to recall. First is that the transition from first to second year implies a shift from a lecture and textbook mode of study to a significant focus on team-based project work and greater course integration. Second, this point in the curriculum is the first time when electrical and computer engineers share most classes. In first year, students shared courses and classrooms with students from other engineering departments. Third, not all students who arrive in second year had attended the same common general first year at CU. Many Canadian-born, immigrant, and international students had transferred from other institutions that run engineering transfer programs. Some of the culturally diverse students who had arrived in Canada after their high school study fed into CU’s second year after attending first year at one of many engineering transfer programs which articulate to CU’s general first year and also cater to English academic preparation needs. The beginning of second year is at the confluence of much social and curricular change.

Table 8. List of CU Engineering Courses, 2012/13 Academic Year

First year general engineering courses

Introduction to Engineering
Engineering Case Studies
Introduction to Computation in Engineering Design
Chemistry for Engineering
Strategies for University Writing + Non-engineering elective
Differential Calculus
Integral Calculus
Linear Systems
Elements of Physics
Mechanics I

Second year Electrical and Computer Engineering courses (common core)

Technical Communication (F)
Data Structures and Algorithms for Computer Engineers (F)*
Circuit Analysis I (F)*
Multivariable Calculus (F)
Introduction to Microcomputers (F)*
Electrical and Computer Engineering Laboratory I (F)
Basics of Computer Systems (W)+
Circuit Analysis II (W)+
Electrical and Computer Engineering Laboratory II (W)
Linear Differential Equations (W)
Mathematical Methods for Electrical and Computer Engineering (W)

* Co-requisites for Design I; + Co-requisites for Design II; F = fall semester, W = winter semester

4.4.5 Design Projects

This study focuses mainly on Design I and Design II, the ECE laboratory design courses, which each involved seven modules and two team-based projects each for 35% and 65% of the course mark respectively. Descriptions for these projects appear in Table 9. In all projects, extra functionality and features were considered for additional marks during the final demonstrations. Design I projects 1 and 2 are overviewed here so as to orient the reader to the type and difficulty level of projects students tackled in the courses and to give context to both the general observations made in the data site early in the study and the development of emerging practices, perspectives, and dynamics of the team in which the researcher was embedded for the duration of the study.

Table 9. Design I and Design II Team-based Design Projects (CU)

Design I, Project 1: Dual Slope Analog to Digital Converter (ADC) Multimeter (fall 2012)

Design, build, test a digital multimeter based on a dual slope ADC. The multimeter will use 7-segment LED displays to 2½ digit resolution; use a team-designed dual slope ADC; and measure voltage (0.00 to +2.00 DC V), current (0.0 to 20.0 DC mA), and resistance (10 to 200 Ω).

Design I, Project 2: Advanced Multimeter using VHDL (fall 2012)

Design, build, and test a high-resolution multimeter. The project requirements include:

- Power supply of your own design which uses the laboratory transformers
- All circuitry on solder boards; packed in a box (pre-made or your purpose-built design)
- 7-segment LED display on the Altera DE2 board; resolution 4½ digits
- Measures voltage (±0.20000, ±2.0000, ±20.000 DC V), current (±2.0000, ±20.000; ±200.00 DC mA), and resistance (10 Ω to 2 MΩ) with automatic range change
- Measures β of NPN and PNP transistors

Design II, Project 1: Automatic Soda Fountain Dispenser (winter 2013)

Design and build a microcomputer base automatic soda fountain controller that will fill, without spills, the user's cup to a predetermined height. The project requirements include:

- Controller programmed in assembly language, allowing user to select cup fill percentage
- Capacitive height liquid measurement: liquid height determined from capacitance on two strips on side of cup to be displayed on DE2 board LEDs
- Simple servo motor-based valve operated by controller
- Temperature display in °C on DE2 board LEDs

Design II, Project 2: Electromagnetic Tether Robot Car (winter 2013)

Design, build, program, and test a small autonomous robot car consisting of three major parts: a transmitter, a receiver, and a car with motor. The project requirements include:

- Battery-operated; microcontroller system consisting of microprocessors programmed in C
- Car must maintain a fixed distance of (minimum 30 cm.) from the transmitter and be capable of four movements: forward, backward, 180° turn, parallel parking

Design I project 1 required student teams to build a dual slope ADC (analog to digital converter) multimeter prototype on a breadboard for measuring and displaying voltage, current, and resistance on 7-segment LEDs (Table 9). Project 2 was based on project 1, but was a more advanced multimeter with its own transformer, integrated analog and digital components, and increased requirements (i.e., higher resolution, transistor β, three ranges of voltage, current, resistance with auto range). Teams had to work out their own designs and seven individual and pair-based course modules gave students experience building and measuring circuits and encouraged understanding of key concepts, circuits, and concepts.

The heart of both Design I projects was a dual slope ADC, a circuit that converts an unknown input voltage into a digital representation. The central circuit (Figure 8) is an integrator with a switch that is used to select between the input voltage to be measured (V_{in}) and a reference voltage (V_{ref}).

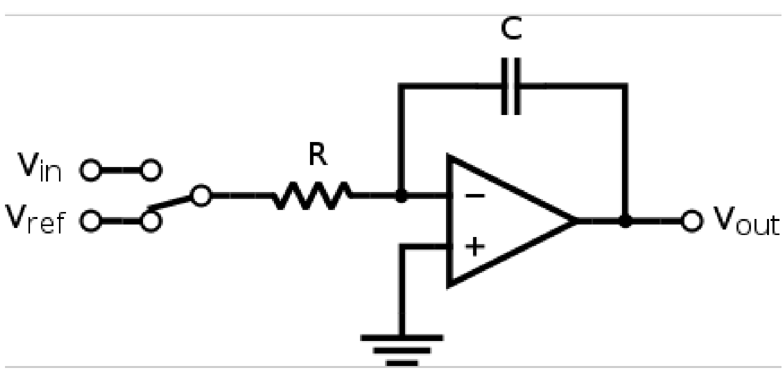

Figure 8. Schematic of a Dual Slope Analog Digital Converter (ADC) Integrator

The basic concept of the dual slope ADC is that the unknown voltage V_{in} is first selected by a controller (not shown) so that the integrator charges up the capacitor, or in other words, integrates V_{in} to produce the ever-increasing voltage V_{out}. A timer (also not shown) measures the time taken for this integration or run-up phase. After a pre-determined time, the controller switches to V_{ref}, which is opposite in sign to V_{in} (and V_{out}), and the timer once again measures the time taken for V_{out} to go to zero (i.e., run-down phase, Figure 9).

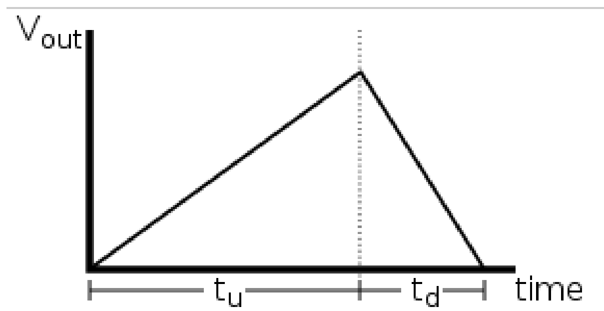

Figure 9. Voltage vs. Time Graph of the Run-up and Run-down Phases of Dual Slope ADC

A comparator (not shown) is a circuit which detects when V_{out} crosses zero and stops the timer counting the run-down phase. The unknown voltage V_{in} is the ratio of the duration of the run-down phase (t_d) and the run-up phase (t_u) multiplied by the negative of the reference voltage (-V_{ref}). In summary, the project's core (Figure 10, contained by dashed line) can be thought of as a voltmeter consisting of the dual slope ADC, which converts the analog voltage to digital time, the comparator, and voltage input controller which select the reference and unknown voltage, and the timers and displays that record and display the voltage. Measurement of resistance and current is made possible by simple circuits that convert these to voltage and feed that voltage into the voltmeter. A photograph of the completed project 1 of the team in which the researcher was embedded, herein referred to as Team Z5, appears in Figure 11.

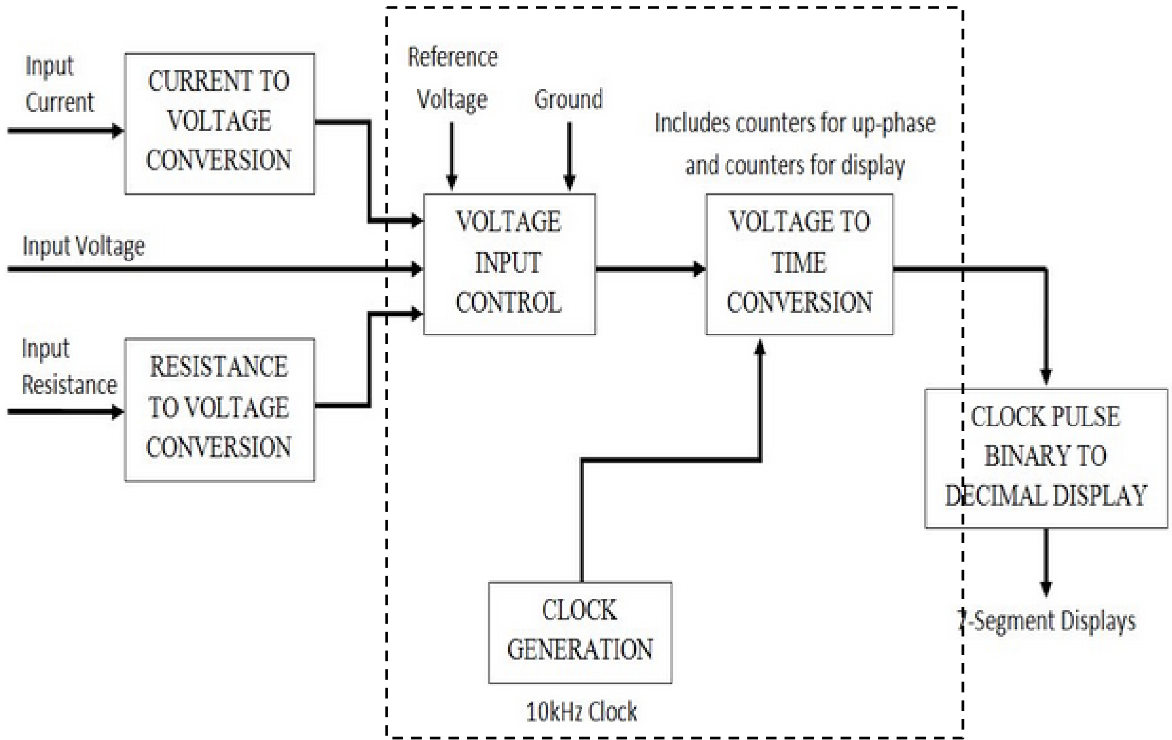

Figure 10. Block Design of a Dual Slope ADC Multimeter

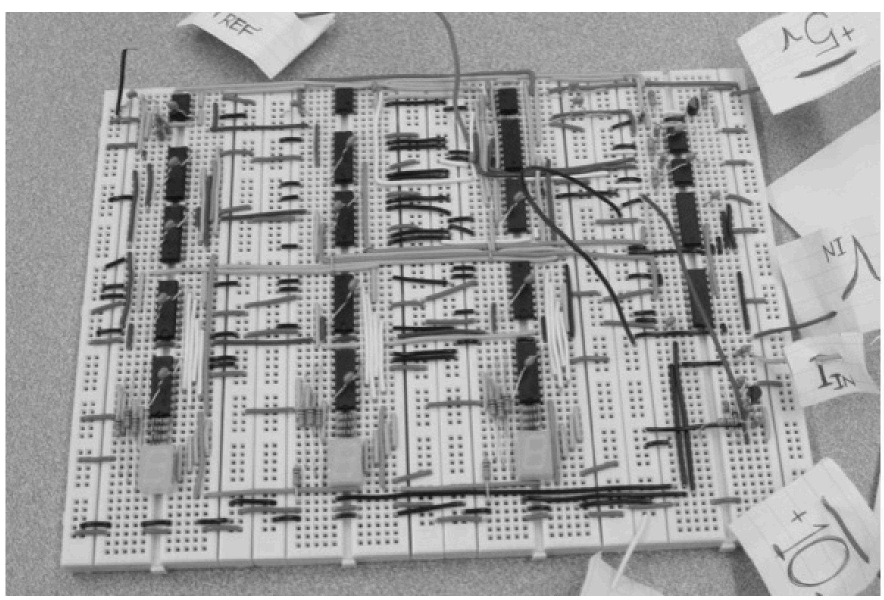

Figure 11. Dual Slope ADC Mulitmeter Prototype on a Breadboard

Project 1 was relatively simple in that it is a single analog circuit design (i.e., one field) that could be built from one schematic on one block for one purpose. In contrast, project 2 involved many fields including mechanical design, analog design with huge extensions (i.e., higher resolution, triple range, power supply), VHDL software design (learned in co-requisite Data Structures and Algorithms for Computer Engineers in Table 8), and digital design/interface using a DE2 board. As such, project 2 was highly modular, with each module being a substantial piece in itself and all parts requiring later integration. In addition, project 2 required the circuits to be manually soldered onto solder boards, whereas project 1 was prototyped on breadboards, which are far less prone to disconnections that can render a project non-functioning. The dramatic differences between the scale and requirements of these projects led one teaching assistant to dub project 1 a "transistor level" project and project 2 a "systems level" project. Accordingly, project 2 required a change in mind set in terms of systems thinking and a greater skill set with respect to technical integration and teamwork.

4.5 Research Design: Planning Extended Data Collection in a Complex Research Setting

An unstructured research design was chosen for this study because the courses selected as the key research setting were known in advance to be messy, sprawling, multi-sited, complex, and unpredictable. A few formal and informal features of these courses, investigated as the research design was being developed, suggest why this was so. First, ECE is the largest engineering department at CU and in a typical academic year, second year has up to 300 students taking Design I and Design II. This amounted to a large number of students being rotated in and out of labs 322 and 303 everyday (Section 4.4.1). Students were grouped into four sections of about 70 students each and in any given term, two sections (i.e., about 140 students) attended separate lectures and lab sessions every week. While the lectures had a formal structure, the lab sessions did not have any whole class activities. Lab time was work time supervised by an instructor, a technician, and TAs, unless pairs or teams were demonstrating their modules or projects. Lab access was around-the-clock and so in a typical year, by the third week of each term, the boundaries of the designated sessions and lectures blurred, meaning that people from any section appeared in labs or lectures when they wanted to, particularly during times of heavy workloads. Labs frequently became crowded and chaotic, almost like public spaces where anyone could enter and be unnoticed.

Second, the barriers between work from different courses also blurred: the labs and project rooms became centres where much studying and socializing not directly related to the Design I and Design II courses occurred. Each section was divided into teams of five or six students who collaborated on the design projects in the eight-month academic year. There were also seven modules for each course and students could collaborate with anyone in their section. Typically ECE students in second year took time getting used to new classmates and forming study and social relationships. Students from all engineering departments were mixed in first year classes and so ECE students came to second year not knowing many others well. As the workload began to affect students, they increasingly began to collaborate on coursework. Besides the formal learning in lectures and labs, informal and incidental learning occurred elsewhere in coffee shops, buses, study groups, all-nighters, co-op work term prep sessions, and homes.

Third, workloads in ECE second year were typically very heavy. Design I and Design II projects were complex and required the integration of multiple streams of knowledge: theoretical knowledge from the course content and practical hands-on skills with electrical equipment, tools, analogue circuits, machine shop, and programming. In addition, students took five other courses with their own demands. Frequent assignments, midterms, reports, and finals meant that students were faced with managing a substantial workload in the program. This was particularly challenging at crunch times around midterm, project demonstration days, and final exams. Hence, students could be doing anything at any time, anywhere. Often teamwork expanded past the course and the nine to five day, late into the night, and sometimes until morning.

These three features made the data site busy, interesting, and unpredictable. At any given time there were a multitude of bodies coming and going in the labs and the many sites of interaction and learning around Design I and Design II projects. The team-based projects required students to immerse themselves in a knowledge-intensive material, semiotic, social, and cultural environment. Hence, capturing change in students over the year was anticipated to be challenging. It was impossible to predict a priori what would emerge as significant and when and where. The emergence and stabilization of new dispositions and thinking in students was expected to vary between being directly observable; being revealed by important and unexpected events; being reported indirectly by informants or the students themselves; being inferred from conversation; or, at times, remaining invisible or untraceable. Accordingly, an unstructured design was selected so that data collection activities could be adapted to a dynamic and unpredictable research setting. Maxwell (2012) notes that the selection of structured or unstructured designs in qualitative research has divergent implications for the nature of the findings:

> Structured approaches can help ensure the comparability of data across individuals, times, settings, and researchers, and are particularly useful in answering questions that deal with differences between people or settings. Less structured approaches, in contrast, allow you to focus on particular phenomena being studied, which may differ between individuals or settings and require individually tailored methods. Less structured methods trade generalizability and comparability for internal validity and contextual understanding and are particularly useful in revealing the processes that led to specific outcomes, what Miles and Miles and Huberman (1994) call ‘local causality.’ (p. 88)

A tentative, unstructured research design was specified at the outset of the study (Table 10).

Table 10. Research Design

Method	Timing	Purpose
Participant observation*	September 15- October 8, 2012*	• Observe features, characteristics, of general community • Identify possible teams for eventual intensive observation
	October 8, 2012 - February 15, 2013*	• Intensive observation of one design team for two projects • Identify key theme for each student trajectory
	February 15- April 15, 2013	• Intermittent observation as fodder for final interview
Audio/video recordings	November 1, 2012 - April 15, 2013	• Capture conversation and interactions during project meetings, lab design/build, demonstrations, lectures • Done to support participant observation
Semi-structured interviews*	mid-October, 2012*	• Initial trajectory interview to establish students' personal, academic history, perceptions of first-2nd year transition
	end-December, 2012	• Midpoint interview focused on perceptions of change over term, tailored questions about trajectory, member checking
	end-April, 2013	• Final interview focusing on perceptions of change over year, tailored questions about trajectory, member checking

* - Delays in data collection

An early and persistent concern of instructors, teaching assistants, the lab technician, and students about their participation in the study was how much time was required and when. It was clear at the outset that, despite a generally positive reception to the research, the workload that instructors and students managed made time a valuable commodity in their lives. As such, the research activities were designed and adjusted so as to minimize time demands and were embedded in the classroom activities so that they were a normal part of what instructors and students did. Nevertheless, time issues meant two to three week delays in many of the data collection activities.

4.6 Accessing the Research Setting and Establishing a Working Presence

In this section, I describe, in the first person, how I became a participant observer at the research site. The initial contact, thanks to the Head of ECE and the ECE Design Chair, was to the two Design I instructors. These instructors were engaged and cooperative from the outset, and provided me with unfettered access to the data site and TA-level access to the course materials on the learning management system on September 26.The instructors allowed me to attend the classes daily in order to better understand the context and the community, forge relations, identify individuals who might serve as informants in the field, and seek out individuals and teams that might be willing to be observed and interviewed. For the first three weeks, the course instructors, TAs, and students acclimatized to my presence, something that was accomplished in different ways at different times with different people. Help came from the instructors, TAs, and the influential students in various teams. Initially, both instructors oriented me to the lectures, labs, project rooms, and classrooms; allowed me to shadow them for the first few days; and gave me an opportunity to announce my research during lab time. The announcement made students and TAs aware of my presence and my research, allowed me to collect consent forms, and gave the impression that I had some kind of official purpose.

Being a graduate student made it easier for me to connect with many of the TAs who also allowed me to shadow them when they evaluated students' modules. Shadowing TAs provided opportunities to speak to them and students, establish positive relations, and claim a working presence in the data site. On many occasions, TAs, the lab technician, and I retired to coffee shops to discuss the events of the day. Thirdly, in order to match the noisy, bustling atmosphere of the lab, I made myself look busy and blended in. I bought the standard student electronics kit and worked on module 1, moved between labs taking jottings in a small notebook, and looked intently at the computer when I needed to de-emphasize my presence. I also used the natural spaces between and around the working benches, and the milieu of bodies moving in an out of the rooms to spot or create natural opportunities for short exchanges with the students.

The first three weeks were not easy. Field relations are essential in ethnography and so I was very careful to manage the impressions I was making on instructors, TAs, and students. Specifically, this meant avoiding impressions that posed obstacles to access such as being too abrupt and direct in approaching instructors and students, looking nervous or uncomfortable, imposing on their time when they were busy, or being overly obsessed with my research needs. Impression management meant projecting an atmosphere that facilitated access. I accomplished this by dressing and grooming myself to look younger; adopting age-specific colloquial language; joking around; making myself look busy; seizing natural but brief opportunities to engage lightly with students; presenting myself as a little tentative and unsure; and using my knowledge of students' home countries or towns to make a personal connection through geography or culture. I managed, not always smoothly, to achieve an acceptable, benign presence in the site. My background as an engineer was apparent from the iron ring I wore and some students came to know that I had taught the technical communication course that many were taking that year. This afforded me status as an indigenous outsider (Banks, 1998). I was able to draw on my experience and knowledge to have program-relevant conversations with students, help with their technical writing, and to act as a sounding board for career advice.

4.7 Becoming Embedded in a Team

In the first three weeks in the data site, I began identifying potential teams within which I might become embedded for intensive participant observation and interviews (Table 10). In the second week on October 5, I accepted an unsolicited invitation to observe a team's project meeting. Although the team was receptive to participating in the study, I did not pursue the possibility because most team members were all native English speaking Canadian-born students and so were not considered as candidates for the study. Through my observations, I identified seven potential teams by early October on the basis that I had positive personal contact with one or more of the students in the team, that two or more students had indicated on their consent forms a willingness to be interviewed, and that the team was characterized by high cultural diversity. I publicized my general interest in observing and interviewing teams through an instructor-approved email, which followed a first email, which offered individuals and teams technical communication writing support. I also began the delicate work of pursuing the topic face-to-face with potential teams during lab time when I sensed individuals in those teams were receptive.

An opportunity in the week of October 14 brought me closer to securing access to a team: project 1 was being demonstrated and evaluated in the labs and so I shadowed both instructors and their TAs over an intensive two-day period. Observing these demonstrations put me in greater contact with most of the teams that I had identified as having high potential. After observing many teams' demonstrations, I took opportunities to engage with students about their projects and the term so far once the instructors and TAs had disappeared. Where appropriate, I reiterated my general offer of technical writing help and my interest in observing and interviewing teams, leaving my card in case they wished to contact me. Two of seven promising teams contacted me by email to request help with technical writing and express interest in participating in the research. Within two weeks, two more teams expressed a similar interest face-to-face in the lab and after a pizza eating/focus group session I had conducted.

Of the four teams that showed interest, the first team who had contacted me by email did not appear at the agreed time due to a miscommunication. They later reported workload issues and I did not pursue it further. An enthusiastic student in a second team who expressed interest face-to-face in his team participating in the research promoted the idea during a project meeting but failed to get unanimous approval. A third team, with whom I had cultivated a friendly but somewhat awkward relationship, was open initially to the idea but grew less interested after project 1. I thought I had put them off, but later found out they had received a poor mark on project 1 and thought themselves a poor example. Finally, team Z5 both requested my help giving feedback on their already submitted project 1 report and showed interest in welcoming me into their team. I was able to gain full consent and unfettered access to all of their team meetings and lab work sessions and 5 out of 6 students gave their consent to a series of interviews. Although I had been observing them from their demonstration on October 15, I became officially embedded in their team on October 26.

4.8 In-Field Data Collection and Analysis

As Section 4.2.4 notes, in ethnography, data collection and analysis are intimately intertwined rather than being separate, sequential stages and that researchers require a commitment to maintaining a dialectical interaction between data collection and analysis (Hammersley & Atkinson, 2007). The discussion of taking and writing up the first field notes from the site to follow in Section 4.8.1 is illustrative of this iterative, dialectical process of data collection and analysis. Field notes are typically jotted down in situ and the researcher retreats while fresh to reflect on and write them up in larger research book. Implicit in the reflection and writing process is interpretation and analysis of the meaning of what was observed: it represents one iteration of a data collection and analysis cycle that gives the researcher a slightly different orientation towards the field for the next day's observations. Indeed, "data are materials to think with" (Hammersley & Atkinson, 2007, p. 158).

Viewing data collection and analysis as having a dialectical relationship encourages the researcher to remain in close and persistent interaction with the data while in the field. In quantitative research, data collection and analysis tend to be thought of as separate - and are reported as such - whereas data collection and analysis in ethnography is intimately intertwined. The difference stems from epistemology as Hammersley and Atkinson (2007) make abundantly clear when they warn ethnographic researchers not to mimic conventions of quantitative research:

> Some representations of analysis – notably vulgar accounts of grounded theorizing strategies – seem to imply that there is a standard set of steps that the ethnographer should go through in order to make sense of their data. It is vital to ignore any such implication. (p. 158)

This quote might be interpreted by researchers of a more conventional orientation as a lack of concern for validity and reliability in collecting data, analyzing it, and reporting the findings. It is, however, a recognition that qualitative research should work on its own processes for ensuring high quality observations that lead to plausible inferences about social worlds.

Accordingly, the two subsections that follow describe how this study's unstructured research design (Table 10) was enacted in the field. Implicit in these descriptions is a blend of data collection and analysis that is the hallmark of ethnographic approaches to research. The amount and kind of data that was collected will be summarized at the end of Section 4.9 (Table 11). Section 4.10 will then describe data analysis activities as they were conducted after leaving the field with the understanding that data analysis in ethnography is also closely related to writing (Hammersley & Atkinson, 2007).

4.8.1 Participant Observation

Participant observation was a major source of data in the study. The approach used for making and recording observations is described herein. The process of making and recording observations did not come easy in the first three weeks. I had entered the data site as a novice researcher not sure what to observe and record. I was aware that “one does not ‘see’ everyday life laid out like a sociology or anthropology textbook, and one cannot read off analytic concepts directly from the phenomena one experiences in the field” (Hammersley & Atkinson, 2007, p. 81). I was aware of a number of orienting notions in ethnographic research: fight familiarity (Delamont & Atkinson, 1995), find the remarkable in the mundane and the mundane in the remarkable (Silverman, 2013), bracket or suspend beliefs in the interests of inquiry (Husserl, 1970), and maintain reflexivity (Hammersley & Atkinson, 2007). I found these to be helpful in a general sense as perspective-taking and bias-minimizing principles. I struggled early in the data site over what to observe and record in the jottings books and field notes. This translated to some anxiety and disquiet that perhaps I was just not capable of observing what I should be observing. I frequently thought that maybe I was missing something somehow, a common feeling in ethnography identified by Lacey (1976) as the “‘it is all happening elsewhere’ syndrome” (p. 71).

After my first day of observation, I left the site and immediately wrote the field notes into longer prose with other things I remembered or reflected upon. I was not satisfied with what I captured in the field notes and the write-up: there had to be a better way of seeing and capturing significant data. I was aware that researching the evolution and change in students through their participation in teamwork projects meant tuning into what was likely to be important: themes or tracers related to student trajectories that enabled episodes, observations, and reports to be linked over contexts and time. I had anticipated this challenge when I conceptualized the research; however, capturing the data needed to produce plausible and trustworthy accounts of student trajectories when faced with the data site seemed daunting. It was unclear at the outset what would emerge as significant. When a myriad of interactions occur at the same time it is difficult to decide which particulars to focus on and how they should be recorded for later analysis. Consulting the literature around participant observation once again helped. In the spirit of ethnography grounded in constructionism rather than naturalism, Emerson, Fretz, and Shaw (2011) used multiple accounts of the same scene to show how descriptive accounts are not just the facts about what happened, but entail a viewpoint: “field note descriptions of even the ‘same event,’ let alone the same kind of event, will differ, depending upon the choices, positioning, personal sensitivities, and interactional concerns of the observers” (p. 9).

Emerson, Fritz, and Shaw (2011) offer four implications for writing field notes. First, they suggest that “what is observed and ultimately treated as ‘data’ or ‘findings’ is inseparable from the observational process” (p. 15). This means that observers with an objective mind-set will tend to see the process of writing field notes as recording objective information as if the method of getting that information was independent of the information itself. Instead, effective field notes on what occurs at the site requires additional information related to how that information was acquired. Connecting the data with notes on how the data was collected allowed me to capture the contingent nature of the observations and judge the quality of the data at a later stage. Second, they suggest that “the field researcher should give special attention to the indigenous meanings and concerns of the people studied” (p. 15). As such, words recorded at this data site such as “rite of passage”, students “cracking” under pressure, and having to “man up” under workload pressure, represent indigenous meanings that are significant to their concerns and doings and afforded me the opportunity to tune into and more faithfully represent the values, practices, and voices of those observed.

Third, Emerson, Fritz, and Shaw (2011) suggest that “contemporaneously written field notes are an essential grounding and resource for writing broader accounts of others’ lives and concerns” and note that since ethnographers immerse themselves in another culture, it is important to capture the “subtle processes of learning and resocialization as they occur” (p. 15). For example, in this study, I built a circuit for one of the Design I modules, which gave me an appreciation for the patience required by the work – one mistake means much lost time debugging the circuit. The field notes I wrote immediately after preserved this experience in ways that would not be possible later, as time blunts memory. Finally, Emerson et al. recommend that field notes should “detail the social and interactional processes that make up people’s everyday lives and activities” (p. 15). Recording close, detailed reports of interactions helped me identify and follow processes of witnessed events so as to develop and sustain processual interpretations of what is emerging between participants. One example was multiple observations on the minute interactions around interactions between Tony and Yao when Yao’s more practical ideas for saving time and being cautious on Design I project 1 were continually neglected or left unanswered. These guidelines were extremely helpful in focusing my observations. I also drew additional tips in taking field notes by paying attention to concrete details of the setting, participant appearance, participant interactions (e.g., relationships, proximity, gestures), events, processes, acts, and talk (Glesne, 2011).

Blumer’s (1954) notion of *sensitizing concepts* in social science research was also helpful. Sensitizing concepts “give the user a general sense of reference and guidance in approaching empirical instances ... where definitive (i.e., derived from theoretical frameworks) concepts provide prescriptions of what to see, sensitizing concepts merely suggest directions along which to look” (p. 7). I looked for traces or manifestations of underlying inner contradictions (Leont′ev, 1978) that might be the drivers of change for students, such as conflicts, tensions, and disjunctures (e.g., doing school vs. learning, Holland & Reeves 1996), as identified in the literature review in Section 2.10. Jordan and Henderson (1995) also recommend attending to the ‘C-issues’ (e.g., cooperation, conflict, conviviality, competition, collaboration, commitment, caution, control, coercion, co-optation, etc.) in participant structures, which are potential manifestations of the underlying dynamics. Hammersley and Atkinson (2007) provided additional sensitizing concepts, including attending to folk terms, observer-identified concepts, and atrocity stories. I took these as sensitizing rather than definitive concepts (Blumer) as orienting devices to provoke questions and possibilities in my mind when doing field observations. I renewed my efforts to observe and record in a manner that avoided both premature analysis and unfocused description. I also took heart in Hammersley and Atkinson, who note “it is only through watching, listening, asking questions, formulating hypotheses, and making blunders that the ethnographer can acquire a good sense of the social structure of the setting and begin to understand the culture(s) of the participants” (p. 79).

Observations of the general context and community took place largely in the electronics labs, whereas observations of team Z5 meant following the participants between formal, informal, and non-formal learning sites. These observations were recorded in the field in multiple small Moleskin jotting books. Larger notebooks were used on a daily basis to render, while fresh, the observations signified by the jottings into full descriptions. A third notebook and audio recordings were employed as a research diary to record personal reactions to observations and field notes (e.g. inferences, things that are surprising, intriguing, disturbing) and to record and guide research activities. The data collected in these notebooks were used to identify fruitful themes or tracers that could be tracked through the duration of the study and followed up in interviews. As intense observation of team Z5 began, audio and video recordings were taken of project meetings, work sessions, module and project demonstrations, and informal conversations.

4.8.2 Semi-structured interviews

Semi-structured interviews were the second major source of data for this study. This approach to interviewing involves asking specific pre-determined questions but without a strict protocol. As such, I had the flexibility to follow unexpected leads and to probe in depth so as to "capture the unseen that was, is, will be, or should be; how respondents think or feel about something; and how they explain and account for something" (Glesne, 2011, p. 134). I began the process of planning and conducting interviews with the understanding that my theoretical position, research interests, and questions would shape the answers (Diefenbach, 2009; Schwarz, 1999). Further, while interview questions give as well as elicit information, responses are also influenced by interviewees' backgrounds, moods, and the interview situation. Interviewees infer their own meanings from questions (Schwarz & Oyserman, 2001), harbour their own biases

(Diefenbach, 2009), have their own perceptions of the interviewer, and are affected by the interview's framing and context (Fontana & Frey, 1994). I consulted models of good questions, thought through how interviewees might respond to the questions, and consulted my supervisors before finalizing these questions (Appendices). In starting interviews, I gave an outline of the purpose of the interview and created a light, comfortable tone by breaking the ice and using appropriate non-verbal communication. As the interviews got underway, I asked open, accessible questions before focusing and probing and used an appropriate balance of focus and open-ness in asking questions. I aimed, but was not always successful, in creating an environment where respondents were able to express their feelings and thoughts and explain and account for the topic at hand. I attempted to minimize my own impact on the responses to allow interviewees' responses to be heard.

The core 13 semi-structured interviews analyzed in this thesis were from five of the six Z5 team members (Jay, Lee, Hyuna, Tia, Yao) and an additional student, Li from Hong Kong, who replaced Jay in January. These interviews were core because they were conducted in a purposeful manner at three points of the academic year (i.e., beginning: October, middle: December/January, and end: April) in order to complement the intensive observation and audiovisual recordings of the team in the field. Members who left the team or joined late were interviewed twice. An additional 20 interviews were done with twelve additional students (one to three interviews each); however, these data were not collected in concert with intensive field observations and recordings and so were not analyzed and reported in this thesis.

The first individual semi-structured interviews with Z5 team members can be described as historical trajectory interviews because they provided the background for which to understand their starting points early in the year. These were conducted as soon as possible after I had become embedded into the team (Appendices). The interviews focused on students' personal and academic histories and the significant transitions they had experienced in their pathways from school in their countries of origin to early second year electrical or computer engineering. A key goal was to establish the background conditions and key transitions of the student up until the end of first year as these data would be the starting point and the substrate for changes that occurred through their participation in the team-based design projects. A second aim of these first interviews was to understand team members' perspectives and perceptions of team life and Design I project 1: to identify early challenges and incidents in the team; emergent features of the team interactions, decision-making, processes, and roles; and other points relevant to students' trajectories or their overall evolution as a team.

The second and third interviews were to some degree, opportunities for linking in to the goings on observed in the participant observation data. As intensive observations, frequent informal conversations, and audiovisual recordings around the team continued in the field. Hundreds of potentially significant interactions, events, and episodes occurred that were recorded in the 100 hours of observation of team Z5 in 300 small pages of the Moleksin books as field notes and written up in the 250 pages of the larger research books (see Table 11). For example, disagreements between Tony and Yao over decisions on Design I project 2 were noted and occasionally audio recorded in the lab. Accounts in the field notes might range from a microsecond long look of dissatisfaction from Tony to interactions up to several minutes long over issues with respect to the project. Both general and specific interactional patterns and roles, student-produced observations, and student perceptions were recorded. In order to gain greater insight into the details, perceptions, and perspectives of such observations that were potentially relevant to the individuals' or the team's development and change, a second round of semi-structured interviews was conducted at the end of the term in December 2012 after the Design I project 2 demonstration (Appendices). This was an opportunity to raise key issues that emerged in participant observation and to do informal member checking about the first interview and about the events that had occurred since the first interview.

A third set of interviews was conducted at the end of the Design II projects in April 2013 as an opportunity for informal member checking of previous interviews and a chance to pick up on persisting patterns, themes, and perceptions observed or reported over the duration of the study. These last interviews were also a chance to elicit student perceptions of their and their team's evolution through the year. In addition to individual interviews, a focus group interview was conducted with all Z5 team members at the end of Design II in April 2013 in order to touch on themes relevant to team-based project work. A total of eight semi-structured interviews of two instructors and three TAs were also conducted at the beginning of Design I and Design II in order to elicit their general perceptions of students' development and change through the team-based design projects and to confirm and clarify details of incidents related to team Z5 (e.g., their conflict in Design I project 1). TAs and instructors could not be expected to tune into the development and change of specific students or teams and so informal conversations related to episodes involving team Z5 students or team Z5 itself were elicited from TAs or instructors as they happened in the field. Details on the data collected through participant observation and semi-structured interviews are summarized in Table 11.

4.9 Post-Field Data Analysis

The data in Table 11 were analyzed in accordance with its particular purpose with respect to the study's specific research questions and how the findings were to be represented.

Table 11. Summary of Data Collected

Data Collection	Stage*	Duration	Number (Sessions)	Total Time	Form of Data
Observations (General)	B	3-5 hours	12	50 hours	(For all observations)
Observations (Team Z5 Lab Periods)	B, M, E	2-3 hours	14	30 hours	Field note books (2) (300 pages, 3”x4”)
Observations (Team Z5 Lab Overtime)	B, M	1-8 hours	10	35 hours	Research books (3) (250 pages, 8.5”x11”, transcribed into MS Word)
Observations (Team Z5 Project Meetings)	B, M, E	2-4 hours	12	35 hours	Audio recordings (25 hours) Video recordings (15 hours)
Semi-structured Interviews (Team Z5)	B, M, E	1-2 hours	13	20 hours	Audio recordings Transcripts
Focus group (Team Z5)	E	2 hours	1	2 hours	Audio recordings Transcripts
Semi-structured Interviews (Instructors)	M	1 hour	2	2 hours	Audio recordings Transcripts
Semi-structured Interviews (TAs)	B, E	1-3 hours	6	15 hours	Audio recordings Transcripts
Documents	--	--	--	--	Course modules (14) Project assignments (4) Course Documents (5) Team Z5 Facebook Posts (124)

* B = beginning (Sept. – Nov.); M = middle (Nov. – Jan.); E = end (Feb. – Apr.)

As noted in Section 4.1, the first guiding question (i.e., What is the nature of the student-instructor, student-student, student-tool, student-assessment interactions in engineering design courses? What knowledge do these interactions foster and hinder?) was addressed through a portrait of the general interactions at the data site (Chapter 5). This became a secondary data source that was used to contextualize the five student trajectories over the two courses and highlighted change in their engineering dispositions and thinking (Chapter 6). Hence, the data for Chapter 5 came mainly from the intensive general field observations before the researcher was embedded in team Z5, more intermittent observation after that point, and the instructor and TA interviews. The analysis of this data will be described in Section 4.9.1. The data for Chapter 6 were drawn primarily from the intensive observation of team Z5's project meetings, lab sessions during class time, lab sessions during overtime, and the semi-structured interviews conducted at the beginning, middle, and end points of the research. These data address the general research question: How do the engineering dispositions and thinking of culturally diverse students evolve through their experiences in the second year of an electrical and computer engineering program? These data were handled and analyzed differently from the general data for Chapter 5, which will be discussed in Section 4.9.2.

4.9.1 Data Analysis for a Portrait of the Research Site

This section details how data were handled and analyzed to address the first guiding research question (What is the nature of the student-instructor, student-student, student-tool, and student-assessment interactions in engineering design courses? What knowledge do these interactions foster and hinder?). Each interactional pair in the research question was treated differently in terms of data analysis. As noted in Section 4.8.1, observations in labs, project rooms, lecture halls, and machine shops were recorded in the field in two Moleskin books. Larger notebooks were used on a daily basis to render, while fresh, the observations signified by the jottings into fuller descriptions. As an example, early in the term, an entry on September 27, 2012 in the Moleskin book reads:

> Today working on Module 3 – Discrete Digital Logic
> *INTERACTION, T → S "What's going on here?"
> One student hooks circuit up (O) but it doesn't work H helps
> him out by reconnecting it.
> Very good hands-on
> St does it 1½ hrs "frustrated"
> K gives personal experience
> "You have to be patient."

This was re-expressed in continuous prose after leaving the data site an hour later. The corresponding short account appears in the larger research book:

> One student at a nearby desk hooks his circuit up to a power source and is using the oscilloscope probes to see if the digital logic is working (NOT, NAND gates? can't tell) and but it doesn't work. The student is working on Module 3 (Discrete Digital Logic) and appears to be lost. No readings are on the oscilloscope and he stands there not doing anything – can't see his face. The student asks Heisenberg for help and Heisenberg approaches, says "What's going on here?" lightly in a open gesture. Students shoulders relax. Can't recall the exact conversation, but Heisenberg helps the student out by troubleshooting the connections on his breadboard and reconnecting it, modeling how to check. Could not see his actions on the breadboard, but he stepped the probes through small sections of the circuit, asking questions. Student responds and identifies an unconnected wire. The student says something like "I'm so frustrated" and appears to need a kind word. He adds that been working on this circuit for 1½ hours. Heisenberg tells his Jungle story about working overnight to fix a problem, which catches the student's interest – smiles . Heisenberg: "You have to be patient! I spend hours and hours working on circuits–this kind of work requires that. It's not easy!"

In this manner, 160 interactions between instructors (Heisenberg and Kelvin) and students were recorded as part of 159 pages (8.5" x 11") of full prose written in the first larger research book (September 26 to November 1). The books were initially handwritten but were entered into a Word file.

The coding process was conducted as follows. In beginning the analysis of student-instructor interactions for Heisenberg, 90 interactions in the Word document were identified. Although the researcher had experience with NVIVO, a choice was made to inductively code the data in a first pass in Word using track changes and then do a closer reading in a second pass to adjust these initial codes. The term “code” was taken in the analysis to mean an identifying anchor that allowed key points of the data to be gathered. Given that the first guiding research question concerns what knowledge interactions foster and hinder, codes were crafted for each of the 90 instructor-student interactions using gerunds phrases that expressed what the instructor appeared to be indicating to students in terms of engineering dispositions and thinking. Categories were taken to mean a collection of codes of similar content that allowed data to be groups so as to allow for a more parsimonious account of knowledge fostered and hindered to be created.

Returning to the coding process, instead of coding on NVIVO, the MS Word file with initial codes in track changes was printed out and cut up such that one interaction and its code were on each strip of paper. This allowed for text and code to be arranged and rearranged on a large table so as to facilitate interpretation. Moving back and forth between the interactions and their codes multiple times enabled initial codes to be confirmed or revised as necessary until there was a level of confidence in the match. Ninety slips of paper were then arranged into rough categories that were separated out and named. A continuous process of checking the codes, categories, and original text resulted in codes and categories of individual interactions being adjusted. Codes were judged to be stable when there was a minimum of eight interactions with the same code name. Once codes were deemed stable, the codes were grouped into overarching categories. Further adjustments were made as necessary. For Heisenberg, this resulted in two overarching categories, each with three codes, and each code with eight to eleven interactions. Fifteen interactions and four codes did not meet the criteria for being stable and so were eliminated from the analysis. The results of this coding process are found in Section 5.2.1. A sample of interactions for one code appears in Table 12.

Coding and categorizing student-instructor interactions in this manner enabled a picture to form about what was being fostered in students with respect to engineering dispositions and thinking at a general level.

Table 12. Sample Interactions for Code "Encouraging Grit"

Category (Code)	**Interaction (Key words only, 5 samples out of 10)**
Inculcating Generic Skills and Dispositions	Heisenberg to student: "You have to be patient! I spend hours and hours working on circuits–this kind of work requires that. It's not easy!"
(Encouraging grit)	Heisenberg to group having difficulty: "That group over there, they discovered one wire that wasn't connected – it worked. It's persistence that makes the difference. What about you?"
	Heisenberg to a student, who asked him what is wrong with their circuit: "Your oscilloscope is off. You are not trying hard enough."
	Heisenberg to students: "The bad news is that it gets worse. Third year is not bad, fourth year is (pulls an unpleasant face) and then you go to work and it's like this times two. (shocked looks) Welcome to engineering!"
	Heisenberg to student: "They were up all night." Aside to student: "That's what you've got to do."
	Heisenberg to students: "When did you start the project? (A: 3 weeks ago) Did you sleep last night? (A: No. *all laugh*). Very good."

The key categories derived from student-instructor interactional data such as *encouraging grit* are important because they have the potential to directly or indirectly orient students towards what were important dispositions and thinking in the work of the Design I and Design II projects. Embedded in encouraging grit are such dispositions as patience and persistence. These categories and codes are not presented in Chapter 5 as evidence of the engineering dispositions and thinking that actually developed in students. Rather, they are examples of what is being fostered in the general context of the engineering design projects by the instructors. Evidence of change in culturally diverse students' engineering dispositions and thinking is left to Chapter 6.

The general student-student interactional data (i.e., of students other than team Z5's members) were treated differently from the student-instructor interactions. Ample numbers of student-student interactions were certainly observed and available for an analytical approach similar to that of the student-instructor interactions. However, student-student interactional data varied across so many students (i.e., 280+), which had two implications for the usefulness of pursuing such coding. First, they were not judged to have the capacity to dramatically inform the portrait for Chapter 5 when a descriptive portrait would suffice. Second, observations of student-student interactions were highly particular to the specific combinations of students observed and so were thought to be less relevant to the team dynamics and student trajectories in team Z5. The broad descriptive treatment of student-student interactions in the lab, presented in Chapter 5, was judged to suffice for the purposes of a portrait. In addition, once the researcher became embedded in team Z5, the focus shifted to the interactions among the team's six students, which took priority over how students outside the team were generally interacting. Analysis of team Z5's student-student interactions became subsumed into the findings presented in Chapter 6.

Accordingly, general student-student interactions are presented descriptively (Section 5.3) to suggest the general range of interactions at the site as background to the findings from team Z5 (Chapter 6). A similar approach was employed for the student-tool and student-assessment interactions. In the case of student-tool interactions, close observation of physical interactions of student and material and attention to what students said about tools, equipment, and projects became the source of findings on the nature of these interactions. Understanding student-assessment interactions came from what students said in context or reported in interviews. The general descriptive findings of these student-tool and student assessment interactions are presented in Chapter 5 with the understanding that a more specific and targeted understanding of such interactions is subsumed into the findings about team Z5's students in chapter 6.

4.9.2 Data Analysis for Culturally Diverse Students' Learning Trajectories

This section describes the data analysis that resulted in the five trajectories of culturally diverse students in Chapter 6. The first source of data was the field notes, which were produced during the period of intense observation of team Z5. As noted in Section 4.9.2, 150 pages of field notes written up during the fieldwork stage of the research and then typed into a 250-page Word document. Approximately 175 pages of this data focused on team Z5. The second source of data was the audio and audiovisual recordings of project meetings, work sessions, module and project demonstrations, and informal conversations recorded in the field. These recordings contained a number of important informal conversations with individual students and episodes in the team. These recordings were transcribed by hand and used to support, triangulate, and enhance the write-ups of the field notes, allowing a more complete record of observations to be captured for later analysis. Examination of video recordings allowed interactions in the team to be more accurately captured and identified. The third source of data was the recordings of the semi-structured interviews, which were critical for checking and linking changes observed over time in the data site with each students' perceptions of their change. These interviews were transcribed by hand and, together with the full research book of observations and the audio and visual recordings, provided the corpus of data for the trajectories.

These data for team Z5 were analyzed iteratively in order to hypothesize both the primary nature of the change that each culturally diverse student was experiencing and the inner contradiction that might be driving such change (Leont′ev, 1978). This was accomplished by pooling the field notes, the transcripts from semi-structured interviews, and transcripts or descriptions of informal individual conversations and episodes from audiovisual recordings, which related to each individual student. Recommendations by Derry et al. (2010) were used to analyze recordings. The first pass involved viewing unedited footage to produce a log that identified episodes: important events, transitions, exchanges, and themes in team interactions. Subsequent passes allowed relevant episodes to be pooled with the interview transcripts and field notes. Just as these recordings had a role in triangulating and enhancing the field notes, they were also used to triangulate and enhance data collected through the interviews: they provided spontaneous insights into interactions soon after they happened in the team.

The five-stage hybrid activity theory framework of Roth (2009) outlined in Section 3.4.3 was employed to track whether the hypothesized nature of the change and the inner contradiction that drove it was plausible. These five stages and the associated data for them are described herein. Stage 1 is identified as the real historical conditions relevant to a student’s trajectory. Roth (2009) notes this as the starting point: “First, there has to be a demonstration of the real-historical conditions of the preceding level within and upon which the quantitative functional change develops” (p. 11). The real historical conditions relevant to a student’s trajectory are the substrate for change that existed previously. These include relevant aspects of students’ backgrounds (e.g., academic, personal, familial), personal circumstances, and identifiable dispositions and thinking prior to their participation in the design courses. These data were collected for each student during their first trajectory interview and through early informal conversations, observations, and audiovisual recordings.

The second stage is the identifiable changes in external conditions relevant to the student. Roth (2009) notes that “it has to be shown that there were objective changes in the external conditions that allow the internal (i.e., inner) contradictions, which will give rise to the qualitatively new function, to have its equivalent in the external environment” (p. 11). The identifiable changes in external conditions relevant to a given student are those that manifest in unique ways for them as a product of the shift in mode of study to team-based design projects. The data for this stage were collected for each student during their first interview and through observations, informal conversations, and audiovisual recordings in the field.

The third stand is the emergence of evolution and change in the form of engineering dispositions and thinking. Roth (2009) notes that “the analyst (must) articulate a functional turnover that relates the pre-existing dimensions in a new way, and thereby the evolution of the first qualitative change of the specific nature of the new function that makes the organism better adapted (p. 11).” “First qualitative change” can be thought of as the not-yet-dominant engineering dispositions and thinking that emerge because changes in the student’s external conditions engendered by inner contradiction in individuals, which become manifest and make the student better adapted to the new conditions. Such emerging engineering dispositions and thinking begin to co-exist with now dominant ones. These data were collected for each student during their second interview and through observations, informal conversations, and audiovisual recordings in the field.

The fourth stage is the turnover in dominance of students' engineering dispositions and thinking. Roth (2009) notes that "a change in dominance must be demonstrated, whereby the previously dominant function is negated and the co-existing new function becomes the dominant one (p. 12)." This means that newly emergent engineering dispositions and thinking that have become manifest as part of a student's participation in the projects with team Z5 become newly dominant. These data were collected for each student during their second and third interviews and through observations, informal conversations, and audiovisual recordings in the field. This fourth stage was critical for the process of analysis because change that was becoming visible in the data could be checked with data from stages 1-3 as supporting or refuting earlier hypotheses about a given student's change and the inner contradiction driving it.

The fifth stage is the restructuring process leading to a new trajectory. Roth (2009) notes "the analyst must demonstrate the restructuring process that gives the evolutionary trajectory of the system as a whole a new direction following the becoming dominant (function becoming) the system-sustaining determinant function" (p. 12). The restructuring process leading to a new trajectory is when the newly dominant function completely replaces the old and the student takes on a new trajectory. Establishing that a student's engineering dispositions and thinking have completely replaced the formerly dominant ones was perhaps the most difficult to establish; however, data collected in the final interviews and field observations in the team helped to either establish this stage had been reached or not been reached by particular students.

As noted, an iterative, inductive process of examining the data was conducted with the purpose of hypothesizing the primary nature of a student's change and the inner contradiction driving it. The data were examined carefully in order to determine whether there was persistent and internally consistent evidence that the proposed nature of the students' trajectory was apparent and to identify whether an inner contradiction (see chapter 3.3) could be established that was plausibly driving this change. In many cases the nature of a student's change was proposed and rejected because of lack of convincing evidence. In other cases, a primary category of change for a student was proposed and supported, but there was a lack of evidence that a change in dominance in their disposition and thinking had occurred. There was not always enough evidence to claim that every student went through the five stages. There were also limitations in data collection that meant that not all change could be captured, either because it was less visible, the duration was too short, or it was impossible to record everything. The accounts made of students' trajectories that appear in Chapter 6 are based on the best observations from the data corpus, but must be read with this understanding of these limitations.

4.10 Trustworthiness of Findings

Ensuring the trustworthiness of findings in qualitative research is attempted by sampling from multiple data sources over a sufficient period of time to arrive at representative, thick descriptions of phenomenon (Geertz, 1994). Such use of multiple data sources to triangulate a phenomenon does not necessarily lead to a convergence of results. Rather, as Mathison (1988) points out, "the value of triangulation is not as a technological solution to a data collection and analysis problem, it is as a technique which provides more and better evidence from which researchers can construct meaningful propositions about the social world" (p. 15). Denzin (1970) introduces triangulation as a research strategy to improve the validity of findings. First is data triangulation "such that a social phenomenon is examined under a variety of conditions which may include the dimensions of time (i.e. time scales), space (i.e. learning contexts), and person (i.e. study participants)" (p. 301). Second is investigator triangulation through the involvement of more than one investigator in the research process. Finally is methodological triangulation through the use of multiple methods in the examination of social phenomenon.

Concerns for trustworthiness of the results have already been embedded in the research design (Section 4.5) and the description of data collection processes (Sections 4.8, 4.9). In terms of Denzin's (1970) data triangulation, the research design allowed for a responsive approach for progressively focusing on students' trajectories as they emerged in the data. The researcher worked across data sets (field notes, interviews, audiovisual recordings, multiple sources) to establish the nature of students' change and their inner contradictions as hypotheses and following up on them in later data towards the end of Design II. The researcher also collected data relevant to individuals' trajectories in a way that provided triangulation over multiple data sites (i.e., labs, lectures, project rooms, informal spaces) and multiple time scales (i.e., two terms of observation and interviewing).

In terms of Denzin's (1970) investigator triangulation, which is concerned with reliability or faithfulness of observations and inferences, the researcher developed the observational capabilities and procedures for tuning into and capturing interactions faithfully in the field based on the experienced ethnographers (Hammersley & Atkinson, 2007; Glesne, 2011; Emerson et al., 2011; Van Maanen, 2011), particularly on effective observation and writing of field notes. Although this research does not involve additional researchers in the detailed data collection and analysis, investigator triangulation was achieved to a degree through the involvement of one of the TAs on the courses who was familiar with team Z5 and the class. This TA assisted a great deal by reading key sections of the field notes and all project meeting transcripts and adding a technical perspective to the data. Meeting over the space of four months after data collection allowed for a discussion of the technical details of the projects and the interactions among team members. The researcher's doctoral committee provided important support with and insight into some of the significant issues that emerged in the data. Unfortunately, this data collection did not extend to longer time scales such as the entire program. Data triangulation across contexts was also limited to the accessible formal and informal contexts. The features in the research that relate to data collection practices in the field are found in Table 13.

Table 13. Measures to Maximize Trustworthiness

Methodology/ Method	Research design point to maximize trustworthiness
Ethnographic methods, research design	Induction - Thick descriptions of phenomenon Context - Case Study – Recognizes limits to generalizability Unfamiliarity - Represent from the insider's viewpoint Data collection in real time on 'actor' interactions
Participant Observation	Naturalistic observation - Normal part of the class activities Purposeful field note observations - Based on concrete categories (notebook 1) and researcher reactions (notebook 2) Use of 'sensitizing concepts' in observing and recording Patterns observed across interactions, people Observations in formal and informal learning contexts
Audio/visual recording	Visual record mutually supporting participant observation and interviews Identified participant structures and relevant episodes that reveal dynamics Use of sensitizing concepts to identify salient data Iterative and inductive process of data coding and categorizing
Interviews	Beginning, middle, final semi-structured interviews to capture perceptions over time Member checking of transcripts

4.11 Ethical Issues

This study was conducted with ethics approval of the institution in which was conducted. The research activities adhered to the Tri-Council Policy Statement that regulates human subject research in Canada so as to protect participants while serving the requirements of research. The three core principles of the Tri-Council Policy Statement are: respect for persons, concern for welfare, and justice. Letters of consent were provided to students who opted to participate in the study, which outlined participants' rights as part of this study. Participation was voluntary and could be withdrawn at any time without reason. Information of participants remained confidential and their identities protected in this document through the use of pseudonyms.

Chapter 5: Findings - A Portrait of Interactions in a Design Course

5.1 Introduction

Chapters 5 and 6 present findings to address this study's main research question: How do the engineering dispositions and thinking of culturally diverse students evolve through their experiences in the second year of an electrical and computer engineering program? Chapter 5 can be thought of as an ethnographic portrait (Lawrence-Lightfoot & Davis, 1997) of engineering disciplinary learning culture (c.f. Donald, 2002; Godfrey & Parker, 2010 in Section 2.3) at the research site that has the secondary role of contextualizing five students' trajectories, which are the main findings of this study (Chapter 6). Chapter 5 partly answers the first guiding research question (i.e., the nature of student-instructor, student-student, student-tool, student-assessment interactions in an engineering design course; the knowledge these interactions foster and hinder). However, additional data collected of such interactions in team Z5 were necessarily subsumed into the student trajectories that appear in Chapter 6. The findings in Chapter 6 are framed and interpreted through the hybrid activity theory framework of Roth (2009) as discussed in Sections 3.4.3 and 4.2.5. At the end of Chapter 6, an additional level of analysis of the student trajectories revealed five conditions that are critically important for culturally diverse students to satisfy in order to develop engineering dispositions and thinking and capitalize on the benefits of team-based project work modes of study. These are fodder for discussion in Chapter 7.

A reminder of the definitions and highly intertwined nature of engineering dispositions and thinking is timely. As identified in Section 1.1, engineering dispositions refer to an individual's characteristic tendencies (i.e., basic temperament, attitudes, inclinations, drives) as they relate to engineering work. Engineering thinking is patterns of intellectual behaviour, or habits of mind, with respect to engineering work. As discussed in Section 1.1, given the applied nature of engineering work (Bucciarelli, 1994), engineering dispositions and thinking are seen as highly interrelated in that whenever a disposition is manifest, thinking is implied. They are taken as presupposing each other, are treated as one (Section 1.1), and are necessarily reported together as a unity in Chapters 5 and 6.

The sections that follow focus on the student-instructor (Section 5.2), student-student (Section 5.3), student-tool (Section 5.4), and student-assessment (Section 5.5) interactions that were observed at the research site. In addition, Section 5.6 discusses several anecdotes of students "cracking" under workload pressure as a result of the cumulative effects of interactions at the research site on particular students. These anecdotes serve to illustrate how some students come under enormous pressure in this challenging program. Finally, a summary of engineering dispositions and thinking that appear to be fostered at this research site is reported in Section 5.7.

5.2 Student-Instructor Interactions

This section presents the findings on the nature of student-instructor interactions and the knowledge these foster and hinder. This portrait derives from the analysis of 160 interactions observed between the instructors (Heisenberg and Kelvin) and students, which were captured in field notes over the duration of the study and coded inductively to yield key categories (Section 4.9). This section begins with a discussion that occurred during project 1 evaluations in mid-October at the beginning of this study, when two teaching assistants (Saeed and Bahram) and Kelvin voiced diverse views on the nature and value of team-based engineering design projects. The three had just withdrawn from the lab to the technical services room in order to mark a team's project 1. After they had agreed on the mark, Saeed raised questions about assessment and the value of team-based design projects, suggesting that the students were not getting sufficient theoretical knowledge through this approach. The TAs and Kelvin’s views, and that of Heisenberg (elicited later), revealed four varied perspectives on team-based design projects in the speaker’s abridged words (Figure 12).

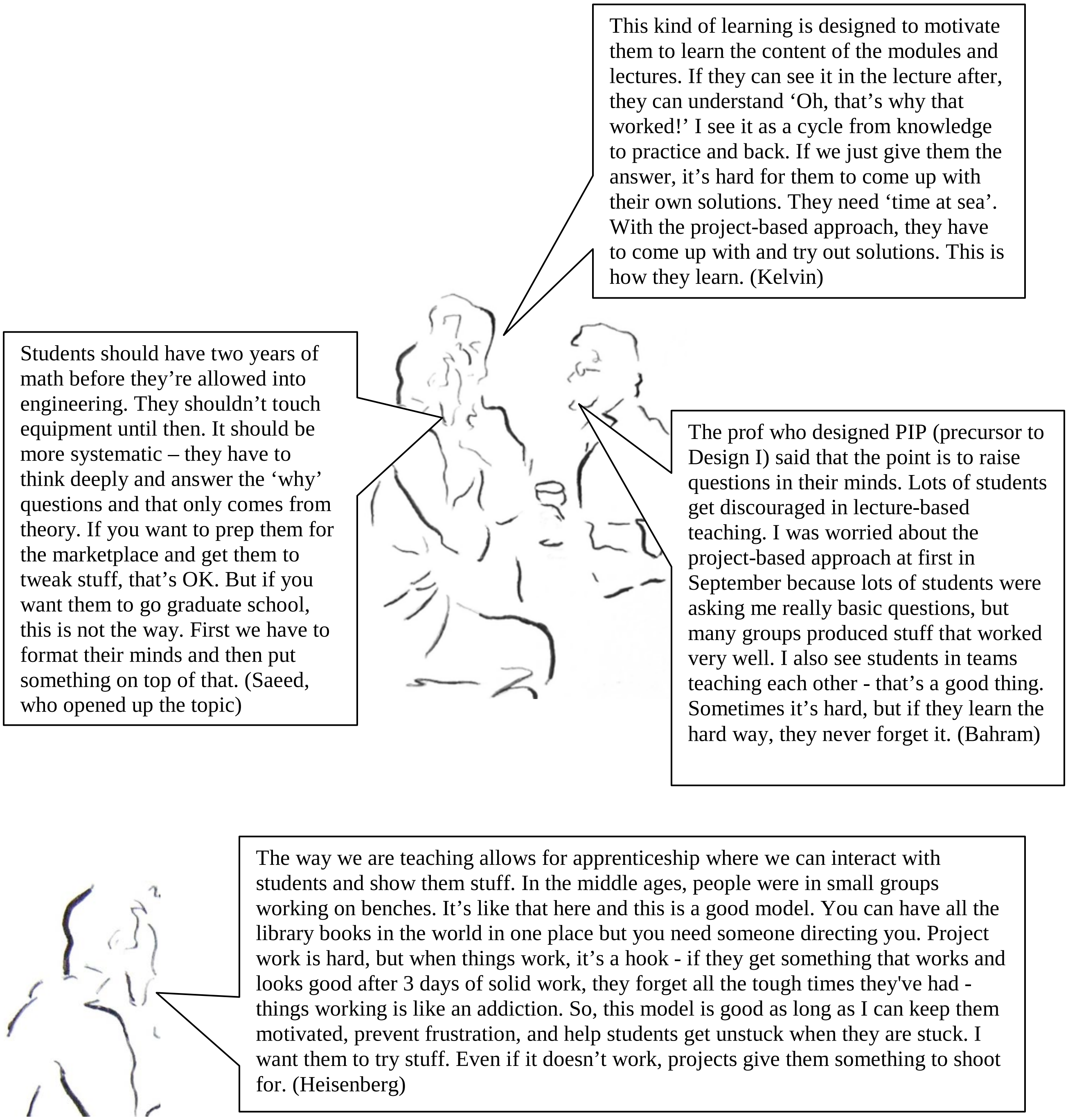

Figure 12. Perspectives on Project-Based Learning (Kelvin, Two TAs, Heisenberg)

Saeed favoured a didactic approach to learning engineering oriented to theoretical knowledge and graduate school. Bahram expressed concerns over students' theoretical knowledge as well, but saw the benefits of an applied approach if it had good results in terms of successful projects, teamwork, and memorable experiences. Kelvin recognized the dialectic between theory and practice that projects brought out. Heisenberg favoured a craft-oriented apprenticeship mode of learning where motivation, hard work, challenge, and success are critical. The orientations of the Design I teachers and TAs to team-based project learning illustrate the varied perspectives and which potentially influence the signals students receive in the environment with respect to what knowledge, dispositions, and thinking are important in engineering work. It is not a unified, uniform portrait.

5.2.1 Heisenberg: Making Projects "Clean and Tight and Packed in a Box"

As lead technical instructor on both Design I and Design II, Heisenberg created and planned both courses' projects and many of the modules and, among the instructors and TAs, was recognized as highly knowledgeable - the "go-to" person for anything technical. Also a martial arts practitioner, Heisenberg reported treating the labs like his *dojo* - a Japanese practice hall in which martial artists work in close apprenticeship in small groups under the watchful eye of the *sensei*, or master. Heisenberg saw his senior instructor role as requiring a high level of awareness of the surroundings so that he could tune into what was going on in both labs and help students or pick up on any dangers. Heisenberg's approach was clearly hands-on. He moved tirelessly in and between labs, observing teams and pairs working on projects and modules, and engaging them through their projects, the tools, and equipment in order to "get them unstuck" – provided there was evidence of proper attitude and investment in their work.

Typical student-Heisenberg interactions are represented in Figure 13 by the key categories (higher level; e.g., inculcating generic skills & dispositions) and codes (lower level; e.g., encouraging grit) that emerged from the analysis as described in Section 4.9. These will each be discussed in turn with reference to examples to illustrative purposes, beginning with the category of *modeling and encouraging technical skills*.

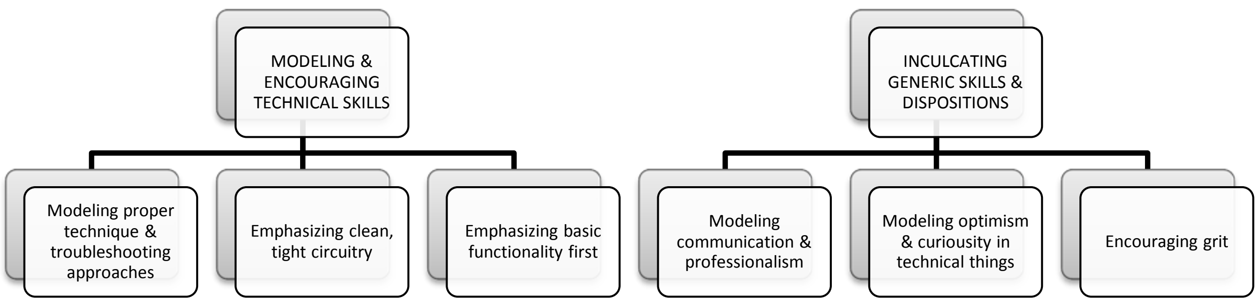

Figure 13. Patterns in Heisenberg-Student Interactions

Beginning with the emergent category *modeling proper technique and troubleshooting approaches*, in one episode, Heisenberg showed students how to troubleshoot a comparator they had built (Section 4.4.5). He worked with students on the first part of the circuit to diagnose the problem, replaced a burnt resistor, and then had a student do the rest while the others watched. While observing, Heisenberg corrected his technique: "You're holding it with one hand and trying to measure it with the other. Why not put it down on the desk and do it properly?" He then helped to identify the problem ("Your converter … the problem is here – this is not set in a logical manner.") and guided them in rebuilding the circuit. Towards the end, he noted: "What I'm doing here is I'm trying to match the breadboard to the diagram. You try. You have to be methodical." He then observed them and confirmed their approach, asking how long they had worked on it. They replied “1-2 hours” and he noted: “It only took two minutes. Just be careful when you’re building the circuit next time.”

Heisenberg was well known for *emphasizing clean, tight circuitry* and coined the term “spaghetti wiring”, which came into common usage by students when referring to poorly or sloppily built circuits. Spaghetti wiring makes circuits difficult for anyone to see and troubleshoot when things go wrong. Kelvin and the TAs were observed dozens of times reinforcing the message using this exact wording. At the end of Design I project 2, Heisenberg was disappointed to see spaghetti wiring persisting in some projects. During a demonstration, he commented to one team: “Oh, mang…those wires (shakes his head)…those wires are project killers. For the first project Design II, don’t do those wires – it’s not good.” In contrast, a different team produced circuitry in project 1 that was, as Heisenberg commented happily and with rhythm: “Clean! Tight! and Packed in a Box!” In another successful demonstration, his parting comment to a team, who had done exceptionally good circuitry, was: “It’s beautiful because it works and it works because it’s beautiful.” Heisenberg consistently *emphasized basic functionality first*; reminding students not to get carried away with “bells and whistles” before they had built a functioning, stable core design. He once noted to a team: “It’s not the shiniest one that’s the best. The one that works is the best.”

It is important to note that technical skills needed to complete tasks such as building circuits and the engineering dispositions and thinking that are called for are linked through the materiality of engineering. They can be thought of as presupposing each other. For example, as my experience as a participant observer, building and prototyping a circuit on a breadboard requires clean, tight wiring which is made more possible through a patient and persistent disposition. Students, instructors, and teaching assistants frequently voiced such connections between tasks and the dispositions required to do them. As a second example, diagnosing and fixing a problem with a solder board so that it functions properly requires a logical, methodical, detail-oriented approach.

The second of Heisenberg's categories, *inculcating generic skills and dispositions*, stands as distinct from the first because the interactions associated with these categories were at a level of separation from the physical projects and modules themselves. Heisenberg often brought key points related to communication or professional behaviour to students' attention, commenting on what were preferred and dis-preferred attitudes and actions towards engineering work. As an example of *modeling communication and professionalism*, a student who Heisenberg had identified as a hard worker claimed to understand how counters on project 1 work, Heisenberg said (lightly, positively): "OK, tell me. Draw it here." The student drew and explained and Heisenberg persisted in clarifying terminology as he spoke, pushing the student on the areas where the student was not understanding. Once satisfied, he said: "OK! Now design your own circuit. How do you make a counter from 1-2-3? That's your challenge." Heisenberg was observed encouraging engineering students to communicate and coached them on how to do it. Interestingly, he reported that many students did not know how to do *handshaking*, his term for an interpersonal strategy in which a person employs small talk to create opportunities for interaction to get technical input and feedback. He noted these students lost opportunities to make personal connections and expand their learning because they lacked such interpersonal and communication skills. He was observed coaching them to do it. Heisenberg also required students to be independent. One female student from China frequently asked Heisenberg's advice for small decisions on the project. He reported that she wanted to know if she was "doing the right thing" and on many occasions told her gently to be more independent; for example:

“You have to try before asking me…you have to be more independent. You have to follow the instructions. Don’t rush to ask me all the time!” He emphasized independence and self-direction as appropriate professional dispositions.

Through his lectures and stories in the lab, Heisenberg *modeled optimism and curiosity in technical things*. In lectures, he brought in demonstrations to illustrate concepts (e.g., 9V batteries in series/parallel attached to a desk lamp), related technology to students’ interests (e.g., video of electronic and mechanical equipment playing Gotye’s “Somebody that I used to know” https://www.youtube.com/watch?v=DkaUsBwe0fo), and stimulated interest by drawing on the history of science, technology, and engineering. He discussed equipment and parts in detail with great interest, often with humour. In doing so, he stressed how someone had to adopt a positive attitude and figure out how to do things. He told students in various ways they would be next to push engineering further, which, from students’ faces seemed to be received as an inspiring message.

Heisenberg *encouraged grit*: through teaching, stories, admonitions, and actions he stressed patience, persistence, hard work, self-discipline, and self-sacrifice. As an example, stories he told in small groups often stressed the need for hard work and self-sacrifice. After he commiserated with a few students about the workload, for example, he gave an assessment of the road ahead: “The bad news is that it gets worse. Third year is not bad, fourth year is (pulls an unpleasant face) and then you go to work and it’s like this times two. (shocked looks) Welcome to engineering!” He also told stories about his own engineering experiences in the field and how difficult, interesting, and rewarding they were. He encouraged and rewarded hardworking students who had the right attitude and did not pass on undeserved favours. In one interaction, he was rewarding a hardworking team with hints. When he saw someone from another team listening, he flatly told them "Go away!" Heisenberg explained the student had not been working hard and was coming to steal ideas. Heisenberg believed in helping those who deserve it:

> I have to have the impression that they are trying, otherwise I can't help them because they can't help themselves. For example, if a team's circuit is not working and their oscilloscope is off, it's not a good thing because they are not trying to diagnose the problem. (field notes)

Heisenberg saw himself as inhabiting a gatekeeper role, declaring that some students somehow get into the program but should not be there and so his duty is to prevent those who would not make good engineers from making it. He reported this as appropriate because there is too much at stake in the profession: technical ability; public, environmental, and social safety; and quality engineering work is the calling of this profession. For Heisenberg, grit was central to this calling.

5.2.2 Kelvin: Giving Students "Time at Sea"

As lead administrative instructor, Kelvin was responsible for teaching two sections of the course and managed the curricular change and administrative issues around Design I and Design II. He played a key role in troubleshooting any difficulties that occurred in the course, particularly disputes in the teams. Kelvin reported that a good way to characterize his approach to teaching related to an anecdote in the book "Surely, You're Joking, Mr. Feynman!" Kelvin reported that the famous theoretical physicist Richard Feynman was called in to guide a group of engineers in a troubleshooting session, but had neither the relevant disciplinary knowledge nor familiarity with the design to know what he was looking at. He started asking good questions that pushed the chief engineer to a realization and a solution. The implication for Kelvin was that good questions draw people to their own answers.

Typical student-Kelvin interactions are represented by the key categories and codes in Figure 14 and several examples are presented to illustrate these, beginning with the category of *encouraging independent problem solving*. Kelvin had a particular way of interacting with students when they asked technical questions or problems related to their projects or modules.

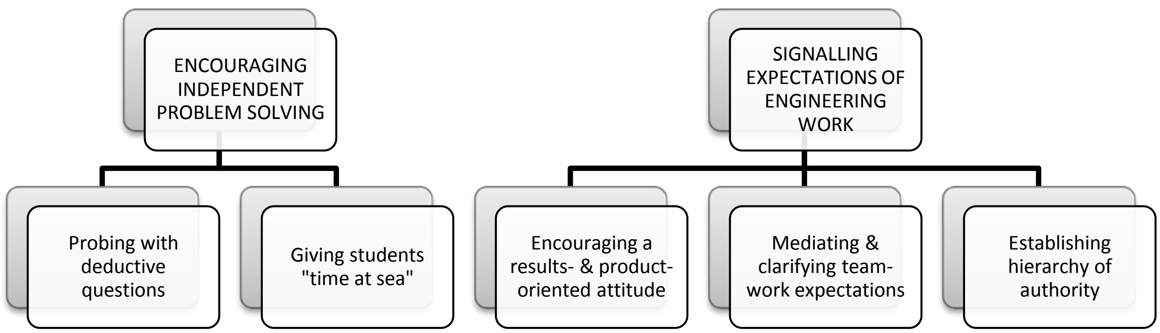

Figure 14. Patterns in Kelvin-Student Interactions

Firstly, he rarely gave direct answers or solved students' problems; consciously avoiding "coddling the student into getting the answer." He did this by *probing with deductive questions* so that they would think things through and explain. For example, a student asked what was wrong with the integrator output on the oscilloscope. Kelvin asked a series of questions:

So, what do you think is happening? (S: Is the voltage too big?) →

Too big for what? →

Try something: What happens when you increase this? →

Is that what you expected? →

Last Monday's lecture was about op amps. Can you recall that? (S: explains) →

Does that agree with what you're seeing here? →

What's happening here should be predictable with what you saw in lectures. (field notes)

Kelvin's use of such questioning techniques, observed frequently with students, were attempts to engage students in a thinking process for troubleshooting problems by relating what was happening with their circuits to what they were learning in the lectures.

The second major code related to *encouraging independent problem solving* was Kelvin's practice of *giving students "time at sea"*. This expression comes from observation of a small group session in the course Circuit Analysis I, in which students had to present their solutions to a TA orally in front of a group of their peers. When one student - standing up at the board with chalk in hand - drew a blank, Kelvin noted quietly to me that TAs were instructed to "give students time at sea" (i.e., leave them alone, unsaved) when they were having difficulties. He went on to explain that such experiences in all classes were critical for inculcating independence in students, which would have the effect of them developing their own thinking about the problem instead of waiting for the correct answer. This was an explicit technique of his teaching: in the labs, Kelvin also asked students to hold off asking questions until they had enough wait time (minimum 15 minutes) so that they would find the answers among their peers or work it out themselves. Although attentive to students in the lab, Kelvin's body language and communication style were reported by some students as hard to read. Businesslike rather than unfriendly, Kelvin tended not to engage students through their diagrams, equipment, and projects, but hung back and asked questions, thus placing the onus on students to come up with something. This approach contrasted with Heisenberg, who tended to jump in, pick up, and examine students' projects or modules, and using the tools, equipment, and diagrams available to engage students physically in finding answers. Unlike Heisenberg, Kelvin tended not to follow up with confirmatory or disconfirmatory feedback such as "You're on the right track!" or "No, think again!” Students were often observed being left by Kelvin with more specific questions and a hint of a way forward.

Kelvin did not save students. In one case, Kelvin was asked basic questions about module 3 on the day before the student was going to demonstration. He mumbled something and walked off. I later asked “I guess he has to figure it out for himself?” Kelvin responded: “Yes. I pretty much give them what they need, but I don’t like it when they come up at the end of the module and ask basic questions.” Later, Kelvin gave a team of students starting module 4 substantial help because they were engaged and proactive, unlike the student working on module 3. Kelvin did not respond emotionally to students’ stress or commiserate with them at all, but probed, asked questions, and suggested an approach, leaving them to work it out by themselves.

The second major category describing the nature of Kelvin’s-students interactions is *signaling expectations of engineering work*. Firstly, Kelvin *encouraged a results- and product-oriented attitude* towards modules and projects. Kelvin usually began project evaluations, saying “Show us what you’ve got!” Students whose teams had failed to produce a fully functioning design often began demonstrations by explaining the basis for their design, identifying the problems that they had encountered making it, and how the project ended up as it did. In such cases, Kelvin was often observed cutting students off: “More demo, less talk.” or “No, no, no, just demo.” In doing so, he signaled an attitude that could be described as “it either works or it doesn’t.” In one case, a team had no functioning design and Kelvin rejected their offer to explain it. In another case, a team tried to fake their way through the demonstration with what they had. Kelvin called them on it multiple times: “It’s up to you to show us. We can’t guess what you’re doing. You have to tell us what you’re doing”, “No, it doesn’t look like an integrator”, “So this is trial and error? No analysis?”, and “Again, what else? It’s up to you guys to demo something to us." A TA added: "So, supposing you're going to sell this to someone, so you say 'It works sometimes? How much do you want to pay for it?' Really?" Kelvin was consistently civil but tended to be cut-and-dry when teams failed to come up with something.

Kelvin took an active role in *mediating and clarifying teamwork expectations,* particularly when teams were in crisis. A small percentage of teams ran into conflict usually because of ineffective communication, lack of effective work delegation, unequal work distribution, unmet promises, late project starts, and minor enmities that ran out of control. Student reports suggest that Kelvin effectively mediated multiple disputes over the two terms through private meetings with teams and individuals and, in doing so, clarified students' expectations and responsibilities in teamwork. Such meetings were behind closed doors; however, Kelvin was observed in the lab, asking detailed questions of one team's practices and processes, summarizing what he was hearing back to students, asking whether they agreed with his assessment, and then suggesting they take specific actions. Many students appeared to have limited experience and awareness of good teamwork. This appeared to engage these students in reflecting on their teamwork practices. On multiple occasions Kelvin stressed that teams needed to "divide up the work so that you can all pass." In one of the major disputes of the term, Kelvin advised the team to communicate and delegate tasks on the next project so that everyone could get 100. Interestingly, some students saw these recommendations as revolutionary, which motivated one student to comment "Wow, that changed everything!" It was apparent in many cases that students had only rudimentary ideas about effective teamwork, which Kelvin, on occasion, had to remedy by intervening, mediating, and addressing expectations explicitly.

Finally, Kelvin's interactions helped to *establish hierarchy of authority* between the student teams and the instructors. One key example of this is the pattern Kelvin reinforced with students though his instructions, the TAs, and lab technician: “If you don’t know, first ask your classmates, then ask the TAs, and lastly ask me.” This was designed to foster independence and efficiency; however, it also signified the hierarchy of information flow in the context and signified that students needed to think and formulate ideas carefully before approaching their TAs and instructors for assistance. Kelvin’s manner of conducting demonstrations of projects also appeared to place many students into the position of having to perform for a boss of sorts. Kelvin, unlike Heisenberg, did little to defuse this power differential:

> Kelvin and the TAs begin the demo/evaluation, but the team is not settled. One person seems to be in charge with an assistant on the left and other teammates crowding out this very tight space between the benches. They are not ready and don’t look so confident: the two key people move in a harried manner with their hands moving fast and furtively as they set up, connect the breadboard up, pick through wires, get the equipment ready. Onlookers appear tired, nervous, breathing shallowly with their eyes wide open and unblinking. Only the voltmeter is working, inaccurately, and after several minutes of discussions, the lead person shifts into a verbal mode, appealing to the evaluators with explanation: what they had planned to do, their process/ideas/concepts, what went wrong. Kelvin cuts him off, issuing a blunt time warning. They have nothing more to show. They get 4.5. (field notes)

5.3 Student-Student Interactions

The section describes the student-student interactions in Design I and Design II. As noted in Section 4.10.1, a decision was made with respect to student-student interactions to provide a broad-brush descriptive portrait of the range of student-student interactions observed at the data site rather than inductively code data as in Section 5.2. The focus of this portrait invites a discussion of the factors in the environment that indirectly shape interactions (Section 5.4.1) followed by a description of the general range of student-student interactions at the site (Section 5.4.2).

5.3.1 The General Movement of Students

The program workload and the scheduling and organization of Design I and Design II made labs ‘porous’ to people and schoolwork from other sections and courses, almost to the point of being a semi-public space. With the exception of lecture, lab module, and project demonstration days, there were no scheduled activities during scheduled hours and very limited whole class communication. So, while two sets of two sections (about 140 people each) were scheduled into three lab periods per week, as the term wore on, students from any other sections started appearing in the labs to work on their projects, modules, and non-Design I/II schoolwork. In the labs, students were mostly highly engaged and on task during scheduled hours, with people sitting everywhere in various configurations (i.e., alone, in pairs, in teams) engaged in different kinds of work or standing and speaking with other individuals, teams, TAs, or instructors. Students were given 24/7 security access and many began spending substantial amounts of time in the lab during and after hours. During this time and, to some extent during scheduled hours, friends, boyfriends, girlfriends, and partners joined the regular inhabitants. A fair amount of non-Design I work also diffused into the labs and they became a busy hive of activity during and after scheduled hours, particularly before module and project demonstrations. Sometimes labs became so packed that the instructors gave access to other labs for students to work after hours and overnight. Labs at these times remained full late into the night or the next morning when there were projects and modules – at these times there was a lot of socializing and a wider range of on and off task behaviour. Labs were sparsely populated or empty during lulls in the term when they had cleared off their work and were busy on other courses.

The two weekly one-hour lectures were the other formal sites of learning. Some movement of students occurred here as teams and individuals scheduled for a specific lecture chose to attend during the other slot due to scheduling or instructor preferences. There were also multiple informal and non-formal sites of learning where students met during different points in the week, module, or project. Teams in a conceptual stage of the design process, between project tasks, on break, at a crossroads or cross purposes, or in report writing mode after the demonstration often took their discussions and work to the 3rd floor study-project rooms, coffee shops, the student union building, buses, and homes.

Heisenberg effectively captured how student-student interactions changed over the term:

> At the beginning of the year about 15% of students will interact with other groups if there is a problem. This is quite a low percentage, but it's because they don't really know each other. At the end of the year, the students will mill around other groups to find out what they know and will send out spies to other groups to get information and material. They tend to send out female team members to other teams to see what is going on. On the other hand, some students and teams remain alone for a long time because they don't ask questions. Some students are like pieces of furniture (grabs one of the benches and makes a motion like he is shaking it and that it remains unmoving). These students are hard to detect, so I have to watch them and encourage them to communicate more. (field notes)

By the end of the fall term, most students had forged some kind of network through building projects and modules in a way that went beyond the kind of collaboration seen in traditional lecture based classes: they became networked to other students in and beyond the team, section, or class. Many reported valuing their networks as necessary for survival.

5.3.2 A Spectrum of Student-Student Interactions

Students in teams acted, interacted with, contributed to, and detracted from the team and the project in particular, multifarious, and unpredictable ways. Observation of students' behaviour suggested that they had varying levels of awareness that survival, success, and wellbeing in the course were linked to their collective contributions to their team and to networks beyond team and project. They contributed to their particular localized networks of students to varying ways to varying effects. A tension frequently observed in teams was between individual and collective orientations towards work. Some teams were observed doing a substantial amount of work to help each other: peer teaching, assisting team mates in carrying out related/unrelated tasks, assuming and completing others' tasks, giving feedback, and managing each others' emotions. Others teams had difficulties due to such factors as a lack of planning, ineffective time management, poor task delegation and role distribution, insufficient effort, knowledge, or ability, personal enmities, marginalization, and a lack of social cohesion or team spirit.

Teams had unique, emergent, and dynamic local cultures and practices that inevitably involved role distribution, spoken or unspoken rules, and a cultural and emotional team life. The distribution of knowledge in and beyond the group and the need to delegate tasks required a modicum of social organization, leadership, and task delegation. Certain students became team leaders or recognized as locally constructed experts of one kind or another. Demonstrated and perceived technical knowledge and skills were often a decisive factor that conferred leadership on some and followership on others. Leadership roles were also conferred to students by teams based on evidence of connecting to family members or friends in technical professions (e.g., engineers, scientists, tradespeople) or, alternately, personal charisma combined with professional and communicative skills and some technical knowledge.

As an example, in the course of the research, an informant in one team identified that neither he nor four other teammates had assumed any kind of leadership and had little confidence in their technical abilities. The sixth student had a father with a PhD in electrical engineering and claimed the technical leadership role in the group, saying that his father would design project 1 for them so they could just build it at their leisure and get a perfect score. The other team members surrendered their power to this student, with one commenting that "He is the son of an engineer!” and someone they trusted. They waited for the design to come by email from the father in California. Once built, the project failed to function perhaps because of the design or their lack of skill in building and testing it. The instructors were aware of students gaming the system in this manner and in the downfalls of both poor leadership and poor followership. Kelvin noted the worst thing for a team was having a charismatic leader with poor knowledge and the second worst thing was a knowledgeable leader who stole other students’ opportunities to learn because they provided the answers or an easy way out, which tended to remove opportunities for others to grapple with the project challenges.

Many students suffered in other ways because of interpersonal conflicts, mismatched work ethics, different levels of technical ability, and differing levels of dedication on the projects, which resulted in a number of team conflicts. Kelvin, who mediated in these conflicts, noted that only about 1 in 15 teams each term had problems that led to irreconcilable differences. Episodes of aggressive confrontation on the one hand and touching camaraderie and elation on the other – and everything in between – were observed through the year. In one team, following a poor showing on a demonstration a student publicly blew up at his teammates because they had done a poor job and did not want to redo the work to improve their marks. He was in danger of failing and needed the marks:

> He shouts suddenly to all in the lab: “You guys went against me again!” The other students don’t respond and immediately begin to turn off the equipment and collect their stuff. All the teammates’ faces are unhappy and tense: they are nervous and fidget, turning their bodies away and gathering their things. They had a poor demonstration and Kelvin offered them a chance to redo it, something they had just voted down by blind ballot. He shouts again: “You guys went against me again! We got a double whammy on marks!” The other students just walk out without saying anything. I find out later that the angry student was worried about getting enough marks because it was his second time around on this course. (The team lived with this conflict for the rest of the term and quietly broke up as Design II started.) (field notes)

On the other side of the spectrum were irrepressible displays of happiness and fellowship when teams did well, particularly when stress or uncertainty about the success of the projects was rife:

> On the night before the demonstration just around 11 p.m., the team next to ours get their project fully functional and suddenly all literally jump for joy shouting multiple times "We're going home!" One of the guys in the team (the guy who swears profusely) bellows and shakes like a professional football player after a touchdown, and his friend chucks him a bag of cookies. As the clock moves towards midnight, there are increasingly boisterous displays of camaraderie - one student singing Journey's *Don't stop believing* in a *castrato* singing voice to the delight of his friends - and some students who normally keep it in English default to their mother tongue. People are tired, it's getting late and people release stress: the cumulative pressure seems to put people through various states of mind and heart: tension, quiet work, lightheartedness, bellicose humour and release. Staying til 2 a.m. in closed, cramped quarters results in some interesting reactions and visibly deepening ties between students. (field notes)

Working together appeared to encourage camaraderie through the long hours struggling together in a very difficult program. Most students were forced to make sacrifices in their lives to do well in the program, which often entailed cutting out the pleasures that they had become accustomed to. Adversity was often observed to be a source of camaraderie between students:

> Jolene, a female American student from Colorado blurts out: "I need more friends in engineering. I just come here and end up feeling miserable. I'm miserable when I leave here." The student beside her, an Asian Canadian woman, begins comparing the lives of students in physics and chemistry and saying that engineers work far harder: "It's not like they're not working hard. They are. The arts students are totally free and I see them going out but I know that we're going out on Wednesday night and so we can't go out on Saturday night." Jolene agrees: "I want to do something more with my time that's not just circuits or programs. I was in a Ska band in high school and it was awesome. We've got to go, ignore this workload, listen to music, and drink our faces off. If I accept how much workload we have, I'm going to lose it. I feel like I'm constantly going in and out of a coma–I have to ignore everything. I can't stand the walls in this room. I spend so many hours here than I do in any other place." The woman beside her nods and comments in agreement but lets Jolene continue: "My alarm clock goes off in the morning and I wonder what I'm getting up to do. It scares me because I can do this for a week or so and I don't know if I could do this all my life. This is my battle! I feel so isolated. Sometimes the engineering mind bothers me. What you have to do is problem solve. That's not realistic. Life is not always like that. You know? If money weren't a problem, I would do some kind of NGO music thing. I know I have the work ethic to be here, but I'm not sure if I want to." The woman beside her is listening and nodding and encouraging her to go on. Then she invites Jolene out: "We should just meet up. I live in Fairview." (field notes)

By observing and talking to many engineering students, most understood that they were attempting something very challenging and difficult. Many used phrases like “signing up for this”, “jumping into the deep end”, “going to boot camp”, and so on to describe the difficult challenge they were deliberately undertaking. For many students, the team-based projects were distinctive compared to traditional modes of study. Many students liked and appreciated the ties team-based projects brought with other students. An example is this short exchange that illustrates how difficulty followed by success forges relationships:

Researcher:	How’s it going?
Don:	It’s better than project 1 when we had 2, 3 bosses that just blasted through, went too far.
Researcher:	Do you think teams should divide up the work more?
Don:	Yeah, it’s always the case that two or three people out of the team are the ones that are doing the work and the rest are observing.
Researcher:	Really?
Don:	Yes, I and the other guys didn’t do much – we just sat there and said ‘You want another resistor? Here you go.’ and then we just sat around.
Researcher:	How is it different this time?
Don:	We divided up the work – you do this, you do that.
Researcher:	Did you make a schedule?
Don:	No, that’s too difficult, but now people feel more responsible for their work, which was better than project 1.
Researcher:	If you had to do it again, would you choose to work alone?
Don:	It depends on the size of the project. Large groups may be difficult, but there’s also the moment when you hook everything up and it works. It’s like “Group hug!”
Researcher:	Yes, I guess teams are really good when they’re good…
Don:	…and bad when they’re bad. (Both laugh) (field notes, audio recording)

Being in the deep end, marshaling resources, being persistent, and sacrificing together resulted for many in successful projects. Students appeared to develop a disposition towards collaboration and hard work and an appreciation for their peers, with whom they felt unique bonds. A drawing found in a project room and approved for this thesis by the engineer artists shows what emerged from one team’s experience (Figure 15).

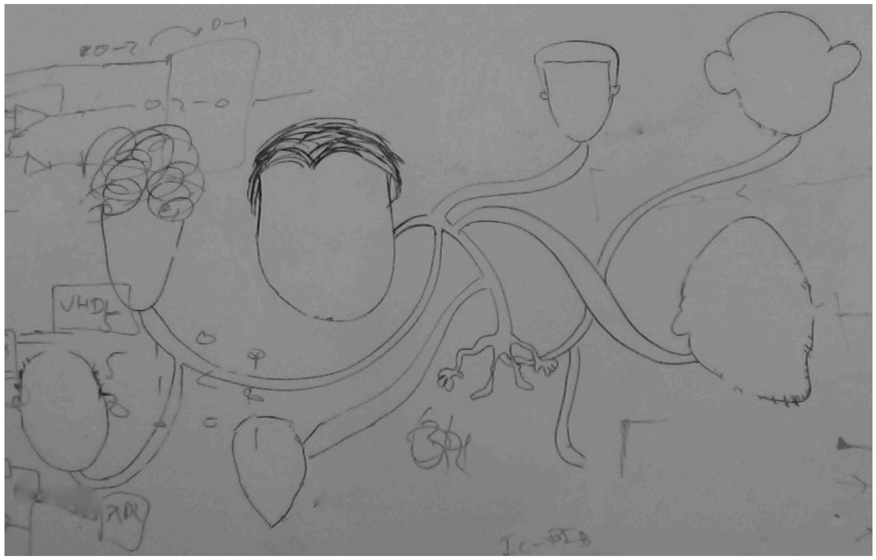

Figure 15. Found Engineering Art in a Project Room – A Unity of Seven Minds?

5.4 Student-Tool Interactions

The transition into project work in second year is the first formal opportunity for students to work with tools, electronic components and parts, materials, electrical and mechanical equipment, and electricity to produce things that work. This transition represents a dramatic shift in students' mode of study because most students had experienced an almost exclusively traditional lecture-based approach to math and science until second year. Yet, few had practical hands-on experience with electronics or other industrial arts. From his many years of teaching undergraduate students, Heisenberg estimated that 70% of students had little or no hands-on experience at all.

The layout and size of the labs - where many students were getting their baptism in engineering design - and the small, bench-top scale of the projects placed large numbers of students in close proximity to each other for extended periods of time. The physical projects and modules, tools, components, and equipment and the diagrams, sketches, lab books, and files on computers drew students into small regions of focus on the often cluttered and messy workbenches. Students’ communication and interaction was observed to often occurred in relation to - and through - these objects and semiotic tools. While in the lab, students came together in tight, enclosed spaces in configurations, which shifted between working alone, in pairs, and in or between teams. For the most part, students engaged in activities such as working away jointly or alone on breadboards or solder boards, looking component data sheets up on computers, drawing circuit diagrams, completing lab books, doing calculations, or having short discussions. In the lab, when students worked alone and were on task, they appeared busy and focused and tended not to break off and talk to others. Long periods of time could pass without any interaction.

Physical tasks in the labs were small-scale, delicate, and required precision: it was picky, detailed work. When two or three students were building or testing circuits on breadboards or solder boards, they naturally tended to work in unison, monitoring others’ actions and positioning and moving themselves in relation to the task at hand. Hands and bodies worked in concert, adjusting to each other in carrying out operations, usually with verbal communication limited to short exchanges related to the operation (Figure 16). Depending on the modularity of a given activity (i.e., the extent to which tasks could be separated out and delegated) centres of focus tended to emerge around recognized technical leaders of the team. Often, these leaders would sit in the inner circle with project, working on its critical or core parts with less central team mates commenting, making small talk, remaining silent, doing auxiliary support, looking at their computers, working on less critical project tasks, or just being off-task.

Figure 16. Four Students Working in Close Concert on a Soldering Job

The project requirements, modularity and the location of the knowledge to do the project significant shaped how the team handled project tasks. Projects required a substantial amount of work, making task delegation a necessity through its research, conceptual, design, build, and test stages so that students could work in parallel on different parts, which would be integrated later. Knowledge was distributed in a complex network of instructors, TAs, students, and documents within, between, and outside teams. The extent to which a team gathered this knowledge potential to produce a functioning project depended on the local conditions and the relevant actors in and around the team. The task, material, distribution of knowledge and skills, and by extension, roles on projects fused together in interesting and varied ways.

5.5 Student-Assessment Interactions

Given the high workload in the program, students had a chronic lack of time and reported grappling with time and mark constraints so as to balance their goal of passing and their other needs. Students were observed routinely discussing the lack of time and the excessive workload such as the number of hours of sleep had, their physical condition, time estimates to complete assignments, how to navigate assignments to maximize return, and the minutia of workloads and due dates, etc. One student complained “We barely have any time to think - you just have to do it in a short time, you just get through it.” The workload was shockingly high at times. After a team’s project 1 demonstration, I commented to a student that now he could go to sleep. He replied wearily that he had three more assignments due that day. As another example, I also began teaching myself Design I module 1 using a kit I had bought. While working on it one day, a student asked how it was going. I said it was coming along but I was far behind him on the modules. He drew a distinction between us: “Yes, but you don’t have deadlines, though.” Marks and time substantially conditioned students’ actions on projects and modules. As noted in Chapter 1, 65% and 35% of the course marks were allotted for the projects and modules respectively. The project was assessed according to a rubric (Table 14) and Heisenberg and Kelvin began *The 85% Rule*, meaning that if teams met requirements, they would get 85%. Additional marks up to 100% were given if team projects had additional functionality that exceeded project requirements. However, the marking scheme did not specify how many marks would be lost for missing project requirements or how many marks above 85% students would garner for which extra features. The seven modules in each course were evaluated by teaching assistants with the support and advice of instructors for a total of 35%. Marks out of 10 for each module were given based on student pair demonstrations, student explanation of key concepts, and quality of their lab books.

Heisenberg and Kelvin noted that it was quite difficult to fail the course, since doing the more scripted or cookbook modules perfectly would garner students 35%.

Table 14. Assessment Rubric for Projects

Mark	The project is:
10	Exceptional, did everything it was supposed to do well, plus some additional functionality. The project looks great and it has original/innovative ideas!
9.0-9.5	Did everything required. Circuitry / project well designed and constructed. It could use a little improvement. The project has some original/innovative ideas.
8.0-8.5	Did everything required, lesser quality but still worked. The project lacks originality/innovation.
7.0-7.5	Mostly worked, not entirely, not the greatest design.
6.0-6.5	Didn't really work, ok design but didn't really come together.
4.5-5.5	Didn't work, not very good design.
0.5-4.0	Didn’t work, poor design.
0	What project?

The knowledge from modules was purposely linked to the projects and so doing well on modules raised students’ chances of doing well on projects. Projects 1 and 2 were worth 30% and 35%, respectively, 5% of which was for the formal project report. Another factor that affected a student’s mark was the peer evaluation at the end of each project in which team members had to negotiate, agree on, and report the division of project marks between team members, which was a potential source of stress for teams with unequal work distribution. Project marks below 4 out of 10 (40%) were a rarity in Design I and Design II, and so it was inevitable that a large majority of people, even if rated poorly by their teammates, would make it through.

Students were sometimes confused on how to interpret the assessment criteria and mark weightings for project requirements, something that affected students and teams aiming above 85% or those who fell below it. Heisenberg explained that he had been using *The 85% Rule* for three to four years and found it an effective way of setting the bar for students and motivating them to work hard and think outside the box. Yet, integrating extra features into the design to get more than 85% could be time-consuming and risky: students had to interpret what qualified as extra features, time invested was not guaranteed to pay off, and as Kelvin noted “extra features can screw up what’s working”. On the first point, when one student asked point blank how he could get these extra marks, Heisenberg replied “Surprise me!” Having built working Design I project exemplars with all of the possible additional functionality he could think of, Heisenberg was clear in his own mind about the specific possibilities for a given project, but left students to figure out which additional features would garner marks. A few groups of students responded creatively and came up with an impressive array of extra features. Yet, others failed to properly interpret what comprised additional functionality, mistaking such things as good circuitry, fancy boxes, alarms of dubious function, or flashy but inefficient mechanical designs (Design II projects) as contenders for extra marks. While the instructors did hint or sometimes clarify, students were, for the most part, expected to think through what qualified and what did not and then make their own decisions.

On the underside of 85%, many students were unable to clearly interpret and prioritize which project requirements were optional, which ones were essential, and which of the others was low, medium, and high priority. This caused stress in teams who had time management problems and partly functioning or non-functioning projects in the run up to the project demonstrations and were attempting to decide the best course of action. Some student sought direct clarification and others were observed passing around second and third hand information. As an example, students discussed whether or not soldering Design I project 2 (a project requirement) in the 11^{th} hour would result in a fail on demonstration day or not. Some did not want to risk transferring and soldering their projects because of “horror stories” of projects ceasing to function. This uncertainty caused stress for some students. Students were also aware of inconsistencies in the marking of modules between teaching assistants, leading some to choose module demonstration times so as to be evaluated by what they called “easy” TAs.

Instructors and students alike were aware of a cost-benefit calculation with respect to marks, effort, and time, which also extended to eating, sleeping, leisure time, and stress. Heisenberg specifically identified the dynamic: “There is a benefit versus effort relationship here which all students have to navigate – sometimes students come to recognize this time-marks relationship and have to find their own balance.” Navigating the program and achieving this balance required students to factor in the substantial workload in the program and their own personal and health commitments, something that put a strain on many students.

Some students were highly and vocally mark-conscious, something evidenced during interviews and chats by comments such as “my biggest priority is to get a good mark” or “I treat marks like money.” This orientation to marks led some students on one end of the spectrum to quibble over small discrepancies in scores, take the attitude that they would only do school work for marks, game the system, and/or spend time speculating and calculating how to maximize return for the time and effort. On the other end of the spectrum many students saw intrinsic value in the projects and prioritized marks less, did not care, or placed their main priorities elsewhere. As an example, one group with a particularly relaxed attitude towards marks had a particularly poor showing on a module but was not bothered: “That's all part of the learning experience.”

5.6 Students "Cracking"

Anecdotes on how cumulative pressure affected students are presented here to suggest that although binary interactions can be analyzed (e.g., student-instructor) or described (student-student, student-tool, student-assessment), their effects on students' engineering dispositions and thinking are not easily predicted by summing up the parts. Complex, cumulative effects of interactions among the elements in the environment need to be considered, requiring a move beyond the general portrait presented in this chapter.

Most engineering students recognized that staying in the program requires hard work and self-sacrifice. Students endured long workloads with individual life conditions and personal capacities that constrained and afforded their ability maintain their wellbeing. The language of discipline, of being tough, and of sacrificing was heard frequently: students had "signed up" and had to "suck it up", "man up", and "take the pressure". The demands of the program placed pressure on many students to sacrifice biological needs such as sleep and food and eliminate other distractions in their lives. For example, many students reported forgetting to eat, skipping meals, or giving up sleep during times of high workload because they were too busy working. An iconic example of sacrificing biological needs in engineering is "the all-nighter", which many students endured in order to finish and demonstrate their projects. An estimated 50% of teams pulled all-nighters for the first project and many wore it as a badge of honour. At the end of a project the night before demonstrations, more than half of students were facing an all-nighter. Someone had written a message in the middle of the night: "Sleep is for the WEAK" (Figure 17). Later, others responded, writing, "I am weak" and "I wish I was weak", which stayed up until morning. By the end of demonstrations, the admonition about self-discipline changed to a reward

(Figure 18): “Sleep for the WEEK.” “I am weak” had been erased. This is certainly a culture of self-discipline and rewards.

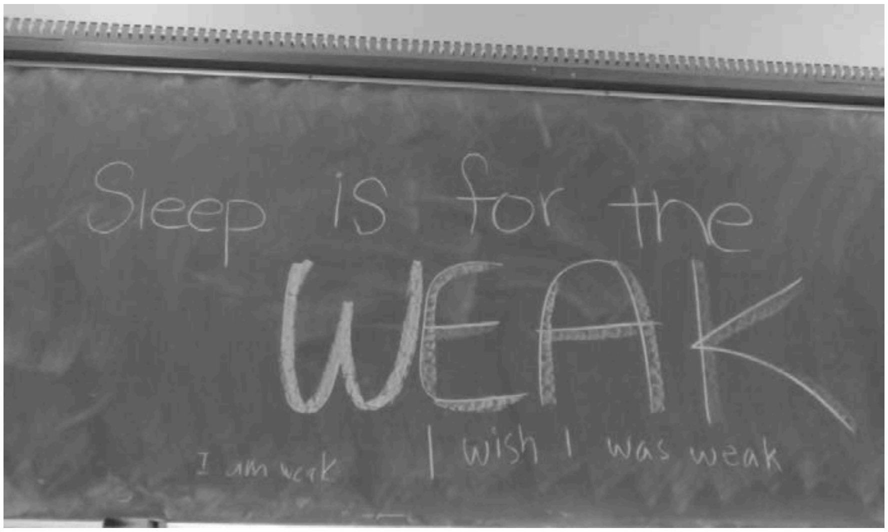

Figure 17. Graffiti the Night Before the Project 1 Demonstration in Lab 322

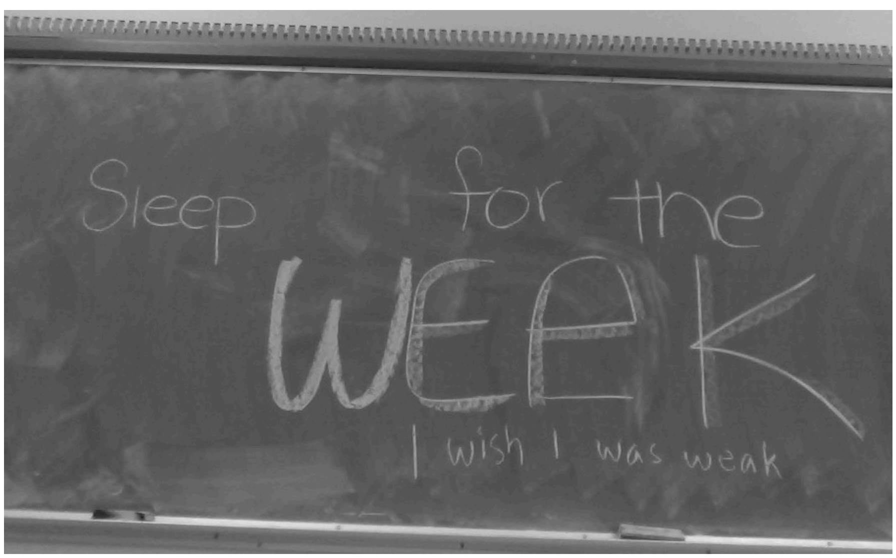

Figure 18. Graffiti After Project 1 Demonstrations in Lab 322

Students expressed to me on dozens of occasions their response to such pressure and to explain the cumulative toll it was taking on them. Edward (a Malaysian international student) and Nancy (an Iranian immigrant student) in Figure 19 spontaneously gushed their frustration to me about their struggles. I anonymously related Edward's story and a second story about an Indonesian student who was coping well to an instructor, asking for a comment. He said that engineering is a "rite of passage", that some people "crack", and that "the young ones and older ones with experience do better".

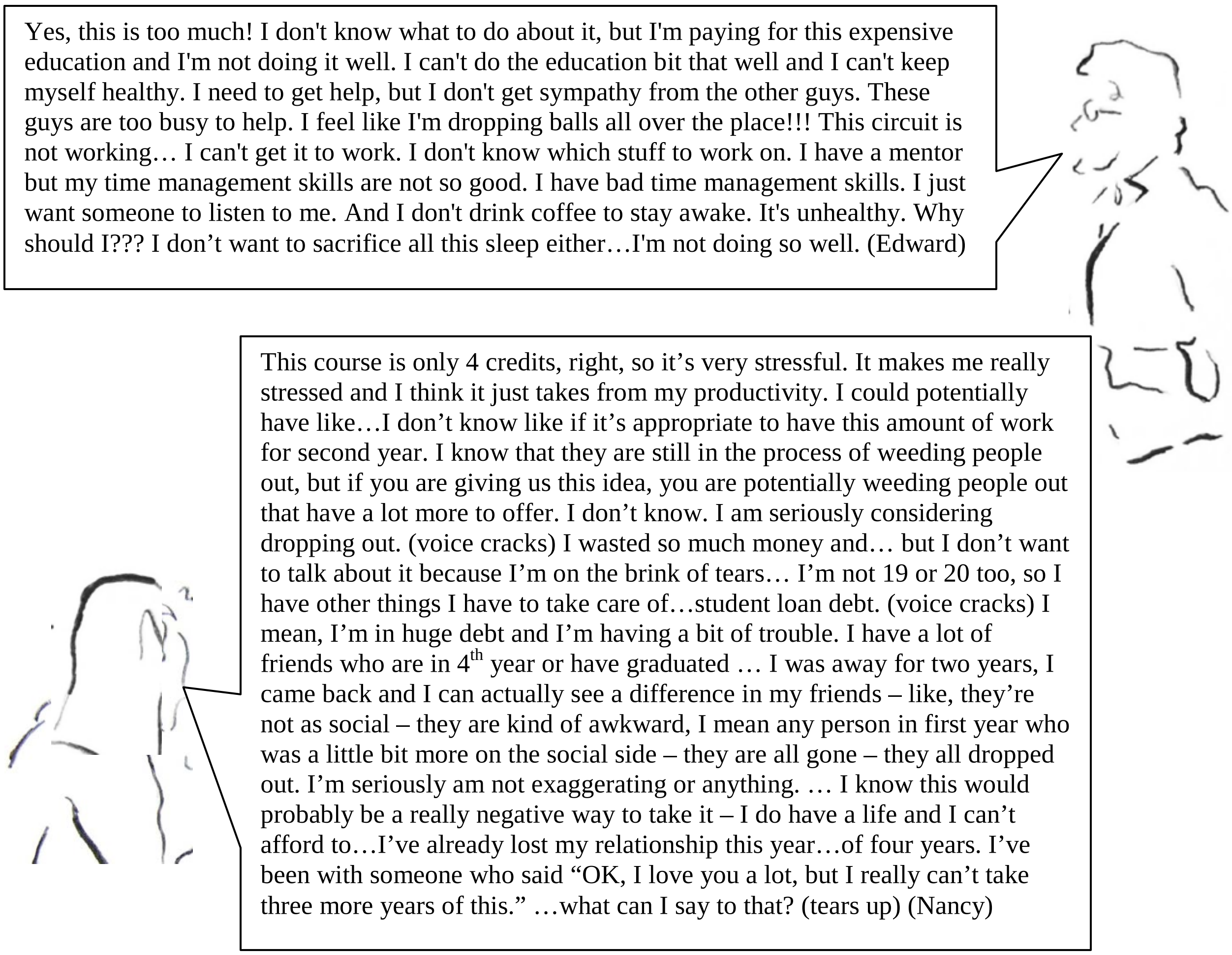

Figure 19. Students "Cracking"

When asked what students take away from the pressure of the engineering program, he replied "basics and a way of thinking." Of the three students (Jolene, Edward, Nancy) who "cracked" and volunteered their stories (Section 5.3.2, 5.7), only Jolene and Edward persevered until fourth year. Jolene was in her last year at the time of writing, Edward took up a capella and began performed at student venues as an outlet. Nancy quit a week later and was never heard from again.

5.7 Summary of Findings

The foregoing portrait has provided an overview of the research setting so as to place the main findings, to be presented in Chapter 6, into ethnographic context. The findings in Table 15 address the first guiding research question with respect to the general student-instructor, student-student, student-tool, and student-assessment interactions observed in the field. They also identify the knowledge - in terms of engineering dispositions and thinking - that these interactions appear to foster and hinder. These findings are not presented here as determining of how a given student will evolve over time. Being that they are in the same environment, it is possible that students may experience similar interactions themselves and their orienting effects on how they evolve. However, it is not self-evident that students will be shaped by these in a uniform manner given complex and contingent nature of the activity around these projects. What this portrait provides is an image of understanding of what might emerge as engineering disciplinary learning culture in the second year projects. Nuanced accounts of the evolution of culturally diverse students engineering dispositions and thinking are now presented in Chapter 6 in the form of trajectories.

Table 15. Summary of Nature of Interactions and Knowledge They Foster and Hinder

Interaction type	What is the nature of _______ interactions in an engineering design course?	What knowledge do these interactions foster and hinder? (dispositions & thinking)
Student-instructor: Heisenberg	**Roles** Craftsperson-apprentice **Mode** Hands-on, diagnostic **Tone** Optimistic, interactive, talkative **Comment** Tended to advise explicitly how to do things better; sought when students needed to get technically unstuck	Being careful, methodical, detail-oriented Adopting troubleshooting approaches Having ‘hard prototyping’ skills (circuitry) Focusing on basic functionality Communicating ideas orally, professionally Being technically curious, optimistic Having grit, being invested
Student-instructor: Kelvin	**Roles** Boss-employee **Mode** Deductive, questioning, hands-off **Tone** Businesslike, quietly objective **Comment** Tended to leave students with questions & ‘time at sea’; sought when teams conflicts needed to get ‘unstuck’	Deducing problems from first principles Being independent: ‘No one will rescue me’ Being results orientated Pulling your weight in the team Communicating effectively Recognizing hierarchy
Student-student	Wide spectrum: not generalizable Labs/workload: frequent, sustained contact Majority in close collaboration by term end Level of buy-in/backup in team varies Frequent workload, school, techie/geek talk	Tendency to value teamwork Tendency to value camaraderie under stress Awareness collaboration means survival Technical knowledge/access confers status
Student-tool	Most having 1^{st} design/build/test experience Close, sustained contact with project/tools Projects mean periods of non-interaction Project requirements necessitates delegation	Technical, hands-on skill confers status Comfort with tool-mediated communication Extroversion not necessarily required Comfort with distributed knowledge
Student-assessment	High workload (multiple assessment daily) Confusion/guesswork expectations Marks/time/resources balancing act	Tendency towards ‘just getting it done’ Tendency towards uncertainty avoidance Tendency towards calculating cost-benefit

Chapter 6: Findings - Evolution in Engineering Dispositions and Thinking

6.1 Introduction

This chapter addresses the main research question: How do the engineering dispositions and thinking of culturally diverse students evolve through their experiences in the second year of an electrical and computer engineering program? As noted in Section 1.3, investigation of this main question was guided by the following questions:

- What is the nature of the student-instructor, student-student, student-tool, student-assessment interactions in engineering design courses? What knowledge do these interactions foster and hinder?
- How do students and instructors perceive the evolution of engineering dispositions and thinking in students over the duration of the engineering design courses?
- How do engineering dispositions and thinking in students in a team evolve over the duration of the courses?

As discussed in Section 5.1, the main findings in this study (Chapter 6) focus on five culturally diverse students in one engineering design project team in the second year of an electrical and computer engineering program. The purpose of Chapter 5 was to present an ethnographic portrait of the research site and to reveal the general nature of interactions there in order to contextualize the main findings of Chapter 6. Chapter 5 also served to partially answer the first guiding research question above for the general milieu observed at the research site.

The main findings in this Chapter focus on the evolution of five culturally diverse students' engineering dispositions and thinking - how they evolve and what change occurs - as a result of enculturating influence of interactions in the same team working on engineering design projects. As was discussed in Sections 3.4.3 and 4.2.5, these are presented as trajectories, which are theoretically framed, interpreted, and presented using the hybrid activity theory framework of Roth (2009). Roth's framework allows for a distinct focus on the student within complex activity and lends itself to the requirements of ethnographic accounts and their concern with integrity in representation (Section 4.2.5). Given Roth's hybrid activity theory framework and the requirements of ethnographic representation, the three guiding questions must necessarily be viewed as subsumed under the main research question and not addressed independently.

This chapter focuses on the evolution of five culturally diverse students' engineering dispositions and thinking over the course of six months in the form of trajectories. As noted, these trajectories are accounts of the effects of enculturation processes that occur through interactions within the environment on students. Recalling Grusec and Hastings (2014), the term enculturation processes is defined as those forces, deliberate or not, in a given network of influences that limit, direct, and shape an individual. These result in the individual having greater competence in the language, rituals, and values of the culture in which they are immersed. The portrait in Chapter 5 has illustrated some general interactions as examples of "those forces" (Grusec and Hastings) in the team-based design courses (e.g., student-instructor interactions in Section 5.2). This chapter focuses closely on how such forces affected five culturally diverse students over time.

A five-stage process of evolution, articulated in the hybrid activity theory framework of Roth (2009), was employed in the analysis and structuring of the five culturally diverse students' trajectories. As discussed in Sections 3.4 and 4.9.2, evolution in activity theory is conceived as a process by which inner contradictions (tensions) within individuals engendered through participation as an integral part of activity become manifest as emergent incremental changes that accumulate and become newly dominant (Leont′ev, 1978; Holzkamp, 2013). The full accounts of the five student trajectories that follow in Sections 6.2 to 6.6 are necessarily highly descriptive and supported by rich quotes and excerpts. Given their length, a guide is provided to understand how the findings are presented. First, each trajectory begins with a summary and visual representation of the key aspects of the student's evolution and the change in their dispositions and thinking. Second, each student trajectory begins with a quote or observation that captures some essence of the student in the activity. Third, each of the five trajectories – framed and interpreted by Roth's (2009) five-stage hybrid activity theoretical framework (Section 3.4.3) - is presented in stages. The remaining part of this section (Section 6.1) serves as a reader's guide for the purposes of clarity. Sections 6.1.1 to 6.1.5 name and describe Roth's (2009) five stages, the sources of data for each stage, and illustrates key features of the accounts with reference to specific students. Details of the data analysis are in Section 4.9.2.

Section 6.7 presents the results of an additional level of analysis of the five student trajectories. These trajectories were considered side-by-side and key conditions critical for the evolution of culturally diverse students' engineering dispositions and thinking were defined. Evolution in these five students' engineering dispositions and thinking was manifest through:

1) Being willing to buy into working as part of a team
2) Being willing and able to claim a viable role as an engineer
3) Grappling with competing identities in becoming an engineer
4) Navigating different perspectives on engineering projects
5) Being able to self and co-regulate while under a complex, heavy workload

This means that within this overall activity system of the team-based engineering design courses, change in a culturally diverse student's engineering dispositions and thinking is influenced by their capacity to satisfy these five conditions. The findings presented in Section 6.7 will be fodder for the discussion in Chapter 7. Finally, a summary of findings for chapter 6 will be presented in Section 6.8.

6.1.1 Stage 1: Real Historical Conditions Relevant to (a Student's) Trajectory

First, there has to be a demonstration of the real-historical conditions of the preceding level within and upon which the quantitative functional change develops. (Roth, 2009, p. 11)

The *real historical conditions relevant to a student's trajectory* (Stage 1) are the substrate for change that existed previously: relevant aspects of students' backgrounds (e.g., academic, personal, familial), personal circumstances, and identifiable dispositions and thinking prior to their participation in the design courses. Stage 1 data were collected for each student during their first trajectory interview and through early informal conversations, observations, and audiovisual recordings. For example, the real historical conditions relevant to Jay are in the shaded box on the left of Figure 20 (Section 6.2.1).

6.1.2 Stage 2: Identifiable Changes in External Conditions Relevant to (a Student)

Second, it has to be shown that there were objective changes in the external conditions that allow the internal (i.e., inner) contradictions, which will give rise to the qualitatively new function, to have its equivalent in the external environment. (Roth, 2009, p. 11)

The *identifiable changes in external conditions relevant to* a given student are those that manifest in unique ways for them because they have shifted from a lecture and text-book based mode of science and math study in first year general engineering to a team-based design project mode of study. This study's focus on students from the start of second year ECE was intentional because it was a key transition in the program. Stage 2 data were collected for each student during their first interview and through observations, informal conversations, and audiovisual recordings in the field. Referring to Figure 20 (Section 6.2.1), the identifiable changes in external conditions relevant to Jay (e.g., increased academic demands; requirement to function more completely in English; requirement to collaborate with teammates; requirement to navigate a turbulent entry into teamwork because he was new to CU, arrived late in team Z5, and got sick) are found in the smaller non-shaded box on the left of the figure.

6.1.3 Stage 3: Emergence of New Dispositions and Thinking

Third, it behooves the analyst to articulate a functional turnover that relates the pre-existing dimensions in a new way, and thereby the evolution of the first qualitative change of the specific nature of the new function that makes the organism better adapted. (Roth, 2009, p. 11)

New engineering dispositions and thinking can be thought of as those that are "not-yet-dominant" (Roth, 2009). Changes in the student's external conditions (Stage 2) engender inner contradiction in individuals, which become manifest and make the student better adapted to the new conditions. Such emerging engineering dispositions and thinking begin to co-exist with now dominant ones. Stage 3 data were collected for each student during their second interview and through observations, informal conversations, and audiovisual recordings in the field.

Referring to Figure 20 (Section 6.2.1), the inner contradiction for Jay is identified in the small non-shaded box in the middle of the figure in the form of a question: How can I apply my technical talents in the most time-effective way in an inefficient and socially-oriented English speaking team to get an equal share of the marks? Referring again to Figure 20 (Section 6.2.1), only the key details related to the emergence of new engineering dispositions and thinking appear in the middle shaded box. For clarity, the specific engineering dispositions and thinking that emerged in Stage 3 are identified in the shaded box on the right for purposes of clarity and consistency, because not all students progressed to Stage 4 and Stage 5. The extent to which they took hold is indicated clearly by stage in the unshaded box on the right as: Stage 3 (emergent), Stage 4 (turnover), or Stage 5 (restructuring). Referring again to Figure 20 (Section 6.2.1), in Jay's case, these are: be technically proactive, mobilize skills and knowledge for team, be more reliable by prioritizing time for team, and be socially engaged. It is also clear that Jay progressed to Stage 4.

6.1.4 Stage 4: Turnover in Dominance

Fourth, a change in dominance must be demonstrated, whereby the previously dominant function is negated and the co-existing new function becomes the dominant one. (Roth, 2009, p. 12)

The stage *turnover in dominance* is when newly emergent dispositions and thinking, which co-existed with old forms in Stage 3, become dominant. In this research, this means that newly emergent engineering dispositions and thinking (e.g., new teamwork practices, habits of mind) that have become manifest as part of a student's participation in the projects with team Z5 become newly dominant. Stage 4 data were collected for each student during their second and third interviews and through observations, informal conversations, and audiovisual recordings in the field. Stages 4 and 5 were not always possible to establish, because a student left the team (Jay: Stage 4) or perhaps because change was slow or there was insufficient evidence to argue for another stage (Hyuna: Stage 3). Referring to Figure 25 (Section 6.6.1), Yao's new dispositions and thinking are listed in the shaded box on the right side of the figure. Again, the extent to which new dispositions and thinking took hold is indicated clearly by stage in the unshaded box on the right as: Stage 3 (emergent), Stage 4 (turnover), or Stage 5 (restructuring). In Jay's case (Section 6.2.1), Stage 4 was reached, but restructuring and a new trajectory (Stage 5) were not observed because he left the team in December 2012 and further observation was not possible.

6.1.5 Stage 5: Restructuring Process Leading to a New Trajectory

Fifth and finally, the analyst must demonstrate the restructuring process that gives the evolutionary trajectory of the system as a whole a new direction following the becoming dominant (function becoming) the system-sustaining determinant function. (Roth, 2009, p. 12)

The *restructuring process leading to a new trajectory* is when the newly dominant function completely replaces the old and the student takes on a new trajectory. The words new trajectory imply, of course, that evolution in a student's engineering dispositions and thinking is not a transition between two stable states, but is an ongoing evolutionary process without a final destination. Stage 5 data were collected for each student during their second and third interviews and through observations, informal conversations, and audiovisual recordings in the field. Stages 5 were not always possible to establish. As noted, Jay left the team and reached Stage 4, while Hyuna's engineering dispositions and thinking evolved slowly. She reached Stage 3, but there was insufficient evidence to argue that emergent change became dominant. Lee is an example of a student who reached this stage. Referring to the non-shaded box on the right of Figure 21 (Section 6.3.1), the general nature of the change for Lee was in coming to know himself as a quiet, engaged hands-on technical leader. The same box indicates that he reached Stage 5. The specific engineering dispositions and thinking appear in the large shaded box on the right (e.g., lead through technical knowledge, assess tradeoffs and compromise).

6.2 Jay – Buying Into Working as Part of a Team and Claiming a Viable Role

"Hyuna texted Jay that if he wanted, he could get the report started. He replied something. I can't remember: it's a bit lengthy. It's so unusual for him to have a lengthy text, so unusual. That was really rare. Hyuna didn't get what Jay was saying, then she showed the text to us. I didn't get what he was saying and then Tony. No one got what he was saying and then Tony said when he read it: "OK, he's totally not doing the report!" and we all laughed. It was so funny."

(Tia, interview 1)

6.2.1 Section Summary

This section gives an account of how Jay changed from working solo on individual tasks at the margins of the social and working life of a team to buying into working as part of a team, claiming a central technical role, and improving his social engagement (Figure 20). The real historical conditions relevant to Jay's trajectory (Stage 1) are that he:

1) had substantial hands-on electronics experience;
2) had studied advanced math and science in traditional mode in his Shanghai high school;
3) was used to the fairly undemanding study of the first year of his Engineering Transfer Program College (ETPC);
4) was able to get by academically in first year with limited English;
5) was new to CU and had a strong network of Chinese friends, with whom he lived and socialized;

6) preferred working alone so he could control his time; and
7) joined team Z5 late because of the integration pilot being run by ECE in Design I.

The identifiable changes in external conditions relevant to Jay relate to his move from an ESL-supported traditional math and science based first year engineering curriculum at ETPC to the far more demanding integrated second year curriculum at ECE, which involved team-based design projects. Specifically, Jay was challenged with the new requirements at CU (Stage 2):

1) meet increased academic demands;
2) function more completely in English;
3) collaborate with teammates;
4) navigate a turbulent entry into teamwork because he was new to CU, arrived late in team Z5, and got sick.

His inner contradiction can be expressed as the question: How can I apply my technical talents in the most time-effective way in an inefficient, socially-oriented English speaking team to get an equal share of the marks?

Jay's evolution from preferring to work alone in the team after arriving at CU to claiming a central technical role was shaped by an important conflict between Jay and the other team members over the distribution of work and marks on project 1 in mid-October. The conflict revealed mismatched expectations between Jay and his team over his contributions and behaviour. The conflict also revealed characteristics of the team's emergent rules, roles, and culture and prompted them to begin communicating more explicitly and delegate tasks. Changing conditions brought about by project 2 (i.e., increased modularity, complexity, requirements, Yao joining team Z5), team expectations of Jay, and his prior technical skill manifested possibilities for him to move into a central technical role designing, building, soldering, and troubleshooting circuits and to engage socially and communicatively in the team.

The change in Jay's engineering dispositions and thinking proceeded to Stage 4 (turnover, but not restructuring). In general, the nature of Jay's evolution was that he came to realize the importance of buying into working as part of an engineering team and that this entailed claiming a viable role as an engineer in the team through his knowledge and skills. The specific engineering dispositions and thinking he developed through his enculturation, that reached Stage 4, follow:

1) Be technically proactive.
2) Mobilize skills and knowledge for the team.
3) Be more reliable by prioritizing time for the team.
4) Be socially engaged.

Jay left the team after Design I in December 2012 because he lacked a key Design II pre-requisite. As such, it is difficult to claim that changes became stable and led to a new trajectory (i.e., that he progressed to stage 5). Yet, there is evidence (Figure 20) of dramatic change in Jay's dispositions and thinking through his participation in Design I.

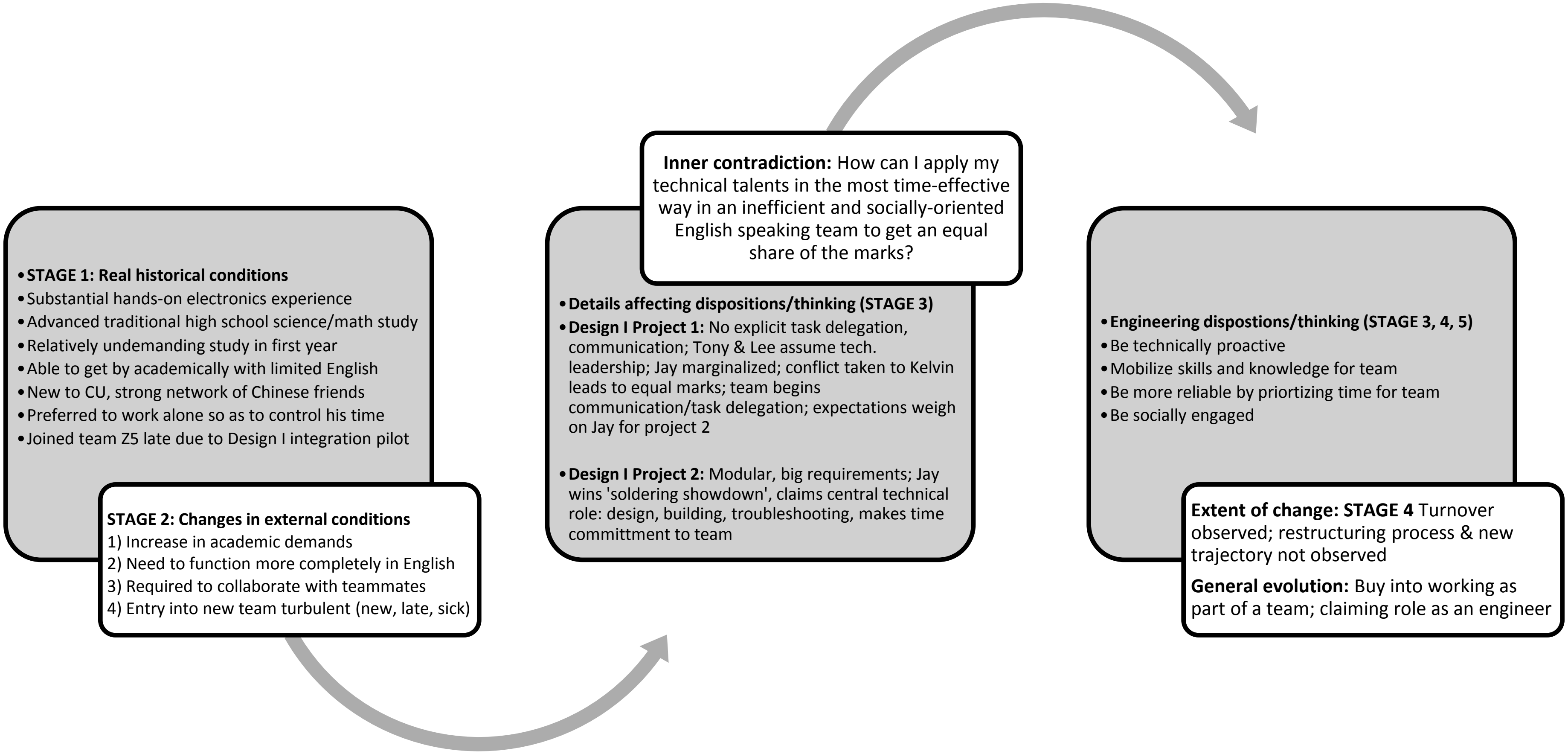

Figure 20. Summary of Jay's Trajectory

6.2.2 Stage 1: Real Historical Conditions Relevant to Jay's Trajectory

Jay knew one day he would be involved in study and work related to engineering or science and found his way into engineering in Canada. As a child, he had observed his father working on electronics in his private workshop at their Shanghai home. Jay's father, an electrical engineer, wanted to spark Jay's interested in electronics and so taught him at an early age how to build and solder circuits. He later urged Jay to pursue math and science study. Jay's Shanghai high school placed high demands on its students: long school hours, copious homework, and advanced science and math study aimed at preparing students for STEM degrees. Jay moved to Canada in January 2010 with the aim of getting a degree from a Canadian university. He enrolled in a three-month English as a Second Language (EASL) course at ETPC to prepare him for academic study in English. He was successful in getting a score of 6.5 on the IELTS (International English Language Testing System) test, a gate-keeping academic English language assessment. Jay decided to study engineering while at ETPC, because he loved math and science and was aware of the job opportunities engineering offered. He was admitted into ETPC's engineering transfer program, which fed students directly into engineering programs at Canadian universities.

Jay reported that first year in general engineering at ETPC felt like review, thanks to his advanced high school math and science study. He had only a few hours of classes per week and about an hour of homework per day, so he had plenty of free time to relax and be with his new friends. Jay reported having no difficulty functioning academically in English because, in his view, math, physics, and chemistry are based mostly on signs and numbers and do not require much English. He also did not use English very much at school outside of academic study. A large percentage of the students in his program were Chinese and Jay shared accommodation and socialized almost exclusively with his Chinese friends.

Studying electrical engineering was not Jay's first choice: he felt pressure from his father to pursue electrical engineering, but did not want to exactly follow in his father's footsteps. He applied to CU civil engineering because he loved physics and thought designing high rises would be cool. Electrical was his second choice. When not accepted into civil, he accepted a place in CU's second year electrical engineering for September 2012. The real historical conditions relevant to Jay's learning trajectory (Stage 1) are that he:

1) had substantial hands-on electronics experience;
2) had studied advanced math and science in traditional mode in his Shanghai high school;
3) was used to the fairly undemanding study of the first year of his Engineering Transfer Program College (ETPC);
4) was able to get by academically in first year with limited English;
5) was new to CU and had a strong network of Chinese friends, with whom he lived and socialized;
6) preferred working alone so he could control his time; and
7) joined team Z5 late because of the integration pilot being run by ECE in Design I.

6.2.3 Stage 2: Identifiable Changes in External Conditions Relevant to Jay

The identifiable changes in external conditions relevant to Jay stemmed from his move from an ESL-supported traditional math and science based first year ETPC engineering curriculum to the second year CU ECE curriculum that included team-based design projects. Jay realized the academic expectations on him had changed. First, the workload in ECE was very demanding, reminding him of his Shanghai high school. Second, his new peer group was ambitious and determined to get straight A's. While watching YouTube videos in a group between classes, Jay observed that some of his new classmates began doing a math assignment while keeping one eye on the videos. He was surprised they were so concerned with time that they multitasked in this way, instead of just sitting and enjoying the videos: "It's different from my idea in ETPC – I changed my mind when I see these people." Thirdly, he had an early awareness that team-based design projects were different from his previous study in terms of time commitments:

> Team projects are very complicated, so I can't finish this on my own and if I want finish – if I want to do it on my own, then it will take a lot of times. And I think the smaller one – the module one and module two - is can be done with two people and when I doing it, it seems very simple and just follow the schedules, steps that the instructor give us. But when you doing it, you can't get it right at the first time, so you debug it and you do it and do it. (Jay, interview 1)

Jay liked the idea of doing hands-on work in a team rather than "just doing math and science", though he preferred working alone so as to control his time.

These changing conditions (i.e., demanding CU study, fading high school advantage, time-intensive team-based projects) in Jay's debut at CU were just the beginning. ECE had made a late curricular decision to run an integration pilot to link Design I's report writing requirements to the formal report requirements in the faculty's technical communication course. Efficiency was the rationale: ECE wanted to reduce student workload by achieving the communication and technical learning outcomes of the technical communication course and Design I, respectively, with the same assignments. Twenty percent of Design I's students were regrouped mid-September, so Jay replaced Jim in team Z5 on September 16. Jay's early relationships with Hyuna, Tia, Tony, and Lee and his role on project 1 are ambiguous because of conflicting reports and a lack of direct observation. Jay and his teammates reported having mutually favourable initial impressions. He collaborated with Tony and Lee on modules 2 and 3 and Tia reported on November 5 that Jay "didn't feel like an outsider" in the team despite his late arrival. Other remarks from Hyuna and Lee counter this picture and so it remains unclear.

What is certain is that a major conflict built up and erupted at the end of project 1 in the last week of October 2012. The conditions discussed around Jay and his entry into the team; differences in teammates' schedules; non-Design I assignment pressures; and different expectations for teamwork, social engagement, and communication contributed to tensions between Jay and his team mates once work began in earnest on project 1 in early October. Firstly, scheduling mismatches between team members and assignments from other courses impacted the time effectiveness of the regularly scheduled project meetings that took place in the project rooms. All team members except Jay were taking Circuit Analysis I, had the lab right after the scheduled project meetings, and ended up studying and preparing during Design I's scheduled project meetings. Jay was frustrated that this work intruded into important project time and that the team ignored long-term project goals to focus on the short-term:

> I don't know that we had one efficient group meeting during project 1. We just stay in the group room and we should discuss the project, but we did indeed was doing our math homework and the homework, yeah … and then we just talk a few words about the project and start doing electrical circuits circuit – the wider class homework. (Jay, interview 1)

Tia later agreed: "The thing we're doing right now is we're being organized for project 2, but we weren't like that for project 1. We would do this and then we stop and we continue tomorrow without thinking about what should be finished tomorrow – something like that." Jay was frustrated by this inefficient use of time because he valued his social life with Chinese friends, did not work well at night, and wanted to leave school at a reasonable time.

Jay’s social engagement and communicative style raised concerns with his team. Lee noted Jay “is more towards himself. He doesn’t, like, he doesn’t really tell people stuff.” Hyuna reported that he was the hardest to approach and work with and that she found him “cold”. For her, blending social and work life in the team was natural and desirable, but Jay did not behave accordingly: “He’s still involved, but I don’t feel really like he’s actually *involved* (her stress). He’s involved because it’s schoolwork – something like that: he’s just thinking of it as only work.” Tia agreed, identifying Jay’s time commitments and lack of communication as a concern:

> Jay didn’t really spend so much time on project 1 because every day we usually work from 1:00 up to say 11 or 12 p.m. Jay leaves at about 4 or 5 to go to his other class and he doesn’t come back. I mean, that’s OK, but he kind of, Jay kind of lacked communication, because (he left) and we were expecting him to come back, but he didn’t say he would be coming back. (Tia, interview 1)

Tia also noted the team often just really did not understand what Jay was trying to communicate:

> Jay left for project 1…early and…he never said goodbye to us. He never said that he is “OK, I’m leaving!” So we thought that he’s coming back. And then…we asked Hyuna “Hyuna can you ask Jay where he is?” and then she texted him…he replied to Hyuna that he’s already gone home and then we thought about…OK, why not: “Hyuna can you tell Jay that if he wants he could get the reports started, so that to give him something to do?” And then he replied something. I can’t remember, it’s a bit lengthy. It’s so unusual for him to have a lengthy text, so unusual. That was really rare. And then Hyuna didn’t get what Jay was saying and then she showed the text to us. I didn’t get what he was saying and then Tony. No one got what he was saying and then Tony said when he read it “OK he’s totally not doing the report!” And we all laughed – it was so funny. (Tia, interview 1)

Observations from October 16 confirm that despite passing CU’s English language requirements through his IELTS test score of 6.5, Jay’s had relatively low spoken and aural communicative competence. He rarely spoke up to contribute to meetings, made personal connection to other students, contributed or facilitated contributions of other team members, and so appeared to lack sociolinguistic, functional, and strategic competence (Centre for Canadian Language Benchmarks, 2012). His teammates, all English Language Learners, employed strategies (e.g., simplifying language, restating questions, paraphrasing, asking for clarification, code switching to Mandarin) to facilitate communication with Jay. Tia, Hyuna, and Lee noted his language challenges. Tia, for example, identified him as having a “language barrier.” Interestingly, Jay did not explicitly report communication and social engagement as problems. He admitted that “communication was not so good in the first one (i.e., project 1)”, but did not report in interviews of having challenges himself. Instead, he mentioned his role in explaining technical content to Tia and Hyuna in English, so that they could keep up. He was knowledgeable and appeared not to be aware of his English limitations, possibly because he viewed communication in terms of delivering technical content and ideas:

Researcher:	Did you have any challenges with language in that group?
Jay:	When I don’t know how to express it, I just go to Google translate. (…) When I discuss it, when we were discussing, (…) so I just when I don’t know something, I just Google it and I know it and…
Researcher:	Was that effective?
Jay:	Yeah, it was very helpful (…) like Hyuna and Tia, they need to...we need to explain very detailed to them, to help them understand what we were doing. Keep everyone on the same progress is very basic, most difficult piece.
Researcher:	OK, OK. So how did you try to do that?
Jay:	Yes, they’d take time and it also helps you to understand the concept after.
Researcher:	So you have to explain it?
Jay:	Yeah (…) yeah, in English. (Jay, interview 1)

Jay behaved differently from other team members with respect to time commitments and contactibility. Tia contrasts Jay and Lee on this point: “For Jay, he does the teamwork but he wants to go home at the right time. But then Lee, he’s like, he doesn’t really care what time he will go home, but he just want to, he willing to stay more if we need to…but Jay…he wants to go home at this time.” Jay was not easily contactable by his teammates. He did not join or reply to Facebook friend requests and invites. Facebook was a key space for the team to post project ideas and files, exchange homework, make arrangements to meet, socialize, and exchange humour and light teasing. Examination of Facebook records shows the team had difficulty contacting Jay through any medium to the point that it became a running joke.

By October 5, four weeks after the project had been assigned and 11 days before the demonstration date, the team had no design for the dual slope ADC multimeter in hand. Nothing had been built. Lee and Tony called a project meeting for Saturday, October 6 to discuss the design. Hyuna and Tia reported that Jay had been sick on October 4 and 5, but that he had been invited to the meeting, which Jay denied. Only Hyuna, Tony, and Lee were present for the Saturday, October 6 meeting, with Tia absent. Lee and Tony produced a design while Hyuna watched, presented it to Tia on October 8, and started building it. Jay recovered, came to school on October 10 and so did not know the design, felt he could not help, and was absent from much of the remaining project for reasons unknown. The project's size and lack of modularity made it difficult to separate out and delegate tasks for later integration. In the days to follow, Tony and Lee, assisted by Hyuna and Tia, completed the project for the demonstration on October 16. Jay claimed Lee and Tony took the project home at this time. Yet, photos and communications on Facebook over the weekend show team members working in the lab and discussing Jay's absence and how to contact him. Jay's dubious claim that they had taken it home may indicate indignation at somehow ending up peripheral or his embarrassment or denial of his role in the conflict. He next appeared at the demonstration on October 16.

The project 1 demonstration was very successful, garnering the team an exceptional 9.2 out of 10. Heisenberg praised the project, particularly Lee's beautiful wiring. Tia called a meeting on October 20 to begin the project report writing for the October 22 deadline. Jay was absent again and photos on Facebook from October 20 to 22 show the teammates surrounding their project, working on the report, and beaming at the camera. The big conflict began when they had to assess everyone's contributions and sign off on a collectively agreed division of the marks. Tia's account of the weeklong conflict from October 24, corroborated by Hyuna, Jay, and Lee, suggests this was the most difficult time for the team. All four unanimously marked Jay down, but agreed to avoid direct confrontation by trying to handle it anonymously:

> So the day came when we had to hand in our team evaluation and we hadn't agreed on what to write. So during that time I saw, when I came in to the lab I saw the other three (Tony, Lee, Hyuna) there in the corridor, and they were discussing about Jay and then so I came in and they told me that they were discussing and I told them that if they want me to call Jay. So I called out Jay and then… This is so awkward!!! And then they were all there in the corridor and then we kind of didn't really know how to do it, so what we really, at first, plan A was that we individually give grades to everyone and have the professor average it and we told that to the TA because the professor wasn't there, and the TA said that wouldn't work because we have to agree on the score (…) and if someone gets a low mark, he has to know why, the person has to know why. And so that's plan A down and then Plan B was to write individually a grade to everyone and we'll just average it so afterwards. (Tia, interview 1)

Plan B was to decide on the marks by secret ballot. Tony took the ballots and averaged them: Jay got 65%, Hyuna 90%, Tia 110%, Tony 115%, and Lee 120%. When Jay saw these results, he refused, requesting a meeting with Kelvin. Kelvin conducted interviews with each member, asked them about their contributions, and then held a team meeting in which he advised them to split the marks equally. Tia notes how much of an important event Kelvin's meeting was:

> It was all good. I think it kind of, cause first, it wasn't Jay's…Jay's fault. Like everything is not his fault. It's because, you know…hmm….how to say this? Jay did something. Although it was so small, but his part of the project worked perfectly well, so cause we asked him why was he always leaves and then he said that because he doesn't think that we still need him because Lee and Tony have their hands full on the bread boards and so he can't get his hand in, so he has a point there. And then, the professor told us … the thing the professor told us kind of solved it, because he said to give tasks to everyone and then try your best to give 100 to everyone. So that to give 100 to everyone at the end of the project to the team evaluation. (Researcher: So was there a lack of communication in some way?) Probably, yeah, I think that's the reason that on his part he didn't tell he wasn't coming back. And on our part, we didn't tell him he needed to do this or that. And so for both sides there's some problems. (…) So you know how our first (project 2) group meeting (November 2) happened the day after the interview (November 1)? So the (professor's) interview changed everything! (Tia, interview 1)

Kelvin, the instructor, later reported:

> Students come in with different expectations, of themselves and of each other. (…) So, in that case, I think the expectations weren't very well laid out at the beginning, and so I understand from Jay's point of view, *he felt that he'd been delegated to do a certain task and in his mind he'd accomplished it.* Whereas *for the other students, they felt that as a team, if something is not working then you as a team member need to – you are expected to help resolve it,* and so there's a little bit of truth to both sides, right? Certainly you need to accomplish what you are delegated, and then at that point, if other group members are not able to finish what they are doing, then I'd say that to some degree, you should contribute but only to a reasonable degree. So everyone has to recognize what's reasonable. (Kelvin, instructor interview)

Kelvin told them that they needed to delegate tasks and communicate so that everyone would get an equal share of the work and the marks on project 2. Tia's question to Jay during Kelvin's meeting (i.e., "so, we asked him why he always leaves") suggests they had not communicated expectations. Based on early interviews with Hyuna, Jay, Tia, and Lee, no explicit discussion of teamwork expectations and guidelines for communication, time, and scheduling had occurred at the beginning of the term before or after Jay joined the team. Interestingly, Tia and Hyuna perceived that no one really was "in charge" and that expectations were understood naturally without being verbalized. Yet, the conflict appeared to surprise everyone, Jay in particular:

Researcher:	Would you say that they (Tony and Lee) kind of controlled the project?
Jay:	Yes in the first one. (…)
Researcher:	OK, how did that make you feel? If they're – so you weren't able to join them to do it, so how did you feel about that?
Jay:	At first I felt "Oh, you have done it!" It's OK.
Researcher:	It's OK? It's nice?
Jay:	It's nice yeah. (…) But when we go to the evaluation they decided they want most of the marks and they give me a very low mark and *I* said *"You didn't ask (me) to join you so even if you did most of works but (I) also want to do the works but (I) didn't have the chance to join you so..."*
Researcher:	I'm kind of interested, how was that decision made that they would go and do it on the weekend? I mean did you talk about it?
Jay:	I think the time is very, we don't have much time when we were doing the first one so...
Researcher:	OK, so did you discuss those kinds of decisions with your group? For example they went and they did the work on the weekend. Did you discuss the problem that it was very late? Did you ever discuss it as a group?

Jay: No, we haven't discussed how to do it – how to do the first project, so it's also my first time to join a course and in doing a project. So I don't know it's a first time so I learn it and I deal with this single one. (Jay, interview 1)

The conflict reveals much about the emerging culture of the group. Tia's note that "it changed everything" reveals either a lack of awareness of basic team functioning or is an attempt to re-establish harmony by sharing blame. Evidence shows that Jay contributed very little to the project that would justify a full share of the marks. However, Tia and Jay's comments that they were surprised and their willingness to share blame and move on may have prevented Jay from being uncomfortably implicated, which might have led to problems in project 2. The meeting resulted in unfair marks for Tony and Lee if the metric for deciding marks is taken as the fair division of labour. Yet, in this case, the metric for deciding marks appeared to be the maintenance of team harmony rather than who did how much. Sharing blame despite an unfair division of marks appeared to be an attempt to preserve the harmony of the team and not unfairly implicate Jay. It is possible they swallowed unfairness and shared blame for the team's collective benefit.

6.2.4 Stage 3: Emergence of New Dispositions and Thinking

The engineering dispositions and thinking that emerged in Jay are introduced in this section. Project 1 was significant for the team because it resulted in role differentiation by the end of October, with members in central technical (i.e., Tony, Lee), secondary support (i.e., Tia, Hyuna), and peripheral (i.e., Jay) roles. Judging from his turbulent entry and relative absence, Jay appears not to have been able to anticipate, realize, negotiate, shape and/or adapt to the team's emerging expectations. The dispute over marks was a surprise to Jay and he was able to manifest a more central technical role in the team and become slightly more socially engaged in ways that would not have seemed possible in project 1. For Jay, change appeared to stem from the contradiction between his behaviour and the expectations of his team, which had remained unclear and unvoiced. As he noted soon after that “it’s a first time so I learn it and deal with this single one.” No mention of the conflict was made afterwards. The equal division of project 1 marks despite Jay’s limited contributions gave him the benefit of the doubt but had placed the onus on him to contribute more. Project 2 also afforded Jay the possibility for a greater role because its requirements, complexity, and modularity led to substantial role differentiation, making the control that Tony and Lee had exerted over project 1 unworkable. Yao’s arrival in the team may also have been a factor in the change. Following the conflict, change emerged in Jay and in the team’s awareness and practices around communication, expectations, task definition, and delegation.

On the technical side, a new disposition towards being more technically proactive in design emerged in Jay. He began identifying challenges, doing research, and presenting design ideas to the team in the conceptual stage of project 2. Jay began to claim a larger technical role by contributing to the multimeter design in the first two project meetings, specifically by taking on the task of researching and designing the β meter and explaining it to his teammates on November 6. All were clearly impressed, and before the team moved on, Tia pumped her fist, saying enthusiastically to Jay “Wow! Good job! Ca-ching!” (i.e., the sound of a mechanical cash register). This research, design, and peer teaching role was made easier for him because he had found the β meter design on a Chinese website and attempted to explain it in English after using Google translate and the diagrams he had prepared. The team members were intrigued by what was available on Chinese sites and Jay became the gatekeeper to this source of knowledge because he read technical Mandarin, though he was not always successful at communicating the knowledge he found there in English. Jay's demonstration of knowledge in these first project 2 meetings earned him a technical role at the table with Tony and Lee.

A second disposition that appeared in project 2 was that Jay began willingly mobilizing his knowledge and skills for the team. Jay already appeared to have substantial prior knowledge and skills that were directly useful to the projects. Jay's shift to a central technical role came on November 8, when Lee, Hyuna, and then Jay each performed a simple soldering operation in what amounted to an informal soldering showdown over who would solder the project. The team had to "mod" (i.e., modify) the Altera DE2 board so it could be used in project 2. The DE2 board is a teaching platform designed for university and college electronic laboratory use that supports the learning of digital logic, computer organization, and field programmable gate arrays (FPGAs) through electronics projects. The DE2 boards had been bought on discount from Altera for each student in the course; however, the decimal points of the 7-segment displays on the board had not been connected to the pins of the Cyclone II FPGA. This meant that, without modification, the DE2 board would not be able to display the decimal point necessary for the multirange voltage, current, and resistance measurements (e.g., ±2.0000, ±20.000, ±200.00 DC mA) required by the project. Modding the DE2 board required a simple operation in which three resistors and wire-wrapped (i.e., insulated) wire were soldered between the decimal point pins and the connectors of the 7-segment LEDs on the back of the board. Lee did the first soldering job of his life. Hyuna, who had done it in high school, handled the soldering iron improperly and burned the plastic on the back of the board. Jay went last, and did a quick, professional job:

(Jay solders the final resistor onto the pin quickly and effectively.)
Tia: Oooh! (rising and falling intonation) Didn't burn the plastic.
Tony: Beautiful!
Tia: So good! (rising intonation) Next step.
Jay: My father is an engineer – electrical.
Tony: You used to do this?

Jay: Yeah.
Tia: Instead of biking, he taught you soldering? (laughs)
Jay: When I go to kindergarten.
Tia (in a dramatic, deep male voice): Son, you have to know how to solder.
Tony: In my case it’s how to change a fricking tire.
Tia: Really? Is he a mechanical engineer?
Tony: Uh, no, he had studied, like, vehicle mechanics. (video recording)

Jay became the designated solder person for the team. Lee had done a good job, smiled at everyone and rubbed his hands nervously on his jeans like he was unsure. Hyuna had not performed well. Jay appeared comfortable and professional, as if soldering was a matter of course. Interestingly, Jay announced his connection to soldering as a child through his electrical engineering father, garnering him respect in the team and contributing a story about Jay that was retold by Tia and Tony until the end of project 2. Tony also mentioned his father’s occupation as a mechanic, but his comment and tone suggests he recognized that this experience held less currency in an electronics lab: “In my case, it’s how to change a fricking tire!” The team came to place a large amount of faith in Jay’s ability to solder the project quickly so that it was bug free, meaning it had no disconnected parts. This was a critical, high-stakes job because of the project 2 requirements.

Jay developed a disposition towards being more reliable by prioritizing time for his team. He allocated more time to project 2, aligned his schedule to the team’s requirements, and attended all project meetings and lab work sessions. Although he sometimes arrived late, he demonstrated greater awareness about time and scheduling. During the kickoff project 2 meeting on November 2, a day after the team’s meeting with Kelvin, Tia and Jay voiced mutual concern and flexibility about Jay and the team’s time needs. Open negotiation of time and schedules, a concern for all, became a key part of project meetings and working sessions in the lab at the beginning of project 2 and Jay engaged in these discussions and decisions. Jay remained somewhat unpredictable about when he would appear and whether he was contactable. Tia, the team's coordinator, did not know whether and when he would show up at the beginning of the day or after meal breaks or classes. Yet, Jay stayed when there was critical work to be done. In contrast to project 1, Jay's unpredictability was somehow acceptable two weeks into project 2, perhaps because he was growing into a central role and they had accepted his tendencies, as noted by Tia (interview 2): "As for Jay he - I think it's really his personality that he doesn't like replying that much, to text messages, though sometimes I have to guess, is he coming to the meeting or not I don't know. I just have to see if he shows up." Jay continued to limit his communications to occasional texts of a few words, which Tia's would receive on her cell phone and then pass on to the team verbally, by text, or on Facebook. Jay remained unconnected on the team's Facebook page or to the general ECE Facebook page for reasons unknown.

Jay developed a disposition towards being socially engaged. He became more accessible to the other team members. Jay still held himself back from whole team discussions in project meetings, which tended to be driven by the more communicative Tony, Tia, and, by now, Yao. Jay tended to position himself physically apart from the center of the team's talk and was frequently observed peering into his computer or papers while the others were engaging in on-task and off-task talk. Once there was a functional reason to be centrally positioned, he would move to the centre and then move out again when he had finished. Jay still rarely generated the type of off-task talk and social banter that Hyuna and Tia did during project meetings, but he did begin to project more warmth to his teammates. He occasionally made side comments or initiated short exchanges while working with individual students in the lab, such as acknowledging members' physical state (e.g., touching Lee's wrist while soldering, smiling: "Why are you shaking today?" Lee: (smiles) "Because it's important."), considering their feelings (e.g., Hyuna: "My password is my birthday." Jay, on Hyuna's computer: "Oh! So sorry! I forgot your birthday!"), or commenting on their characteristics (e.g., good-natured comment on Lee's extreme detail orientation: "Oh you! Thinking too much!"). Jay preferred engaging in physical or functional tasks that benefitted the team and project directly, such as searching and retrieving a table from quite far away for the team to sit around, collecting parts, and gathering useful information from the Chinese Internet.

In general, Jay's emerging change was generally related to an apparent realization of the importance of him buying into working as part of a team and his moves in claiming a central viable technical role. New engineering dispositions and thinking emerged. Jay became more reliable by prioritizing his time for the team, more socially engaged, and mobilized his knowledge and skills for the team.

6.2.5 Stage 4: Turnover in Dominance

Jay's movement into a central technical role in the team was observed throughout the duration of project 2, something confirmed by Tia (interview 2): "You know, looking at project 2 – if I were a newcomer or I was an outsider, I would never thought that the problem from project 1 ever happened." Yao, new to the team from November 2, had no idea that anything had occurred and only found out about the conflict during an interview in December 2012. In later project meetings, Jay's disposition for mobilizing his knowledge and skills for the team grew. He drew again on Chinese sites to bring design ideas to the team (e.g., auto range design). Jay also engaged in discussions on a number of key design problems with Tony, Lee, and Yao. As an example, on November 15, these core members had a lengthy, detailed discussion to solve the challenge of selecting the proper reference voltage when the sign of the voltage to be measured was unknown. Jay's practical knowledge was critical to this discussion, particularly in relating the physical project to the circuit diagrams. For example, he clarified a basic misconception that the V_{in} input to the dual slope ADC, represented on the circuit diagram as a line, was a single value. V_{in} input is the difference between two points in another circuit, which corresponded to two wires instead of one. This was an obvious point missed by people with less hands-on experience with electronics. His practical knowledge contributed to important design decisions for the team.

Jay also mobilized his hands-on technical knowledge about electrical circuits in other ways by troubleshooting difficulties encountered by the team as they prototyped their designs on breadboards. For example, Tia was building the power supply circuitry, which would convert AC from the power source to specific DC reference voltages for use in the multimeter. She was checking the output of the transformer's rectifier by attaching the oscilloscope probes to the rectifier output and ground. The oscilloscope displayed strange, unexpected waveforms and Tia asked Tony and Lee for help. Both checked all the connections to see where the interference was coming from but gave up and just stood around wondering what to do. Tia was trying to measure the rectifier's voltage from the resistor to ground. Jay came over to Lee and Tony, who were standing around, and swiftly identified the problem:

Tia:	(to Jay) Oh, you're the one who helped us last time. It's a half wave…
Jay:	(checking, looking at connections, oscilloscope) There is something wrong.
Tia:	Yeah, probably…
Jay	(fiddling) Something must be connected wrong.
Tia:	We checked it before.
Jay:	(hooks probes up to different points on the breadboard): OK, let's try.
Tia:	(seeing the half-wave on the oscilloscope) Wow, what did you do?
Jay:	You're should to measure across the resistor, not from the output to ground.
Tia:	It should be across the resistor. Thank you so muuuuuuch! Tony! It's the same mistake that we made before.
Tony:	Is it? (video recording, field notes)

The ground, if attached to a rectifier, is likely to have interference, which may be surprising to someone expecting to see the clean half-wave typical of this rectifier's output. The correct way is to measure across the output resistor of the rectifier. Bahram, a TA, noted this as a common mistake and that Jay gets high points for this because he obviously understands electronics.

Consolidating his central technical role and being reliable was not always painless for Jay. Following his design of the β meter and ammeter, Jay failed to successfully build and test it on November 21. Tia had been checking the measurements and complained to him that they were not accurate enough. Jay realized his circuit was not working and dismantled it. Lee texted him later and asked him where it was so that he could work on it again. Jay told him it was in the locker and claimed it was almost done. When Lee went to look for it, it was not there - it had disappeared. Lee went on to build it by himself after failing to understand Jay's explanation of the design in English over the phone. Tia later confirmed that she had seen him dismantle it. Jay did not admit that it had not worked out. Lee redesigned and built it, quietly dropping the topic, which was never mentioned again.

The final and perhaps most important event for Jay was consolidating his role as the team's solder person in the last days of the project. The team had run into time challenges. As late as November 28, the team was still working out problems with the circuits on the breadboards, considered soldering a critical requirement, and opted to solder those that were working. The team was relying on Jay to do a fast, effective job and was relieved when he declared confidently that he could do everything in 3 hours. Jay painstakingly soldered the voltmeter, ammeter, ohmmeter, β meter, the autorange circuits, and the power supply on November 28 and 29 with Lee and Tia's assistance. Through his central involvement over the last two days on critical tasks, Jay grew into his role as the team's designated solder person. Tia dubbed him "our solder man" and "The Solder King" in the final days of the project. Yet, despite his claims of being able to solder the project flawlessly in the 11th hour, much of the project, previously working on the breadboards, failed to work in the demonstration, somewhat muting Jay's coronation as "The Solder King".

Jay's new disposition towards social engagement with the team increased towards the end of the project, although he continued to prefer one-to-one, information, object, and action-focused interactions. The arrival of Yao, who was knowledgeable, open, and enjoyed talking about technical things created a more conducive dynamic in the team for sharing knowledge. Tony tended to engage in technical talk so as to declare his knowledge to the other members, whereas Yao did it for fun. In one discussion in the third week of November, Jay, Yao and Tia discussed a hard drive that Tony and Lee had found in a drawer. Yao began discussing how a speaker can be made out of the parts: a coil, a magnet, an input, and output. Jay smiled, adding excitedly that you can make a cotton candy machine with a hard drive – he had seen it done. Yao and Tia enjoyed that and coined a new product name: "Jay's Cotton Candy". Yao added to the tech talk with an "I saw it on YouTube" story, common among engineering students. He saw a video of someone powering a hard drive up to 10,000 rpm to make it explode "due to the tension", much to Jay, Lee, and Tia's amusement. Another example of Jay's increasing social engagement with the team occurred around a combination lock. Tony told everyone that by feeling carefully, it is possible to sense the combination because the dial on the lock gets tight and clicks. After they all practiced opening the lock using the numbers, Jay took the lock and tried to do it by listening:

> Jay gets the lock after Tony says this and begins pressing the lock very close to his ear patiently for a long time to hear the sound, without looking at the lock, in an attempt to open it. He squints his eyes tight, looking mysterious as he's doing this. There is silence for a long time. Tia says, "You opened it? Without looking?" Yao says, "Maybe he is looking

at the reflection of the numbers on the white board. Maybe if he has good eyes he can see the numbers." Tia and Yao both laugh and Jay smiles silently at them.
(audio recording, field notes)

Jay's willingness to communicate began improving. When Jay left for the day on November 27, Tia announced "Jay is sending his regards to everyone!" After Tia contacted Jay over the team evaluation for project 2 in early December, she reported back to the team on Facebook: "Texted Jay about this thread and, in his exact and only word, he replied, 'Equal.' A man of few words our solder man is!" Jay had come to inhabit a central technical role and an emerging social role in the team but then left the team because he lacked a Design II pre-requisite. Observation was not possible after December and it is not clear whether these changes led to a new trajectory for Jay.

6.3 Lee – Coming to Know Who He is Technically and Socially in a Team

After soldering showdown, Lee examines the end of the solder wire he has been using and cuts off the end of the soft wire to get a clean end that is perfectly 90 degrees and square - not misshapen because of the mess of soldering. (field notes)

6.3.1 Section Summary

This section gives an account of how Lee, a shy, bookish engineering student with a disposition towards perfection, came to know himself as a quiet, socially engaged hands-on technical leader in a team (Figure 21). The real historical conditions relevant to Lee's trajectory (Stage 1) are that he:

1) was a high achieving international student;
2) had learned in a lecture and textbook mode of study;

3) had little hands-on technical experience;
4) had a disposition towards perfection and detail-orientation;
5) was extremely shy with little experience in diverse groups; and
6) had determination and a sense of destiny about being an engineer.

The identifiable changes in external conditions relevant to Lee (Stage 2) relate to his move from a general first year engineering to a second year program, which was a more demanding and integrated curriculum which involved team-based engineering design projects. Specifically for Lee, this means that he:

1) had to cope with a heavy workload;
2) had to look beyond core content, integrate it into his courses, and apply it to projects;
3) was expected to engage in hands-on technical work; and
4) was expected to collaborate in diverse teams.

His inner contradiction or problem can be expressed as the question: How do I function comfortably in a diverse team and achieve high quality work with teammates who have different ideas about what is ‘good enough’?

Lee’s trajectory from his entry into second year from general first year engineering involved an abrupt shift from learning from books and lectures to building tight, clean, well-functioning circuits, which he managed by transferring his disposition towards perfection and detail-orientation to his hands-on project work. In early October 2012, his success in building and testing the core of project 1 positioned Lee as a technical leader alongside Tony. While Lee and Tony had complete control in project 1 and had done it perfectly, the modularity, complexity, and requirements of project 2 required greater task delegation. Project 1 had been a "transistor-level" project, whereas project 2 was a "systems-level" project (Section 4.4.5). Lee did not like to compromise on quality, but work had to be delegated to people with different standards. Lee became more flexible on quality and began to judge when his disposition towards perfection was truly required, possibly as a result of practical constraints. From the Design II projects, Lee responded to issues of delegation, quality, and time by substantial backing team members up, and becoming active in making project decisions so as to avoid problems before they began. Lee also became more communicative and socially engaged through his growing familiarity with the team, his role as a technical leader, and the pressure of projects. Once Tia left the team in February 2013, Lee filled her communication and coordination role.

The change in Lee’s engineering dispositions and thinking proceeded to Stage 5 (restructuring process and new trajectory observed). In general, the nature of Lee’s evolution was that he came to know himself as a quiet, engaged hands-on technical leader. The specific engineering dispositions and thinking he developed through his enculturation, that reached Stage 5, were:

1) Be hard-working, persistent, and detail-orientated. (original disposition enhanced)
2) Do engineering through hard-prototyping.
3) Lead through knowledge.
4) Assess tradeoffs and compromise.
5) Be socially engaged in diversity.
6) Seek quality through team monitoring and backup.

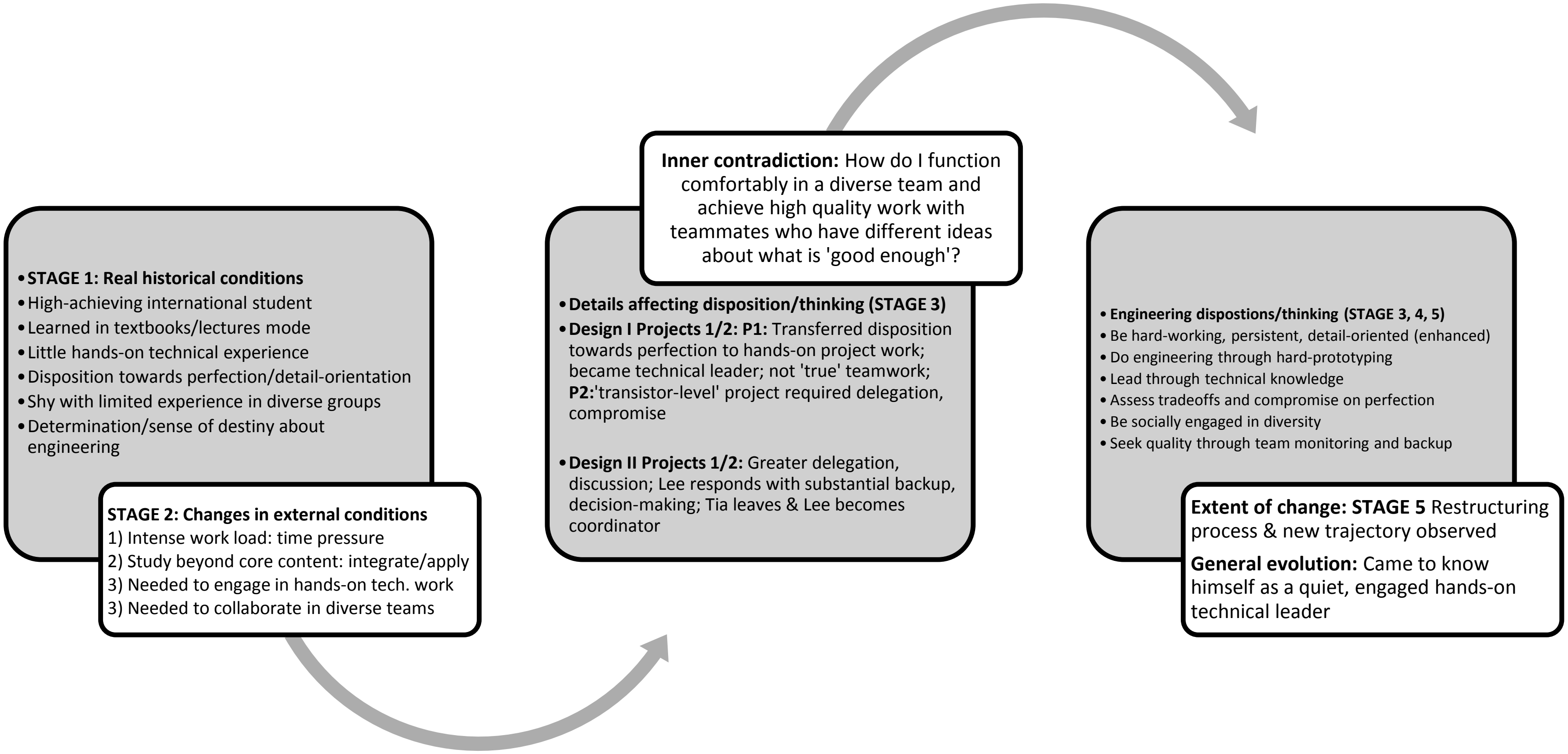

Figure 21. Summary of Lee's Trajectory

6.3.2 Stage 1: Real Historical Conditions Relevant to Lee's Trajectory

Lee is a Malaysian student of Chinese ancestry who was on a university track in high school but unsure which field to choose. Like many Malaysian students facing the option of a science, arts, or business stream in high school, Lee chose science: "I kind of prefer science more than arts. Art is like, expressing yourself, and I'm not good at that." When Lee's parents, both teachers, were discussing what he should study they thought engineering would be suitable for him. He agreed. There were no engineers in Lee's extended network and he had no information or image about what they do. After deciding, he searched Google for information, but quit after seeing a confusing list of links. Despite later choosing computer engineering, Lee confessed he was not good at using computers at the time, and had very little hands-on technical experience.

Lee won scholarships that paved his way to engineering in Canada. Lee took his first scholarship, based on high school results, for a foundational year in engineering at Malaysian University (MU) starting in March 2010. He then won one of a hundred highly coveted national five-year scholarships based on his high school exam results. The third scholarship from his national exam results gave him the chance to study engineering in Canada. Lee's academic English preparation was extensive. Malaysian high schools teach math and science in English and his scholarship included a year of pre-university study starting in September 2010. Lee achieved a 7 in the IELTS test and then applied to and received offers to study at Big Canadian University (BCU) and CU. Lee chose CU because he had heard it was easier.

Lee experienced smooth transitions from high school to MU and then to pre-university because most of the learning was lecture-based, expectations were clear, and students had no need to look outside the textbook, lectures, and materials. The transition from pre-university to CU Engineering was difficult because of social and cultural differences and the workload. Lee missed home and was not used to socializing and studying with non-Malaysians. Lee self-identified as extremely shy and was surprised how expressive CU students were: they raised their hands, asked questions, made comments, and even disagreed with professors. In contrast, Lee reported that Malaysian students were relatively quiet and deferred to professors' authority. Academically, the mode of study was very familiar to Lee because "most of the stuff is lectures, and exams are just based on those stuff", although Lee noted a large gap in technical knowledge between what he had learned in his preparation in Malaysia and what he needed to know. The first year at CU was the toughest thing Lee had ever done: "Actually, I don't know how I survived that!" Despite difficulties, Lee saw moving forward as the only option for securing a good future. He found encouragement and support from a small network of Malaysian friends from engineering at CU and from his religious beliefs:

> Actually, I think God has planned this out for me because I am a Christian and ... it's a good plan so I believe that. I don't think it's a coincidence that I feel. I don't think that three years is a coincidence. (Lee, interview 2)

From interviews and early observations and reports, the real historical conditions relevant to Lee's trajectory (Stage 1) are that he:

1) was a high achieving international student;
2) had learned in a lecture and textbook mode of study;
3) had little hands-on technical experience;
4) had a disposition towards perfection and detail-orientation;
5) was extremely shy with little experience in diverse groups; and
6) had determination and a sense of destiny about being an engineer.

6.3.3 Stage 2: Identifiable Changes in External Conditions Relevant to Lee

The identifiable change in external conditions relevant to Lee was the shift from mostly lecture and textbook based math and science study in first year at CU to a partially integrated second year ECE curriculum that included the team-based projects of Design I and Design II. Moving from first to second year at CU was the most difficult transition for Lee since high school because of the intense workload, the mode of study, the need to engage in hands-on technical work, and the need to collaborate in diverse teams. Lee realized by mid-September that it was “even worse than first year” and that he felt “Why? Why am I in this kind of thing?” Interviews with team members indicate that in the first month, the students functioned more as a study group than an engineering team. The students agreed to project meeting times, but tended to work towards the short-term assignments and Design I modules rather than the project. Heisenberg had warned the class about the dangers of “the illusion of having time”, but Lee and his teammates did not seriously start project 1 work until October 3. Lee remained in traditional study mode, exercising his particular talent for completing regular assignments and studying for early midterms carefully and thoroughly. Lee had already sacrificed his free time activities in first year - computer games, TV, and sleep, in that order - and found that there was not enough time in the day to attend to all the short-term assignments and long-term project work.

Lee reported that team-based project work was different from lecture-based study: students were expected to look beyond the core material, integrate content from across courses, figure things out for themselves, work hands-on in labs for long periods of time, and function effectively in diverse teams. He was now in a position where he had to grapple with hands-on work designing and building projects. Lee had also never done team-based project work and, despite being “a kind of shy person”, recognized its value: “I think it’s good preparation for engineering work. I don’t think that engineers work by themselves. There’s usually a project and a group of engineers, different fields, come together and complete the project.” Working in a diverse team was also new: “I think I felt more comfortable back home because we’re just like, same country, everyone is…we get along quite well together there (Malaysia) than here – most people (here) they are, like, mixed already. I don’t really get to…get along with other people.” Yet, Lee was open to the opportunity to work in a diverse team.

6.3.4 Stage 3: Emergence of New Dispositions and Thinking

The engineering dispositions and thinking that emerged in Lee are introduced in this section. As described in Jay’s trajectory (Section 6.2), the team was faced with a looming project 1 deadline and had no design and nothing built by October 3. Tony (Malaysian, of Indian-Chinese ancestry) and Lee took the lead by mostly designing and building project 1. Lee and Tony began to inhabit technical roles, with Tony focusing on the conceptual design and Lee building the project, and both testing and troubleshooting. Tia and Hyuna began inhabiting coordinating and support roles, respectively. Jay was peripheral. Tia reported that Lee and Tony had mutually complementary technical roles in project 1, something corroborated in Hyuna and Jay’s first interviews and in observations after October 16:

> Lee is supersmart and he’s like Tony, but he's the organized one. So, Tony does these things (designs) and Lee kind of makes sure that their neat, they’re organized. Lee doesn't like… Tony is kind of laid-back, so Lee is the one, the strict one, that the kind of hates procrastination. When it (the project) is not on track, there's always either Lee or Tony who always keeps it back on track.” (Tia, interview 1)

In early October, Lee began prioritizing Design I projects, sometimes at the expense of other courses: “I actually give up time for some other courses as well. Assignments? (laughs) I didn't fully finish the assignments (in other courses).” Lee transferred his disposition towards perfection in traditional study to building neat, functional circuits. He surprised his team with how he painstakingly, carefully, and precisely built project 1 from October 8-15, despite a lack of hands-on experience. Lee's perfectionism aligned with the instructors' emphasis on being methodical, careful, and attending to detail in building and testing circuits (Section 5.2) as a way of avoiding simple mistakes that lead to hours of frustration debugging circuits. Heisenberg's effusive praise of Lee's handiwork (Figure 4, Section 1.4) in front of the team during the project 1 demonstration on October 16 endorsed Lee's emerging technical role:

> Who wired this thing?... because it is quite beautiful." Tia points to Lee, who did most of the wiring. Heisenberg gestures at the project to me so I will examine it as an example of good work. "Look at how this is very clean. It's nicely wired. It's very clean. It's working fine. It's tidy." Tia notes that the wiring is very neat and labeled well - not 'spaghetti wiring' which they all know Heisenberg dislikes. "That's why it works!" Heisenberg mentions extra features that they could have investigated, but declares: "It's very good quality. It's very good looking. I like the wiring - too much yellow, but do you know what? It's easy to see. Some people use white and it's hard to see. OK, good job!" Heisenberg and the TAs begin to leave and Lee, holding the project carefully in his hands, smiles broadly at them as they walk away. (field notes)

Through project 1, Lee saw how his dispositions and thinking towards hard work, persistence, and detail orientation paid off. These already existed in Lee but appeared to be confirmed and enhanced by the projects, starting with Design I project 1. Project 1 also contributed to an emerging disposition towards viewing engineering as hard-prototyping – building things in the lab – in which he could exercise his natural orientation to perfectionism. Lee noted: "I think it worked almost perfectly!" (big smile) The team received a 9.2 out of 10, leaving Lee and Tony in particular full of confidence. This result and the early respect he gained from teammates and the instructor also offered Lee, a self-confessed introvert with little hands-on experience, a glimpse of himself in a new role within a team carefully building perfect circuits that work. This was a departure from his familiar role as diligently learning from lectures and textbooks and solving problems in assignments, midterms and finals.

Lee had emerged from project 1 as a technical leader along with Tony, who was important because of his familiar Malaysian origins, his similar disposition towards perfection and quality, and his conceptual technical knowledge that complemented Lee's hands-on ability. Lee's early technical leadership gained through his knowledge and newfound skill opened a new disposition and way of thinking for him: the possibility of leading through knowledge, which was not apparent in his old mode of study. Tony was important in this shift for Lee because he was an outspoken and knowledgeable extrovert, which afforded Lee vital technical and social backup and security in the team. Tony and Lee tended to share understanding on technical issues and decisions and tended to support each other. They experienced no dissenting technical voices until Yao joined the team for project 2.

The dispute over work and marks that became significant for Jay (Section 6.2.3.) was significant for Lee in other ways. Lee reported that taking control of the project on October 6 with Tony and doing the technical work was a natural response in that the team was under time pressure and others appeared unwilling to take the lead. The project's relative simplicity and limited requirements made it possible for Tony and Lee to shoulder all technical work and bring it to a successful result. Yet, Lee reported "it was a close call" because they had only managed to get the project working the night before their demonstration. Team Z5's project 1 represented a step away from lectures, textbooks, assignments, and exams, but it arguably fell short of full team-based project work in which work was equitably delegated among the members. Tony and Lee were in a position to control and carry the work in the time left so as to produce a multimeter that met their high standards. Although the project was successful in terms of marks and for Lee and Tony in claiming central roles, the conflict brought awareness that a change in teamwork practices was needed. As Kelvin noted, they had to communicate and delegate tasks and responsibilities in order to give all members the opportunity to learn and earn full marks.

Project 2 was very different from project 1 because of its complexity, modularity, and requirements. Bahram, a TA, noted that the instructors intended project 1 to be a “one-block, one-schematic, one-field” analogue circuit design or, alternately, a “transistor-level project” that would enable students to learn and apply low voltage electronics fundamentals and to build their experience working in teams. The project was relatively simple and did not have large, modular parts that required integration. In contrast, Bahram noted that project 2 was a “systems-level project” because it required the design and integration of multiple mechanical, analogue, and digital blocks. Project 2 incorporated the core analogue voltmeter design from project 1 with huge extensions: requirements for auto ranging across three voltage, current, and resistance ranges and transistor beta measurement, all to extremely high resolutions. The project also required a power supply that could be connected to the transformers in the lab. These analogue circuits needed to be transferred from breadboards - used for prototyping and testing - onto solder boards (i.e., not printed circuit boards), manually soldered, and housed in a bought or purpose-built, non-flammable case. There was also a digital block consisting of an Altera DE2 board that required programming in VHDL. Each of these blocks represented a major piece of work and the project required substantial integration of these digital and analogue blocks. The students were still trying to learn some basics (i.e., VHDL programming from the course Data Structures and Algorithms for Computer Engineers, working in a machine shop, soldering) and were simultaneously expected to learn how to design and integrate systems, making project 2 extremely challenging in comparison to project 1.

So, while the need to delegate tasks was understood by the team as a question of fairness, the scope and nature of project 2 made it a necessity. Lee acknowledged this reality after the fact: “I don’t think the project (2) would turn out if it’s just two person working – I don’t think it will work out.” Lee was at the centre of the project because the core designs of project 1 and 2 (i.e., a voltmeter) were essentially the same. Yet, with the increased modularity and number of project tasks, Lee faced a conundrum: he was orientated to high quality and perfection yet found himself in the position of having to give up some control over tasks and responsibilities to teammates with different abilities and ideas about what was ‘good enough’.

The increase project requirements and modularity of project 2 engendered an emergent awareness in Lee of the need to delegate work and to ultimately recognize tradeoffs and compromise on his natural disposition and thinking towards perfectionism. Yet, giving up perfectionism and control were observed to be difficult for Lee. On November 8, the team modified (modded) a factory-made Altera DE2 board so it could be used in project 2. Modding the DE2 board required a simple operation in which three resistors and wire-wrapped (i.e., insulated) wire were soldered between the decimal point pins and the connectors of the 7-segment LEDs on the back of the board. Halfway through the job, Lee was busy routing the thin wires from the resistors at the bottom right to the top left part of the board where Jay would solder them to the pins there. Heisenberg’s photo of this completed modding (Figure 22) shows the three wires taped together and running diagonally across and above the board. Lee ran them horizontally across the board, bent them at 90 degrees and then ran them vertically up to the pins. The team stood or sat around the DE2 board discussing whether to follow Lee’s or Heisenberg’s routing in the picture. Tia called the lab technician Boris over for his advice. Boris said “if you bend the wire in this way, you will not stick it well – just put them here, just like it is there in the picture." Lee nevertheless proceeded with his original routing and explained afterwards: "He said that (gesturing diagonally), but I still think (gestures horizontally then vertically)…I want to put it straight."

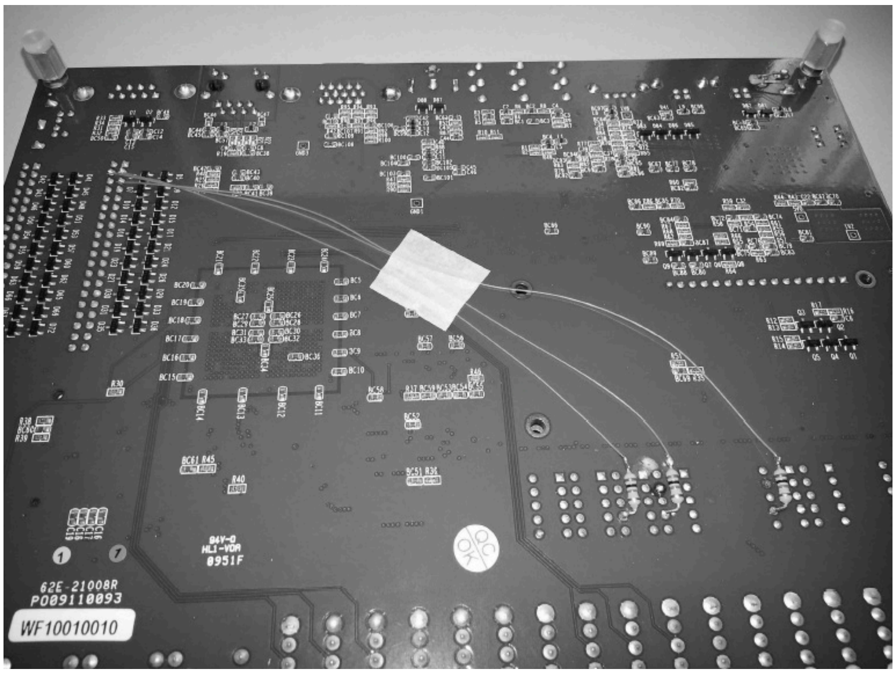

Figure 22. Modding the DE2 Board

When asked why, he said, "It just looks nicer." Bahram noted that, strictly speaking, Lee's routing is preferable when there are many wires because it makes connections visible. In this case, however, it was not critical because there were only 3 wires on the board. Lee continued routing the wires at 90 degrees and taping them down. He and Tony occasionally looked towards Boris' office as Lee did this. When Hyuna asked why Tony and Lee were looking around, Tia replied, "they don't want the technician to see it." Tia had also stepped into the line of sight between Boris' office and their bench while Lee continued carefully routing and taping the wires his way. Such behaviour exemplifies Lee's disposition towards perfection.

Another example of Lee's disposition towards perfectionism was observed when he was building and testing a voltage divider (i.e., a resistor ladder) on a breadboard on November 17. The purpose of the resistor ladder was to step the voltage down by factors of 10 for the autorange feature, which would enable the multimeter to automatically flip through three ranges of voltage, current, and resistance. The R-values of the resistors were not very accurate and so voltage was not divided accurately by factors of 10. Lee became irritated and spent over an hour trying different resistors to achieve the step down, even though the imperfect ratios could be programmed in VHDL to display readings more accurately. Tony suggested Lee let it go:

> Lee and Tony then discuss whether things are connected or not and whether the readouts are reasonable – Lee is getting 0.8008 and 0.9 something, which is close to 1. Tony: "It's very close." Lee thinks one of the values is not accurate enough (although the others are) and wants to change one of the resistors in the ladder to get better accuracy. Tony mentions that if he changes the first big resistor to get an accurate reading at the first node, all the others will be inaccurate. Lee looks flustered. Tony: "Right now this one is inaccurate and these are accurate, accurate, accurate, accurate. If you change the first one it's going to be accurate, inaccurate, inaccurate, inaccurate." Lee pulls a disappointed face. Tony laughs at Lee's expression. Lee: "We need accuracy. We need accuracy." Tony: "We do but I don't see what can be done about these resistors." Tony is obviously less worried about accuracy. "In the end, we can never really match the ideal circuit." Lee continues fiddling with it. (field notes)

Lee's disposition to such perfectionism used up valuable time on a problem that could have easily been fixed through the VHDL code. Yet, even if Lee had been unaware that a VHDL fix was possible, he was still spending time to achieve a level of refinement that did not match the stage of the project at that time: much of the circuitry had not yet been built and time would have been better spent elsewhere. Many similar examples were observed where Lee and Tony wasted time because of an inappropriate focus on perfection over basic functionality. Attention to detail had served Lee before and at this point, he did not yet know that time would become a problem in project 2. As such, there was no reason for Lee to let go of his disposition towards perfection. It had served him well in project 1.

Lee relaxed expectations as other team members began building circuits. While looking at a photo of a breadboard provided by Heisenberg early in project 2, Tia said to Lee:

> I'll bet you these wiring doesn't pass your standards. (laughs, pointing at the wiring on Heisenberg's breadboard in the picture, which is actually pretty clean) … poor professor, but the yellow one, the bulky ones (points to the four yellow wires on the picture), doesn't pass your standard, right? (Lee looks embarrassed, goes back to work)
> (video recording, field notes)

Lee began to see when focusing on details was less critical and to accommodate teammates' work when it was not quite up to his standards. With so many working on different parts of the project, Lee became aware that he could not insist on perfection. When Tia was building a power transformer on a breadboard, she was bending a resistor wire to fit it into holes in a breadboard beside Lee, who was building something else:

> Tia: (talking to resistor) Why are you a pain? Must meet Lee's expectations. (looks up)
> Lee: (looks at her, embarrassed) If it's … if it's just on the breadboard, so I don't really…
> Tia: (laughs) OK. If it's on the solder board, it will be a different story. Mmmm. OK… Can't disappoint Lee. I can't. I can't. I can't. (nodding in sync with 'can't')
> (video recording, field notes)

Lee reported relaxing his original standards when it came to working with others:

> I sort of give and take or so – so let's say I ask her (Hyuna) to just, maybe connect these nodes together, so at first maybe it's some strange ugly looking wire so I just ask them (Tia, Hyuna) "OK – this, maybe tidy this up a bit," so they will and they will tidy it up, but sometimes it's still not up to my expectation but it's already good enough.
> (Lee, interview 2)

Lee became more flexible by working with people: "Comparing to me, I don't think (Tony) is up to (my level), but I'm sort of an - even if I'm a perfectionist, I'm not always enforcing what I think. (…) I don't push it…" He had started judging when his detail-orientation was required.

As project 2 progressed, Lee began to engage more socially, developing an emerging orientation to communicating and engaging in diversity (i.e., talking to women, people from other countries). During early project meetings, he tended to sit quietly in the middle of the discussion beside Tony and speak sparingly. Lee was not observed in Design I project meetings facilitated discussions by such moves as opening, maintaining, and closing topics; managing the direction of the talk, holding the floor, or using strategies to keep the discussion on track. Tony directed much of the technical discussions with the increasing presence of Jay, Yao, and Tia. Lee took a monitoring and backup role, speaking only when he thought something was missed or incorrect (i.e., discussing, clarifying schematics or pictures; providing/clarifying information about parts, designs, and concepts; suggesting ideas; clarifying facts; pointing out problems/weaknesses). He also engaged in talk when it was task-focused and technical: he did not engage very much in off-task talk in early Design I. Lee engaged with teammates more in the lab than in project meetings, perhaps because he preferred building and testing circuits and he could engage teammates quietly in ones and twos rather than speaking out in front of the whole team. Tia and Hyuna reported feeling comfortable with Lee at the beginning, noting most of the talk he initiated related to the project rather than off-task social topics.

Yet, Lee reported enjoying the social life that sprung up around him because of the team. They liked each other and shared huge workload commitments. This made it natural for them to sit together in the labs, eat meals together, collaborate on and trade homework, joke around, travel to and from school, and take care of each other. Team life extended beyond just the course. Over time, Lee went from observing, to engaging in social talk, and the to participating in the inevitable teasing and joking that went on in the team. Tony, Tia, and Hyuna generated a substantial amount of mirth and the usually good-natured teasing found its target mostly in Tia, Hyuna, and Lee. Tia and Hyuna made multiple attempts to tease Lee at the end of project 1 and the beginning of project 2 (e.g., getting a girlfriend, his need for a haircut) with little response from Lee. In the latter days of project 2 and into Design II, Lee began to respond with greater frequency. Once, when Lee's bench in the lab was covered in bags of resistors, parts, tools, and equipment, Tony teased Lee about the mess:

Tony:	(to Lee): Why are you always covered in a bunch of resistors?
Lee:	I don't know why!! (smiles broadly)
Tony:	Even when you're over there you were covered in resistors. Why? (Both laugh)
Researcher:	I wonder if you visit Lee's bedroom it would be covered in resistors.
Tony:	Ouch! That would hurt. (all laugh) (field notes)

In general, Lee's emerging change was generally related to having to function in a demanding second year with team-based engineering design projects in which he had to cope with the workload, look beyond core content, integrate it into his courses, and apply it to projects, engage in hands-on technical work; and socially engage and collaborate in diverse teams. Emergent engineering dispositions and thinking in Lee first included a confirmation of his natural dispositions and thinking with respect to being hard working, persistent, and detail-orientated. New engineering dispositions and thinking that emerged through Design I projects 1 and 2 include: doing engineering through hard-prototyping, leading through knowledge, assessing tradeoffs and compromising on perfection, and being socially engaged in diversity. An additional thing that would emerge as Lee continued leading through knowledge was his orientation to seeking quality through team monitoring and backup.

6.3.5 Stage 4: Turnover in Dominance

Lee's experience of team-based project design continued to shape him. Lee was at the centre of the project team in project 2 because he had built project 1 and had the greatest working knowledge of its core: the dual slope ADC design (essentially a voltmeter). Lee, the voltmeter, and his knowledge of it became intricately linked, consolidating his role at the core of project 2:

> Researcher: Did anybody have the power…to convince other people, compared to other members?
>
> Yao: I think everyone had a fair share of power but of course we respect Lee, like because he is working on the central piece. So any changes we make has to comply with him. So if our change affects his piece or anything and he rejects it, we need to respect that. So… (Yao, interview 2)

The last disposition and thinking to emerge in Lee through his leadership relates to his growing awareness of quality: he had to seek quality through team monitoring and backup. Lee had increasingly become the final word on technical decisions that affected the core and team members would, at one point or another, consult Lee and take his opinion on board. Yet, when work was delegated to teammates, Lee respected the need for people to have their own tasks and responsibilities in the team, even if they did not produce work up to his standards. He reported coping with the tension between his desire to do the perfect job and delegating the work to others with lower standards by lowering his expectations when quality was not critical and by engaging in substantial backup behaviour for his teammates when it was. A good example of this relates to the β meter for project 2 discussed in Jay's account (Section 6.2.4). Jay had been working on a β meter design and after he had gone home, Lee wanted to bring together the various parts of the design on the breadboard. Lee and Jay had texted about the issue. Jay claimed he had built it, it had worked, and it could be found in the locker. When Lee could not find it he concluded that Jay had dismantled it, something that Tia confirmed. Lee took it upon himself to build both and got them to work on the breadboard. Yet he quietly dropped the topic with Jay. Lee had maintained quality by investing extra time and had maintained harmony by remaining silent.

When asked about the incident and others, Lee noted tolerance and anger management as most important for a team to function well, because otherwise "it would spoil everything." Lee was observed on many occasions being very tactful around people and their opinions. He expressed his hesitance to engage in direct confrontation of any sort or to speak out if there was conflict. On one occasion during a project meeting he deferred to Yao's ideas on the auto range:

Lee:	One of it was auto-ranging pilot…So I was planning on another way, I can't remember who was thinking of some other ways (It was Yao) I can't remember, so in the end I think I gave in so…
Researcher:	Why did you give in?
Lee:	I think it's my personality I…I'm not that kind of person that I want the way, I want it my way and it must be my way. (…)
Researcher:	So when you gave up, you said you don't really feel like you want to push your idea or something.
Lee:	Because really I think of it - both are okay.
Researcher:	So you didn't see a big difference in the quality of the idea wasn't so different. If it was different would you say more about it?
Lee:	If it was different like, if that would definitely not work then I would say "Oh no, man." (Lee, interview 2)

With the familiarity he had built up in the team, his status as a technical leader, and the pressure at the end of project 2, Lee continued to become more open and communicative within the team. The team was a safe place for Lee to take social risks because being shy was accepted in the team. Secondly, he had a secure position besides the more talkative Tony as a technical leader. Thirdly, the team camaraderie developed in the final pressured days of projects before demonstrations and the energetic bustle of the labs appeared to allow Lee to come out more. One example occurred at the end of term in the last project meeting. Lee rarely displayed negative emotions and seemed always to have a good-natured, almost innocent, smile on his face. After the meeting and before going into the lab for a night's work, Lee was quietly frustrated. While taking a sandwich away for later, he uncharacteristically thrust it roughly into a bag that already had a cookie in it, making a mess:

Tia: (laughs loudly) What are you doing – you just threw it in there! Lee!
Lee: Oh!
Tia: Lee!
Lee: I didn't know! (Hyuna laughs)
Tia: You've changed, Lee, you've changed!
Hyuna: You've changed.
Tony: That's right!
Tia: We're just seeing the real him.
Lee: It was a mistake!!! (protesting his innocence, in an unusually loud voice)
Hyuna: Lee is coming out! (audio recording)

Another reaction to pressure and stress observed in students working to a project deadline is humour. Mostly good-natured humour was a daily staple in the team and Lee began to engage in this team practice by the end of the term. The night before the demonstration, project 2 was not functioning. Hyuna came to Tony and Lee to ask how the digital part of the project was going, and in doing so, exaggerated the pronunciation of the word 'working' (i.e., 'whirr-king') for fun:

Hyuna: Is it whirr-king?
Tony: Oooooooooooohhhhhhhhhhh! (in a comical high-pitched, panicked voice)
Hyuna: It's whirr-king!
Tony: What do you mean it's whirr-king?
Hyuna: It's whirr-king!
Tony: Oh, we haven't switched the pins back. Ah! (pretends to fiddle with pins.)
Lee: That's why it's whirr-king.
Tony: That's why it's whirr-king
Hyuna: You make me laugh. It's not whirr-king.
Lee: Yes, it's whirr-king! (jumping up and down comically)
Hyuna: It's whirr-king!
Lee: It's on! No, I know. The code is saying keep it on! (looking at it up close)
Yao: It's doesn't have to be always on.
Hyuna: Does it always have to be on?
Tony: No!!!! (like what she is saying is ridiculous)
Lee: It doesn't have to be on!!!
Hyuna: Oh, I'm so jealous!
Lee: We need a physical switch to switch the…
Tony: Yes.
Hyuna: Physical switch, how are we going to make a physical switch?
Tony: Reed relays is a switch, we have a switch IC.
Hyuna: Make this one as a switch then it's whirr-king.
Lee: Dun Dun Dun Dun (pushing the DE2 buttons like a piano, Hyuna starts to sing).
(audio recording, field notes)

The prolonged stress and lack of sleep in projects that builds on the night before a demonstration can produce a zany camaraderie in engineering labs that can be quite entertaining. Lee, previously an observer and a recipient, has slowly become a participant and a creator of mirth.

That Lee had come to inhabit a central technical position is clear from the team's recognition that he might dissolve the team after Design I to join his Malaysian friends. All except Lee had expressed the desire to remain in the team Z5 for the next design course Design II. Everyone was waiting for Lee's response. From Yao's account, it was clear that Lee had the power to make or break the team for Design II:

> My first priority was always to stick with them, but I had a backup group to go in, just in case if, because we didn't discuss about are we going to stick with this group or are we going to split up. So we only discuss it the night before, when Tia messaged people saying, "I asked Lee are we staying in the same group and Lee said yes or something" so when we received that message we know we're going to be together, but before that we didn't really know. (Yao, interview 2)

6.3.6 Stage 5: Restructuring Process Leading to a New Trajectory

Lee's technical backup for his teammates continued in Design II project 1 but evolved with Design II project 2 into more proactive intervention and decision making in order to avoid having to invest large amounts of time downstream after tasks had been done improperly. Lee's experiences in Design I had made him very aware of the pitfalls of soldering circuits as he had spent hours debugging, desoldering, and resoldering them. This danger was also present in the smaller soldered circuits in Design II project 1 (soda fountain) and Lee took it upon himself to desolder and resolder the temperature sensing circuit after Hyuna had soldered it. Yao attributed the success of Design II project 1 to Lee's persistence, backup (e.g., soldering), and knowledge. In Design II project 2, Lee was proactive in stopping Hyuna and Li from soldering Tony's transmission circuit in the robotic car. Yao commented at the scene: "he didn't want them to mess it up." Lee had adapted his perfection from building perfect circuits to backing up his teammates' less than ideal work and then to finally voicing his opinion and making larger project decisions about his teammates' work. He also tried to have critical tasks delegated to those who he thought could handle them: Lee, Tony, and Yao. Lee's perfection and concern for quality had been qualitatively changed through his role as a leader. Yao notes this shift in Lee in the four months between Design I project 2 and Design II project 2:

Yao:	So if they know, like the first time (Project 1) maybe they got 9 point something, so second time they aimed for the same thing. So that's why they always want to go for the one that's 100%, like stick with the instruction sheet (project requirements) and wouldn't sacrifice any marks or…
Researcher:	Yeah, Why didn't a discussion happen where someone sat down and said "OK guys wait, look at the time we've got to do this we've got to…"
Yao:	Like they really want to aim high and even for the box like which they put so much time in it like, even during the last day they still want to add more stuff to it. But I was saying….they want to recolor it (the box). Coloring doesn't worth anything and even at the end we didn't even show them the box even though we've put so much time in it. So it was kind of like they aimed for a high mark.
Researcher:	They have this ideal, like perfect ideal?
Yao:	Yeah but at the end we kind of panicked and we just couldn't show them what we got. (Yao, interview 2, December 2012)

Yao:	**I think Lee's attitude has changed.**
Researcher:	Yeah? Can you explain that?
Yao:	He will do, he always complete the task and he always does a good job, but for the second of project of Design II like we were discussing, because we didn't have don't really big bonus feature. So I know some other groups they would prefer to spend that extra two days to work on the bonus feature and try to impress professor. But we got him working on that day just actually we got him, we got working right before the demonstration so we were still adjusting the values on the computer, and modifying it and we just got a working piece five minutes before the demo. So before that it was working with one range or something like that but we have three ranges, so Lee like what Lee did was like we could have spent the extra time and make a bonus features. But instead he just said, like I think during term one, we would have gone with the bonus features to better impressing the professors.
Researcher:	Yes?
Yao:	This time Lee said "Just demo!"
Researcher:	Just demo?

Yao: Just demo. Yeah, because he thinks we did enough to get at least a mark. So, spending that extra bit, like spending that extra time is not worth it this time so, if he's still a perfectionist he would, I mean a perfectionist he would have gone with the bonus feature and get all the marks. (Yao, interview 3)

Interestingly, Tia, at the beginning of Design I project 2, had characterized Tony as the leader of the team. On a lecture on November 5th, a guest lecturer on teamwork had shown a dated video (early 1970s) of a plant production meeting to present scenarios and provoke discussion about teamwork. The main character was Mac, the plant manager (aka "the leader of the pack"), who had to direct the team and deal with conflict to find solutions. Tia had dubbed Tony 'Mac' and Lee 'Ansel', a secondary leader, at the beginning of project 2. After three projects, when asked during an interview who it was that they saw as being a good example of an engineer, both Tia and Li endorsed Lee over Tony. This shift is dramatic. Tia explained it best:

> I think it changed—it kind of, a little bit changing my ideas of what a leader is, because at first, I was thinking leaders be the one, who's got the strongest personality, and then because right now I look at Lee as leader of the group, and but before, the first time I met him, he's the most shy in the group and on the first day, he was the one who would be stuck and it was Tony who would say the jokes and introduce everyone to this group. And then I realized that, being a leader is more than just being talkative and social, because Lee is definitely not the most social person in the group. But then I realize that being a leader also you need to be very knowledgeable, of the material that you're doing….and that's Lee. (Tia, interview 3)

Interestingly, after Tia left the team due to health problems Lee stepped in and took over her communication and coordination role. A clear change had occurred in Lee over the 6 months from shy, perfectionist to a quiet technical leader and project coordinator. Lee himself offers the final comments on how he evolved through his participation in Design I and Design II:

> Professional engineers will need to work in groups. I think - I think for this (i.e., thanks to this teamwork experience) I will be able to work better, to see I were to give anything in the group. So, maybe from what I've had I can, I can get along better (…) cause before, before this it's just back in Malaysia, I'm working with a bunch of close friends, right? Now it's brand new people. Next year it may be a new group.

> I think group…I get a lot of chances to work in groups, so I think – change? I don't know about change, but then about discovering more about myself, yeah. **I know how I would…** (pauses, looks up thoughtfully) **I know how I am in a group**. (Lee, interview 3)

6.4 Hyuna – Being Technically Uninvolved to Seeking a Meaningful Role

"I learned that maybe I should - because sometimes I more, like, depend on the group - so I think I should be more assertive to the work and then maybe actually, like, try to do by myself some stuff. So I can do more stuff than depend on the help of the group. Like soldering."

(Hyuna, interview 3)

6.4.1 Section Summary

This account describes Hyuna's evolution from being initially uninvolved in most of the core project work to seeking a meaningful role in the team by compensating in indirect ways and trying to engage in technical work (Figure 23). The real historical conditions relevant to Hyuna's trajectory (Stage 1) are that she:

1) was a sociable, active student with the greatest time commitments outside of engineering study than anyone in the team;
2) had functioned in a largely Asian peer group since immigrating to Canada from Korea;
3) had chosen engineering because of subject preferences and ability, status, parental expectations, and life opportunities;
4) had little awareness of and investment in engineering; and
5) harboured traditional views and values regarding gender roles and expectations in the capacity of men and women for work.

The identifiable changes in external conditions relevant to Hyuna (Stage 2) relate to her move from a general first year engineering to a second year program, which was a more demanding and integrated curriculum which involved team-based engineering design projects. Specifically for Hyuna, this means that she:

1) encountered increased workload and time pressure on her outside activities;
2) was expected to engage in engineering design, which she was not invested or interested in;
3) had to work with “smart kids” who she perceived as having greater knowledge and ability; and
4) had to cope with new expectations of teamwork that were different from traditional study.

By the end of project 1, being in the team working on projects manifested an inner contradiction in her that can be expressed as: How do I maintain my outside activities and my place in engineering and satisfy my teammates without engaging in much project work?

Hyuna began the term by inhabiting a peripheral, assistive, and social role in the team and relying heavily on others to do the technical and coordination work on the projects. She sought ways of contributing indirectly to the team in exchange for her lack of technical project work so as to garner equal marks. She was observed being consistently present, socializing, creating an enjoyable atmosphere, pretending to work, and helping her teammates with their other courses (e.g., doing their math assignments, sourcing complete assignments). At one point, she acquired and distributed a mostly complete design for Design II project 1. Towards the end of Design I, Hyuna reported sacrificing her social life and sought to contribute more time to the projects. She worked to demonstrate her soldering ability to Jay and Lee and succeeded in the last days of Design I project 2. By Design II, she had become one of the team’s designated solder people and collaborated with Tia on two small circuit designs for the Design II projects. She voiced doubts about being in ECE and her desire to leave the program for fields of study that were more socially and outdoors oriented, suggesting that her investment in engineering remained low. Hyuna's behaviour did not result in the kind of pressure that partly prompted Jay's evolution, possibly because of her willingness to assist, her social ability, her sharing of homework, her consistent presence at meetings and work sessions, and because of the team's cultural expectations of female students. In the end she had not yet carved out a full technical role for herself in the team, though she was making improvements and continued to compensate in indirect ways. No one seriously objected to this arrangement. It seemed to be functional for the team; but was not functional for her development as a pre-professional engineer.

The change in Hyuna's engineering dispositions and thinking proceeded to Stage 3 (emergence of new dispositions and thinking, but no turnover observed). In general, the nature of Hyuna's evolution began with her inhabiting a peripheral role from the outset in her early experience with team-based project work. Conflicting engineering dispositions and thinking emerged in her. On the one hand, she was aware that she could rely on others to do the projects' technical work by compensating them in other ways. One the other hand, she was aware that she should develop technically to contribute to the team. Related tensions appeared to exist between her life outside of engineering and her investment in her chosen discipline. The specific emergent engineering dispositions and thinking, which reached Stage 3, were:

1) Be dependent on others to do technical project work.
2) Compensate for technical weaknesses with unrelated work.
3) Viewing and pursuing hard-prototyping skills as engineering work.
4) Sacrificing social life to demonstrate solidarity to the team.

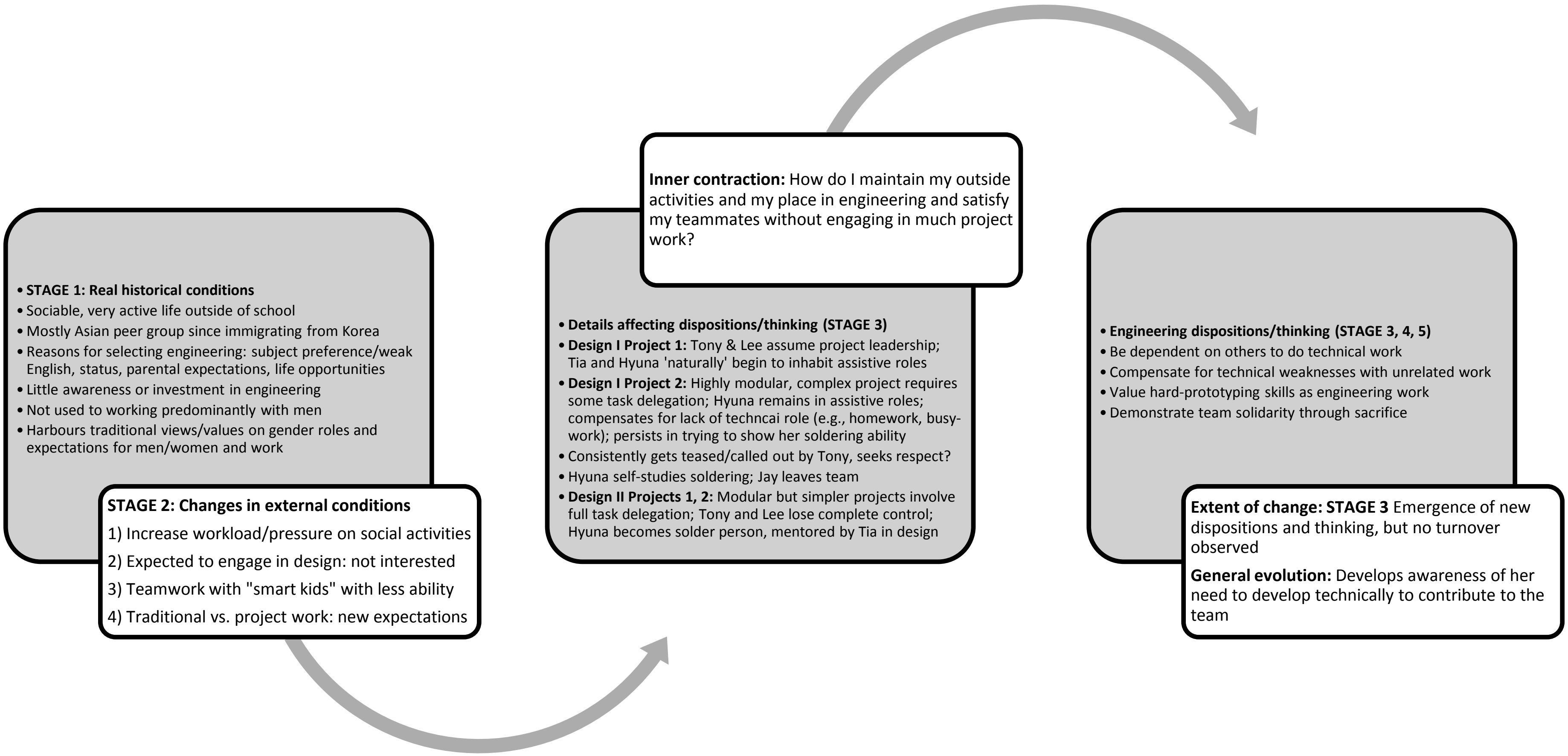

Figure 23. Summary of Hyuna's Trajectory

6.4.2 Stage 1: Real Historical Conditions Relevant to Hyuna's Trajectory

Hyuna's family immigrated to Canada from Seoul, Korea in 2007, taking her from a demanding school environment in Korea focused on getting students on an early path into top schools to a more relaxed public high school environment in Edmonton. Hyuna noted that "(entrance exams in Korea) decide everything…if you don't get into those (top) universities, it is hard to survive even though you graduate." She felt these demands in grade 7 and 8: it was "very high pressure and then my friends were all *dying*." Her parents valued education but were concerned about the demands Hyuna and her sister faced, which factored into their decision to immigrate to Canada. Hyuna experienced language and cultural challenges when transitioning to high school in Canada. She joined mainstream grade 9 high school classes without formal ESL support: "I went to the small school and there were no Koreans or no ESL students, so I was kind of the only one who speak English not very well, so I was really shy and I didn't talk that much." Hyuna noticed how the social norms were very different between Canada and Korea:

> Because in Canada you have to talk to people first so you can get close, but then in Korea people are more like 'Just wait till they come and talk to us…and that's how you can get close.' In Korea if you talk too fast and talk a lot, people feel like 'Oh, that's too much- he or she is trying to show off.' In Korea being a show off is a bad idea. (Hyuna, interview 1)

After difficulties functioning in English for a year, Hyuna was placed in adjunct ESL classes, where she met students from other countries (e.g., Taiwan, Vietnam, China, Korea). This was a turning point for her: "I kind of feel, let's say, 'same people around me!', so I started talking to people in the ESL class." She became close friends with one student and joined his Taiwanese-Chinese social network. While shy in grade 9, Hyuna reported that three years later she was a far more fluent and social English speaker with a broad engagement in a number of activities: tutoring, church activities, family gatherings, friends, a boyfriend, and hobbies.

Hyuna chose engineering for several reasons: subject preference and ability, parental expectations, life opportunities, and status. First, she had focused on math and science in high school, partly because she was not so good at English or Korean, social studies, humanities, or the arts. Hyuna's parents voiced a preference for professions such as medicine or law, but her English ability meant she avoided key pre-requisites (e.g., Biology 11, 12) because they were language dense. She also thought getting a good job in law, science, or medicine required 10-12 years of study. Engineering offered a short route to a profession, status, good money, work experience, and opportunities to travel. She achieved A's and A+'s in high school and was accepted into CU:

> My mum's friends they think 'Oh she is your daughter, she is pretty and bla, bla, bla' and then when she says like 'Oh, she's an engineer' they are like 'Oh!' (Researcher: There is status connected to it?) Yeah something like that. Well it is kind of like special. Not like 'Oh she's super smart or whatever but she's kind of super special.' (Hyuna, interview 1)

Hyuna's acceptance into CU was important to her parents: "Asian parents want kids to kind of go to top universities still." Her whole family moved half way across the country in time for the start of her engineering study.

Up until second year, Hyuna was largely unaware of the engineering profession: "I don't really have an image…because I can't…I can't imagine how things we are working on can apply to actual jobs." To her, engineers design and make devices; are responsible, nice, and smart; and enjoyed a special status as professionals. Hyuna harboured pride about being in engineering and noticed how she and her engineering friends began to look down on art students: "We always make fun of arts students: they have lots of time to party and they always go out…we study harder and we think arts courses are easy." Hyuna noticed "people look at me differently" because she is in a tough major and can do science and math, which are sources of pride.

The experience of being a female student in engineering affected how Hyuna responded to team-based project work. Firstly, she was not used to working predominantly with men. Hyuna felt she had an advantage as a female student: "because I'm a girl, I feel more chance on me to be an engineer…I feel kind of special." Feeling special also meant feeling isolated. In first year engineering and second year ECE respectively, only 30% and 15% of students were female and Hyuna reported feeling isolated until she "started to getting comfortable with guys more." She compared notes with friends in other faculties: "I go to class – it smells like guys...but then my friend is like 'Really? When I go to class it smells like perfume everywhere.'" Hyuna noticed that the talk is different: "guys have different topics to talk about – they talk about cars, and then they more talk about stuff we're learning." Grooming was also different: "In arts, I think they dress up real nice every time. Engineers? They don't have time to dress up, and they don't even have time to shower." Hyuna joked she would never introduce her male engineering friends to her other friends – her friends also said "No thanks!"

Secondly, Hyuna disidentified with female engineering stereotypes and harboured traditional values and expectations around female and male occupational, social, and family roles. She had an unflattering, stereotyped image of women in engineering: "what I imagine is like, stiff face…and then looks not that…pretty, but just looks more formal" – although she "doesn't like being, like, stiff because that's horrible" and won't become like that. She also identified differences between male and female engineering students:

> And then one more thing about being a woman in engineering. I feel kind of pressured too, because guys – they have more strength – and physically they can, I don't know, work more and stuff. So, and for girls, I don't know, it's kind of different because in future, girls being, like, mom, and they do houseworks too, so I don't know, I think it's kind of different with guys. When I look at guys they are like: "Oh, they're engineers!" But for girls, even though we have to graduate and then get a job and after we get married and like women get married then they might just stick in the house. (Hyuna, interview 1)

Hyuna drew a distinction between her and Tia, the other female student in the group, noting that Tia has never had a boyfriend and “doesn't want any…and then she doesn't even want to get married, so I don't know…it's difficult to share (with her).” These factors appeared to contribute to Hyuna’s low investment in engineering: she felt an obligation to graduate and get a job, but would naturally get married and perhaps “just stick in the house.” She harboured traditional views about gender roles, including the belief that male students had a greater capacity for work.

From interviews and early observations and reports, the real historical conditions relevant to Hyuna’s learning trajectory (Stage 1) are that she

1) was a sociable, active student with the greatest time commitments outside of engineering study than anyone in the team;
2) had functioned in a largely Asian peer group since immigrating to Canada from Korea;
3) had chosen engineering because of subject preferences and ability, status, parental expectations, and life opportunities;
4) had little awareness of and investment in engineering; and
5) harboured traditional views and values regarding gender roles and expectations in the capacity of men and women for work.

6.4.3 Stage 2: Identifiable Changes in External Conditions Relevant to Hyuna

Hyuna reported that while first year and high school placed similar workload demands on her (i.e., “just working with textbooks and stuff”), second year study was different:

> I think it depends on how many courses you take, but then first year we do not have projects, so we have more time. I think I can actually like hang out with other people and then go party, go rest on weekends. But in second year I don’t really, I can’t really rest on even weekend. (Hyuna, interview 1)

This realization did not occur to Hyuna for a month because team Z5 effectively functioned as a study group until the project 1 deadline became imminent in early October. As the project began in earnest, the luxury of time she had been used to in first year disappeared.

Functioning in a team on design projects was a different mode of study for Hyuna and she had mixed feelings about this new reality. On the one hand, she lacked confidence: there were “a lot of smart kids around me…when I do a project, I feel like I don’t know stuff…so I feel discouraged.” On the other hand, she could rely on others: “we can discuss about other courses as well and get more ideas…in teams, there are like, smart people, and then like less smart people and then, like, less smart people…can kind of like…I’ll say balance.” She reported her preference for math and traditional assignments early in the Design I: “I don’t feel like doing stuff (design) I don’t really know because I really like math.” This preference was observed in action as Hyuna relied heavily on her teammates to do most of the technical work on the projects which she compensated for by working on other assignments for them in the lab. Yet Hyuna was sociable, had good interpersonal communication skills, was able to engage other teammates who were from different countries (e.g., asking about pop culture, trying out singing in Malaysian), and contributed to the positive climate of the team. She was well liked and contributed to positive social relationships in the team. Yet, in terms of technical contributions, Hyuna recognized in interviews that “some people work harder and they do more work than others,” and that she was doing less than they were.

Being in a team placed different, unique expectations on Hyuna from first year that derived from the emerging team culture. In contrast to the team’s reaction to Jay’s behaviour in Design I project 1, the team was surprisingly tolerant about Hyuna’s initial lack of technical contributions. Lee reported at the end of Design I that the main complaint about Jay in project 1 was that he did not show up: “actually if Jay were to be there, even though he didn’t – if he’s just there, I would have agreed to make it equal.” He recognized that everyone has different mutually complementary roles even if they were not central technical ones. Hyuna and Jay were initially marked down to 90% and 65% respectively in project 1, with the only apparent difference in their contributions being that Hyuna was physically present and was socially supportive. Jay’s frequent absence in project 1 registered as significant, whereas Hyuna’s lack of technical engagement did not appear to be a basis for a reduction of her marks in the projects. This suggests that the team valued members being present, interacting harmoniously, and demonstrating solidarity with the team as the criteria for equal mark division than a careful assessment of who worked on what and how hard. It is also possible that the emergent culture of the team around gender expectations and work and the team’s personal relationships played a role in Hyuna’s slow change during this period. It is apparent that they expected more of Jay and less of Hyuna on the technical side of the project. By the end of project 1, time pressure and changing expectations around engineering study had created an inner contradiction in Hyuna between her drive to satisfy her teammates on projects in which she felt neither technically competent nor invested and her drive to remain in the programme and still engage in her activities outside of the engineering.

6.4.4 Stage 3: Emergence of New Dispositions and Thinking

The engineering dispositions and thinking that emerged in Hyuna are introduced in this section. The emergence of new dispositions and thinking in Hyuna appeared to come from her divided response to the reality of team-based project work. On the one hand was a slowly developing desire to be more technically independent and competent in a team in which she felt a lack of confidence and in a discipline she was not entirely invested in. On the other hand, she was also content to let other teammates do most of the technical work and try to compensate by doing secondary and supportive tasks and compensating her teammates with work in other courses. This emergence followed a long period during projects 1 and 2 in which Hyuna remained peripheral in the team by assisting them, compensating indirectly with other work, or pretended to work.

At the beginning of second year, Hyuna responded to the time pressure and new requirements by freeing up and organizing her time and relying on other team members to do technical work. She began doing homework during her 2-hour commute and cut back on sleep. In early October, she dropped the Data Structures and Algorithms for Computer Engineers course, saying, “It was too much for me!” This was an unusual choice because it was a key course for the projects. She also became highly vocal during team meetings when schedules were being decided so as to control her own time and maintain her outside activities. Hyuna confessed a lack of technical knowledge and so remaining relatively unengaged in the technical decisions on the projects: “Yeah, (the project 1 demonstration) went pretty well but I don’t really know much about the project, because Lee did the most.” Lee’s account of the start of building project 1 on October 8 reveals how technical roles were decided:

Lee:	On breadboard, at most is two person can work on it at once. So it was myself, Tony and the two girls at the side and then Jay took the day off. Last two days he said he was sick…myself and Tony was assembling the components based on the design and so we had all the jumping wires around so we asked Tia and Hyuna they shortened the –
Researcher:	To shorten that, OK, so Hyuna and Tia were there as support? (Lee: Yeah.) …You and Tony were the central people in the project and I’m wondering why that happened and Hyuna and Tia were support. How did that – how did those roles get decided, how did they come out?
Lee:	**I think it’s automatic. We didn’t really… we didn’t say you’re supposed to do this, you’re supposed to do that and it’s just like: they are this side**

and this side he says "Can you please help?" and then she say "Yeah." and then there is, then without me asking they just do it.

Researcher:	OK, so without you asking they were kind of supporting you? And Tony as well?
Lee:	Yes.
Researcher:	So it just was a natural relationship?
Lee:	I think so. (…)
Researcher:	So those roles – you said it happened automatically but was it because you have some special concept of the design or is it because you work well with the breadboard, is it a technical knowledge or skill that you and Tony have that created that kind of relationship or – what do you think?
Lee:	I think, I'm not sure. I think it's the skill.
Researcher:	It's the skill level, OK. (…) Do you think it's a male-female thing as well? Like in Malaysia, if you're in a working group like that, do the central people tend to be men or is it kind of equal?
Lee:	I think they tend to be men. (Lee, interview 1)

Tony and Lee took the initiative in designing the project while Hyuna watched on October 5. Their central involvement also meant that they would be the ones to build it. Lee and Tony also had the requisite knowledge for the design because they had taken the lead in the modules:

> Because in terms of the knowledge Hyuna and I are doing the least in the group, we have the least knowledge on that stuff, so you'd always see me working with Tony – he's a stronger one. And she will be always working with Lee who is a stronger one….I think when we do task, I would always end up either doing it with Lee or Tony. And Hyuna with Lee and Tony but not two of us (i.e., Tia and Hyuna) together because they (Tony and Lee) are aware of that, that we have the least knowledge on what's happening.
> (Tia, interview 2)

Hyuna began inhabiting a peripheral assistive role, something that appeared to manifest from a combination of her lack of interest and investment, her technical knowledge, and tacit values around gender and work in the team. Three points are interesting here about the foregoing quotes from Lee and Hyuna. First, Lee claims that it is the skill level that determined who was in central technical roles. Second, Hyuna and Tia also note that Tony and Lee are the stronger ones and so they paired up accordingly. Finally, Tia and Hyuna recognized Lee and Tony publicly for being smart while they downplayed their own abilities. Yet, until Lee got into second year, he had had little hands-on experience and, like Hyuna and Tia, was mostly focused on traditional math and science study. Tony was not so different. While Tony and Lee were top students in Canada on scholarships and so were certainly knowledgeable, that did not explain the vast difference in technical ability between the men and women that Hyuna and Tia had perceived. Team members' expectations (i.e., who take initiative, leads) seemed to be gendered to some extent. While Lee and Tony merited technical roles, unchallenged cultural repertoires that manifested in the social life of the team potentially primed them for these roles. What Lee described as "automatic" likely involved a mutually consenting process of signaling and positioning of self and others from the time that they had first met. Whether conscious or unconscious, such conditions amounted to the team requiring less of Hyuna.

The first engineering disposition that appeared to emerge in Hyuna was to be dependent on others and identify strategies to compensate them for their work, which included doing their math homework and sourcing completed assignments for the team. Hyuna benefitted from relying on technically stronger teammates, but tended not to actively learn and apply their knowledge from the periphery: "Well, I asked him because he is good and then he actually like worked on the project and he doesn't slack off. So I can't actually like…when I'm with someone who is like focused on the work then I can work better. I can focus on work too. So I asked him to work with me." Hyuna saw Lee as persistent: "He works on the project or lab until it works." Yet Lee's work and Hyuna's work were distinctively different. Observations during modules and projects show that Hyuna assisted Lee, lightened the atmosphere up by talking, waited for the work to get done, and did not fully engage in the learning that modules and projects were meant to promote. Lee very much enjoyed the attention and the chance for social interaction with Hyuna, who often observed on the side, asking him questions that he was always happy to answer. As Lee notes: “Hyuna most of the time, she is the supportive kind of person. I don’t know if I should say this but, I don’t think she knows well most of the stuff. So if there’s a decision, I'll make the decision and then she’ll do something else.” Such patterns were repeatedly observed when Hyuna worked with other people: she socialized, supported, and did unrelated work while they were working on core project tasks. At the end of project 1, the team judged Hyuna’s contribution as less than average (90%), representing the only real warning over her lack of technical engagement.

Hyuna remained in a peripheral technical role during Design I project 2 despite the new practice of attempting to share technical work that resulted from the dispute in project 1. In meetings, she remained technically unengaged, remained silent for long periods of time and only became active on issues of tasks and scheduling. Improvements in the team with respect to communication and task delegation were underway, but the clear and equitable distribution of roles and responsibilities remained elusive. This led Tony to comment once during a project meeting, after hearing her coordinate scheduling decisions, that “We are meeting now today and we really have nothing to bring to the table other than when to meet again!” Hyuna spoke up about coordination issues, asked basic technical questions, made off-the-mark suggestions, and was often interrupted, talked over, or ignored. Hyuna got teased or called out, usually in a good-natured way, over her lack of knowledge, impractical suggestions or choices, and for not doing her own work. Yet, Hyuna engaged humorously in banter and appeared to enjoy people’s reactions when she said technically outrageous things or expressed her disinterest. They found her funny. At the beginning of project 2 when the team was brainstorming ideas, she laconically suggested just programming the entire advanced multimeter project in VHDL, which Tony pronounced as ridiculous: “You can’t do everything in VHDL! It’s code!” In another example, Hyuna announced dropping the Data Structures and Algorithms for Computer Engineers course in a devil-may-care fashion, to everyone's surprise:

> Tony: Cause 259 (Circuit Analysis I) is working with….
> Hyuna: I hate 259.
> Tony: Oh, that's your thing - you're computer!
> Hyuna: Maybe I should change to electrical.
> Tia: Do you like (Data Structures)?
> Hyuna: I dropped that one.
> Tia: Wooo-hooo! (everyone laughs)
> Hyuna: No, it's not because I didn't like it. It's because I had a heavy course load and that's the only course I could drop, so…. (everyone gasps, laughs in a rush, surprised)
> Tony: (in a high voice) Which one should I drop? I want to drop something!
> (audio recording)

While good-natured teasing was often employed to create good relationships in the team, Tony called Hyuna out in ways that made her appear naïve, frivolous, and lacking in technical competence. Hyuna was also observed playing to this reputation through her comments and technical disengagement, which garnered laughs, but little respect for her abilities.

While Hyuna continued relying on others to the project's technical work, observations and her own reports in informal conversations and the second interview suggested that she was seeking ways to be more technically competent and contribute as an equal team member. In the lab, Hyuna also struggled to secure a serious technical role in project 2. She was assigned to work on the digital block (DE2 board and VHDL code) with Yao, but there was little for her to do because Heisenberg had provided much of the code necessary in mid-November, the team had decided to pursue an analog solution to the auto range requirement and Hyuna was not learning VHDL because she had dropped Data Structures and Algorithms for Computer Engineers. She had expressed interest in making the multimeter box early in the project, saying, "We all want, we all love it (the machine shop)." It was Tony and Yao who actually went to the machine shop to build it. Interestingly as well, Hyuna spoke frequently to the team about her readiness to "pull an all-nighter" in the last few days to bring the project together. Lee, Tony, Yao, and Tia pulled an all-nighter on November 28 - Jay and Hyuna went home. When Hyuna did engage in tasks, they tended to be low-priority or ill timed. One example was her repainting the multimeter box pink in the machine shop. Another was writing up the report as people were working desperately in the last few days of project 2 before the demonstration. The latter irritated Tia and took Lee away from critical work to patiently explain the design to Hyuna so she could write it up. In the end, as Tia began coordinating the report writing after the demonstration, she had to rewrite Hyuna's sections because they lacked technical precision. In project 2, Hyuna remained uninvolved in most of the technical work on the project. The team generally liked Hyuna, saw her as part of the team's social life, and until the end of project 2, accepted her as someone who just did not do much technical work.

Hyuna's only emerging and sustained technical interest was in soldering during project 2, which contributed to her securing a soldering role in the Design II projects. Interestingly, Hyuna exclusively focused on attempting to get involved building something concrete rather than doing conceptual design work. On November 8, the team tackled the first project 2 task of 'modding' the Altera DE2 Board, as described in Jay's account (Section 6.2.4). In this task, Lee, Hyuna, and Jay had what amounted to an informal 'soldering showdown' to decide who would solder the project. As Lee began, Hyuna watched intently, commenting, "Oh, I did this before. Can I try?" even as Lee was in the middle of the task. As Lee finished, she pressed closer, cutting off Tony's attempt to get in and try:

Hyuna: Can I do it? (Lee hands Hyuna the hot soldering iron, which, standing, she picks up loosely from the end where the wire connects to the solder iron's handle and waves it uncertainly around, pointing it towards Tia and then herself.)
Tia: Be careful with that! That's 410 degrees Celsius! (she means Fahrenheit)

(Jay takes it from her, puts it back in the holder. Hyuna sits down, takes the iron)
Hyuna: How hot is it?
Tia: 410. Careful! (laughs, Hyuna takes it, holding it properly like a pencil this time)
Lee: Resistor on top… (pointing to the DE2 board closely)
Hyuna: Resistor on top of the… I guess
Jay: No, no, no, no, no. Let me try, let me try, let me try. (Jay takes the pliers and resistor away, puts them on the desk, backs off, takes off his jacket in preparation to do it.)
Hyuna: No, it's working! It's working. It's working. Put it here. Put it here! It's working. (Lee picks up pliers, resistor, puts it back so that Hyuna can continue)
Tia: It's melting!
Hyuna: Why is it so slippery?
Lee: So, what do you think?
Hyuna: Good! (finishes, sitting back, Tia laughs, Jay takes iron from her hand, replaces it)
Tony: Yeah, that works!
Hyuna: It's better. I'm doing it!
Jay: No, it's not better.
Hyuna: Why?
Jay: It's not better.
Hyuna: Well, it's because…
Tia: Is it on?
Jay: Damage – it's burning.
Hyuna: No.
Tia: What is burning?
Jay: The board. (video recording, field notes)

Despite her persistence, Hyuna made errors that disqualified her as a potential solder person for the team: she had held the iron improperly and burnt the plastic on the back of the DE2 board. Jay claimed the role through his skill and by citing his soldering experience with his electrical engineering father. After winning the role, Jay continued to 'mod' the DE2 board. Hyuna began playing with the soldering iron and wire in a way that Jay labeled dangerous and undesirable:

Hyuna: (Hyuna shapes the wire into a heart.) Heart! (Jay doesn't notice.) Heart! (Jay notices, smiles. Hyuna picks up iron, melts wire end.)
Jay: (Checking DE2 board wires with Lee, looks up.) Wo, wo, wo! Don't do that! (She stops, he looks at her, makes a sniffing motion to check if it's still burning. She starts again, checks end after the melted wire solidifies. Lee and Jay are at the DE2 board. Hyuna reaches across them to take a piece of wire-wrapped wire, applying the iron to that.)
Jay: You can't hold this (the wire)! (i.e., it's going to get hot)
Hyuna: It's the other one. (i.e., not the solder wire)

Jay: You can try. (he smiles, like he's giving up on telling her she shouldn't do it.)
Hyuna: (pausing, like she's thinking whether she should continue)
Jay: You can try… (Hyuna starts heating up wire, but then Jay takes the solder iron out of her hands and puts it back in the holder.)
Hyuna: So, this thing (wire-wrapped wire) cannot be melt?
Jay: No.
Hyuna: No?
Jay: No.
Hyuna: This one? (pointing to her jewelry)
Jay: It can be melt, it can be melt after 400 degrees, maybe it can be melt.
Hyuna: Oh really? I want to melt this.
Jay: Why you want to melt this?
Hyuna: I don't know.
Tia: For fun.
Hyuna: Yeah.
(Hyuna waits for response, Jay is looking at DE2 board, she takes iron, holding her necklace.) Hyuna: (decisively) I'm going to do it.
Jay: You're dangerous. (Smiling, watching her)
Hyuna: Why?
Jay: You're dangerous.
Hyuna: Why?
Jay: OK. (Hyuna melts her jewelry, fumes come off it.) Don't do that. You're dangerous.
Hyuna: You can have it.
(Hyuna puts away soldering iron, then picks it up again, giving it back to Jay, who uses it to solder the wires onto the connectors as Hyuna/Lee watch. When the iron becomes free again, she attempts to fuse some solder from the wire onto the plastic cap of her mechanical pencil, Jay says it is not possible because solder only sticks metal to metal. Hyuna then produces globules of solder which she cools and then presents to everyone, saying they are diamonds.)
(video recording, field notes)

Such play was discouraged by the instructors and TAs. The solder iron's tip is an expensive, precise piece of equipment with a specific shape and metal combination that creates and focuses heat. Jay and Lee's reaction to Hyuna also signals play around tools as dis-preferred behaviour. Her behaviour enhanced her reputation for being frivolous and not a credible alternative to Jay as a solder person. However, through her play, she learned first-hand that you cannot solder plastic.

Hyuna's negative reputation around tools and the project was reinforced on other occasions. On November 17, Tony, Lee, and Yao were trying to figure out the pin assignments on the ribbon cable so as to connect the DE2 board to the analog circuit. Hyuna had been assigned this task with Yao, but remained peripheral as the male students did the worked:

> Unlike her teammates, the sleeves of Hyuna's sweater extend down over her hands so that only the ends of her fingers show. Hyuna is idle and starts poking wires attached to the circuit randomly into the ports of the ribbon cable. Tony quickly, but gently says "I wouldn't do that if I were you, Hyuna. That's just going to send weird signals through." Hyuna stops for a second and then takes a cable that's lying around and starts moving it up and down the end of the bus, which makes a ratcheting noise. Yao announces that they don't know which pin in the ribbon cable needs to be connected to so they continue looking on the data sheet. Hyuna continues to randomly poke wires into the bus and Tony looks on saying "You think poking your way like that is going to give you the route (connection)?" (field notes)

Hyuna appeared undiscouraged by such shows of disapproval and tried to gain soldering experience as project 2 was being built. She persisted, asking Jay and Lee for chances to solder, observed closely, and lent an assisting hand where possible. Hyuna did not appear to care if she was called out, as she was by Tony when she asked why they were soldering the project:

> Hyuna: Why are we soldering things?
> Tia: Because we have to, because it's more secure. He is soldering these because they fall off so easily.
> Tony: Cause breadboard is meant for prototyping
> Hyuna: What?
> Tony: Breadboard is meant for prototyping – you don't sell anything on a breadboard! (…) As if you're really going to make something and then sell it. You can't keep it on the breadboard right? It's just…
> Hyuna: What about solder board?
> Tony: Solder board – you solder on it so it stays. There's no point making a box for everything if you're just going to keep it on the breadboard right?
> (audio recording)

Tony had also called her out when she asked, as Yao did, why they were building a box when they could just buy one. Tony called her out frequently and Hyuna tended to play along or stay on the defensive. It is likely that, by the end of project 2, she was motivated by a growing desire to be taken seriously by her teammates and continued to seek a meaningful role in the team.

Hyuna persisted in her desire to solder until the end of project 2. On November 28, Jay was soldering several circuits once they had been assembled and tested on the breadboards. The team re-emphasized how critical soldering was, confirming the trust they had placed in Jay:

Hyuna: Can I solder?
Tia: Why not? (i.e., Why can't she?)
Hyuna: (in a quiet voice) But maybe it's, like, Jay's going to do it.
Yao: I think, like Jay…
Tia: Jay's the man…
Yao: Yeah.
Tia: …when it comes to soldering. It's really difficult (in a funny voice).
Yao: Maybe he does the major components first, and just, like, some wires and some easy parts, some other members can try.
Hyuna: Mhmmm.
Yao: We can't risk … too much. (…) Yeah, we must get the soldering done in one shot
–
we don't have time for debugging anymore, so…
Lee: We can't afford to do debugging.
Yao: Yeah, so, just let Jay do it.
Tia: Just let Jay do it.
Hyuna: Mhmmm. (audio recording)

It is very interesting that in several exchanges between Jay, Lee, and Hyuna over the soldering, Tia supported Hyuna's attempts to solder and mentored her in the role later in Design II. For now, though, Hyuna is not being taken seriously:

Hyuna: (Comes by standing up) Can I do soldering?
Jay: Ah? (laughs, Lee looks at Hyuna, Jay doesn't take his eyes of the photo of the voltmeter)
Hyuna: I see you guys bored by it.
Jay: We are busy, sorry. We are busy.
Tia: Participate! Participate!
Jay: You can demo it – you can demoing and you can solder it after the demo. (Laughs with Lee, Hyuna moves away from them.) (audio recording, field notes)

On November 29, the night before the demonstration, Hyuna finally seized her chance:

(Hyuna comes by for a look at Jay soldering with Lee assisting.)
Hyuna: Can I solder now?
Lee: Huh?
Hyuna: Can I solder now?
Lee: (picks up unused circuit board, waves it in front of her) Try it out…solder this.
Hyuna: (after Jay's last solder, Hyuna pulls hair back) Tia! I want to see your hair longer!
Tia: You want bangs? You mean with my hair down?
Hyuna: Yeah, cause…
Tia: I want to fix it back and keep it out.
Hyuna: Yeah, it's better if it's long.
Tia: But it's not short and I want to tie it up.
Hyuna: But it looks better long.
Tia: Yeah, but you'll get electrocuted! (both laugh)
(Jay does another unexpected soldering task. Jay and Lee examine the board with Hyuna looking on. She picks up a piece of solder wire and waits for her chance.)
Hyuna: I'm going to try it.
Lee: You want to solder? Try this one.
(Hyuna takes the circuit, places it on the desk and without hesitating, takes the soldering iron deftly from the holder. Lee places a wire in the top of the board for her.)
Hyuna: This one? (Confidently turns the circuit board over with the wire secure in it, takes the solder wire and iron and proceeds without hesitation.)
Lee: Mmm. (Hyuna does one wire while Jay and Lee look on intently.)
Hyuna: Another? (very clipped voice) Yeah?
Lee: Yeah. One more? (solders one more, carefully, effectively)
Jay: OK!
Hyuna: You see? It's good!
Lee: It's good. (smiles)
Hyuna: Yeah. (smiles) I can solder. (quickly moves away after she has proven herself)
(video recording, field notes)

Hyuna had finally demonstrated to Lee and Jay that she can solder, has a professional demeanour, and has proper respect for the equipment in a way that she did not before. After she left, Jay picked up the soldering she did, examined it, pulled on the wire, and looked satisfied when it did not come out. She was not observed playing inappropriately with equipment again. This marks the emergence of engineering dispositions and thinking towards respecting equipment and being safe and precise. It also indicates that Hyuna had come to the awareness that claiming technical roles in a team was critical to becoming an engineer.

Jay left the team in December, after which Hyuna and Lee began soldering for the team. Design II project 1 involved building a soda-dispensing machine with mechanical, analogue, and digital parts, which measured the level of liquid in a cup by measuring the capacitance across two aluminum strips on either side of the cup. It then activated a servomotor to control the flow of liquid into the cup until full. The project also required temperature to be displayed on the DE2 board. The circuitry for the project was far less complex than that of Design I project 2. Lee recognized it as less complex, less soldering-intensive, and hence, less prone to failure because of soldering mistakes. Hyuna had learned soldering techniques from a Korean friend over the holiday season in order to get more technically involved. During the early stage of Design II project 1, she discussed and demonstrated what she had learned: to hold the iron properly, to clean the tip off regularly, and not to use excessive solder, etc. After Hyuna's first soldering job in Design II, Tia confirmed her skill, saying "She's really good! She's really good!" Hyuna was very happy and went on to solder much of the circuitry early in February before the demonstration. Tia had assisted Jay and so mentored Hyuna on these jobs:

Tia:	The way Jay does it is he takes the wire and the resistors, the smallest ones first – because they're all the same height. The shortest ones are the wires, so he put those ones on first and then just put this like that (…) because they're all the same height so that nothing will fall down. So, wires first.
Researcher:	I get to observe her technique.
Tia:	Yay! She's really good. (both silent for 1 minute as Hyuna solders) So you can put this one lower. (1:40 passes as she solders, Tia puts more pieces onto board)
Hyuna:	I'm just trying to do this
Tia:	Oh, trying to fit everything first? (Hyuna: Yeah.)
Hyuna:	I can't…. (being careful to keep parts in place as she turns it over)
Tia:	You could use this (hands her a ruler)

(35 minutes of soldering goes by, most of it quietly. Hyuna transfers parts from breadboard to circuit board, uses a ruler to keep the pieces in place, turns the circuit board upside down. Tia watches, checks and holds it down as Hyuna soldered. Hyuna completes the soldering,

Tia:	Yay! So goooooood! Look at this – isn't it beautiful? This is what Hyuna did! (audio recording, field notes)

In a follow up chat, Tia noted that though Jay left the group, they did not miss him anymore because Hyuna was now the solder person.

Yet, the results of both Jay and Hyuna's soldering were mixed: circuits that worked on the breadboards ceased to function once soldered. In Jay's case on project 2, four of six key circuits failed after Jay had soldered them: "We soldered everything - every part was tested to be working – and then suddenly the voltmeter just stopped working properly." Hence, despite the team's confidence in Jay, the failure of most of their circuits before the demonstration meant 6 out of 10 points – a far less successful result than project 1. When Hyuna began soldering the Design II projects, the results were similar. The debugging job fell to Lee: "(I) resolder the temperature sensing part – it was working, and after she (Hyuna) soldered it, it wasn't stable…it jumps." Lee spent hours debugging the circuit, and in project 2, he started to take charge:

> I remember something like, Lee was really concerned about soldering after the first and the second project of Design I. So when Li and Hyuna want to touch that Tony's transmission piece (Design II project 2) and they want to solder it, Lee stopped them because he doesn't want them to mess it up or do dangerous stuff with it because if that piece break down, the entire project's done. He realized the risk of soldering and if you don't know the piece well enough like you can't fix it so you might actually spend a lot of time to fix it.
> (Yao, interview 3)

Soldering required good technique combined with an understanding of circuit design, and because Hyuna did not understand the design, she could not debug the circuits. Soldering problems were not limited to this team: almost half of the fourteen groups observed demonstrating project 2 had problems; a smaller number of failures were observed in Design II projects. A running joke between students and instructors/TAs during demonstrations was that "It was working fine until last night!" or "It worked well until 30 minutes ago!" In the next year after deciding that manual soldering had detracted from learning, Heisenberg made the switch to printed circuit boards (PCBs).

Hyuna compensated for her lack of technical engagement in the form of homework assignments that she either completed by herself or acquired from her extensive social network outside the team. Beginning to Design I project 2, she worked on assignments during lab time when others were working on the project, offered them to the team members and even completed and submitted them online on their behalf. This was appreciated by her teammates as a time saver while they worked on the project, although Jay and Tony were observed deriding her lightly (e.g., "Yeah, of course you didn't do it yourself."). Some of the team's assignments also went back into Hyuna's network. During the team's kickoff meeting for Design II project 1 on January 15, Hyuna provided a 2008 project report that she had acquired from her Korean CU network. Hyuna claimed the report had a very similar design to project 1, although she did not "have any of the stuff" (i.e., the physical project itself). The teammates expressed great interest in the report and scavenged it for ideas that they could apply in the project.

Larger roles began appearing for Hyuna on occasion. In the January 15, Tony asked her to lead a discussion at the whiteboard to delegate the tasks and draw up a schedule for the new project. The lackluster showing in Design I project 2 had exposed flaws in the team's approach to projects that resulted in another shift in the team towards better communication, improved prioritization of project goals, and full task definition and delegation. Design II project 1 offered Hyuna the opportunity to work with Tia on the capacitive liquid height measurement design. They still deferred to Lee, Tony, and Yao on technical matters but tasks were fully delegated in Design II, so Hyuna had a better technical role and began investing more time in the team by curtailing her social life. Yet, she had not become invested in computer engineering per se, sharing several times that she regretted going into the programme and had told first year students not to join. She voiced interest in programmes and jobs that were more social (e.g., MBA) or involved outside work (e.g., civil, mining engineering).

The emergence of new function in Hyuna's case can be described in three points. First, Hyuna scaled back her non-engineering activities, particularly her social life, as a necessary step to dealing with her workload. Rather than this resulting in greater buy-in to computer engineering, it represented buying into the team. Second, with Jay gone, Hyuna gained an emerging role for as one of the team's soldering people, though to mixed reviews. Third, the greater task delegation gave Hyuna more chances to move to more meaningful roles. Despite her emerging technical role in the Design II projects, for whatever reason, condition did not really, as in Jay's case, pressure her to go past the peripheral role she had inhabited. Her secondary, assistive roles on tasks, homework exchange, tendency to be off task, and her position as a social figure seemed to be somehow functional for the team in the projects. Yet, her freedom to inhabit these roles was not necessarily functional for her learning.

Yet, Hyuna reported that soldering the projects in Design II was one of her most significant changes over the year and demonstrated an emerging awareness that she needed to be less dependent:

> I learnt that maybe I should - because sometimes I more, like, depend on the group so I think I should be more assertive to the work and then maybe actually, like, try to do by myself some stuff. So I can do more stuff than depend on the help of the group. (…) Like soldering. (Hyuna, interview 3)

At the end of the study, her new disposition to contribute to the team through a more meaningful technical role was merely emergent. A turnover in dominance was not observed.

6.5 Tia – Coordinating, Communicating, and Trusting Her Own Technical Authority

"I'm thinking that because we're all from Asia, we were more comfortable with each other. Like during the first meeting: 'Oh! Fellow Asians!' I think it would have been very, very different if another person or say two or three (Canadian) students were there. I'm not sure if anyone would get intimidated by that, but I think…that person would have an edge over speaking because that person could be, could be the one who would do most the talking in the meeting, probably."

(Tia, interview 1)

6.5.1 Section Summary

This section gives an account of how Tia developed from a student who went from learning in a lecture and textbook-based math and science mode of study as an engineering transfer student and an unclassified CU student to learning in a team-based project mode of study in second year ECE. In her team, Tia immediately occupied a key coordinator and communicator role and gradually shifted into a technical role in which she came to trust her own authority (Figure 24). The real historical conditions relevant to Tia's trajectory (Stage 1) are that she:

1) was an engineering transfer college student;
2) was used to a comfortable intimate learning environment prior to CU and now felt isolated as an unclassified student;
3) preferred traditional math and science to a team-based mode of study
4) tended to avoid interpersonal conflicts; and
5) was confident in her academic and communicative English ability.

The identifiable changes in external conditions relevant for Tia stemmed from her moving from a traditional science and math mode of study as a transfer and unclassified student to the far more demanding integrated second year curriculum at ECE, which involved team-based design projects. Tia was challenged with the new requirements at CU (Stage 2) because she:

1) went from an socially isolated learning context at CU as an unclassified student without a programme into a comfortable team in Design I;
2) moved from a traditional math and science mode of study which had allowed her to control her time and avoid interpersonal conflict to more demanding team-based project mode of study; and
3) came under new expectations to do hands-on work and be self-directed.

Tia's inner contradiction can be expressed as: How do I do the right thing in cultivating the team's emotional life, following the rules, and doing engineering well? These conditions and this inner contradiction placed interesting tensions on Tia, which drove her evolution.

First, Tia moved from preferring to work alone in traditional math and science study and disliking pair or team work in labs to rapidly inhabiting a key role as the team's coordinator and communicator. This was made possible by Tia's communicative ability, her capacity to foster harmony and avoid conflict, and the cultural and personal backgrounds of her team members. For Tia, the experience of being the team communicator and coordinator "kind of opened my eyes to what could be my role be in a group." Tia came to understand that such communication and coordination was critical to engineering and that conflict avoidance came with a price. As such, she began clarifying and questioning technical decisions in her team. Second, Tia's academic preferences shifted from traditional math and science study to hands-on application of math, science, and engineering knowledge. This shift was observed through Tia's experiences on the projects: her informal technical apprenticeship by Tony, Lee, and Jay; her designing and building of the power supply circuitry for Design I project 2; and her lead and mentoring technical role designing and building a capacitive liquid height measurement design for Design

II project 1 with Hyuna. A third shift related to Tia moving into a more central technical role was a change in how she responded to authority and rules. Tia tended to defer to the authority of 'experts' in her team and to the instructors and TAs, conferring and enforcing this authority through her role as team communicator and coordinator. Yet, the poor performance of Design I project 2 made Tia question her previously unquestioning faith in the leadership. Tony's claims and easy confidence in project 2 had not been matched by results and so Tia was more active. She began to clarify and question others' technical ideas, define project requirements, analyze tasks, and delegate work, signaling an emergent self-reliance with respect to technical knowledge and project decisions. There was not enough time to observe whether this last shift became a newly dominant trend. Stress-related health issues possibly brought on by her increased work load from term 1 to term 2 caused Tia to take a leave of absence from the programme in early March 2013.

The change in Tia's engineering dispositions and thinking proceeded to Stage 5 (restructuring process/new trajectory observed). In general, the nature of Tia's evolution was that she immediately assumed a communication and coordination role in the team. Through designing and building important parts of the projects in Design I and Design II, beginning with the power source, Tia came to appreciate practical application and to trust in her own technical authority rather than always turning to others. The specific engineering dispositions and thinking she developed through his enculturation, that reached Stage 5, were:

1) Value engineering communication as integral to technical knowledge.
2) Value constructive collaboration.
3) Trust one's own technical authority.
4) Value practical application of knowledge.

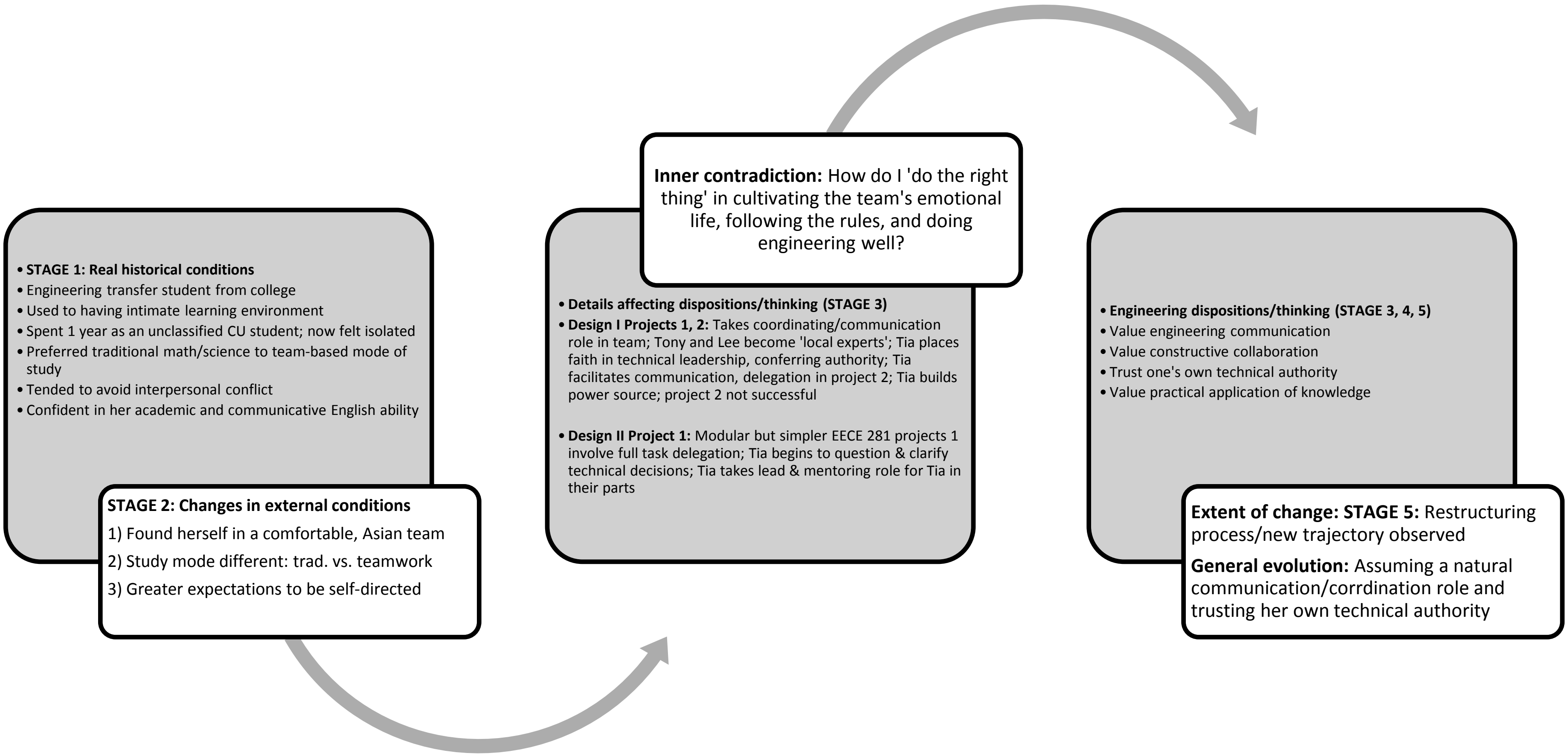

Figure 24. Summary of Tia's Trajectory

6.5.2 Stage 1: Real Historical Conditions Relevant to Tia's Trajectory

Tia was born in the Philippines, where she did all of her K-12 schooling. Tia had loved math since elementary school and later discovered her love for physics in high school. Her father is a mechanical engineer and he indirectly influenced Tia to do something related to math or science. During high school, she focused on math and science subjects taught in English while taking the required social studies and humanities classes, taught in the Tagalog language. In her first year of university study in the Philippines, she enrolled in a bachelor degree in math and was considering a career either teaching or working in actuarial science. She had some doubts about both and, while in first year, she identified engineering as a possible career path to the delighted her father. Tia's family immigrated to Canada in 2009 in search of a better future and with the encouragement of their extended network of relatives already living on the Canadian West Coast. Tia took a year adjusting to the change, relaxing, traveling, and visiting relatives and friends. She reported that her mother "turned her around" and had her join Other Engineering Transfer Programme College's (OETPC) science programme in fall 2010.

Tia experienced several transitions going from university in the Philippines to second year ECE at CU. First, relationships with professors in the Philippines tended to be formal and distant: Filipino students were expected to address professors properly with their titles. In contrast, professors in Canada were less formal and more accessible: Tia could call professors by their first names and talk to them easily after class or during office hours. She loved the small intimate classrooms of 20 to 25 people at OETPC because it was easy to get to know professors and students alike. She became close to many of the international and immigrant students there by the end of the term and found the first group of people she could feel comfortable with since coming to Canada. Her results from year earned her an offer to take CU general engineering courses in fall 2011 as an unclassified student. Although this did not give her full entry into CU's engineering programmes, her engineering father was proud. She worked through a number of pre-requisites that year so as to be ready for second year ECE by fall 2012. While an unclassified student and without membership in a cohort at a large university prior to September 2012, she missed the intimate and supportive educational environment of OETPC. She felt isolated.

Second, Tia understood that study in second year ECE at CU would mean far more team-based learning than she had experienced as an unclassified CU student or at OETPC. Her pre-requisite courses at CU from September 2011, like courses in OETPC's programme, were mostly lecture-based and focused on assignments and exams, which was a very familiar mode of study for Tia. This changed as she joined the second year ECE programme, which involved team-based design projects. Until this time, Tia had limited and negative experiences with teamwork in high school and at OETPC, largely due to poor communication and personality conflicts between teammates. Her most recent negative experience was in a first year engineering lab course at OETPC in which Tia was in a team with a male Canadian-born native English speaking student who was "really bossy" and insisted on his ideas and opinions. When Tia shared her ideas or solutions, he "(cut) me at the middle of my explanation - he really wanted to have his way." Tia reported that whenever she encountered such conflict, she deferred to others:

> During group work and I think of something and another person thinks of something else…I wanted really try avoid going into some discussion or fight, so I would just zip it and I would just say "Let's have it your way." (…) At first I'd try to explain, but if it's getting, the tension is getting higher, then, 'OK, let's have it your way!' (Tia, interview 1)

Tia reported hating conflict of any sort, noting that when someone is not really listening, there is no point in carrying on: "Usually, when that happens, I usually succumb to the other person to avoid conflict. (…) Sometimes I'm a pushover!" Tia volunteered that she has a tendency to seek what “the right thing to do” is in any situation, and attend to what others think, and follow the rules, sometimes at the expense of her own feelings. Her teamwork experiences before coming to CU explained her preference for working alone: she could control her own work and time and avoid communication problems and unpleasant differences in opinion.

Third, Tia was challenged to improve her academic English. When she came to Canada, her English was functional, but not “easy flowing”, particularly her productive skills (writing and speaking). She reports having to translate what she wanted to say from Tagalog to English and was concerned about her ability. She focused on language during the year at OETPC by taking English 12 and then the Test of English as Foreign Language (TOEFL) and became quite proficient and confident in her academic English. From interviews and observations, the real historical conditions relevant to Tia’s learning trajectory are: 1) she had been a transfer student who had been comfortable in friendly, intimate learning environments at OETPC prior to coming to CU, 2) she had been studying for a year as an unclassified CU student without a peer group or a programme before September 2012 and felt isolated, 3) she preferred traditional math and science study to team-based projects because she had experienced many team conflicts in high school and OETPC, 4) she tended to “zip it” and remain quiet when interpersonal conflicts occurred, 5) she was confident in her academic English ability.

6.5.3 Stage 2: Identifiable Changes in External Conditions Relevant to Tia

The identifiable changes in external conditions that Tia experienced stemmed from her transition from first year courses at OETPC and pre-requisite courses as an unclassified student at CU into CU’s second year ECE programme. Firstly, she had lost her close learning community at OETPC and found it difficult to replace it at the much bigger CU: she got lost in classes. There were also Canadian-born students who had grown up together in classes, making it harder for her to make friends. With her entry into second year ECE, Tia found herself in a team during the first lecture that was very comfortable:

> I'm thinking that because we're all from Asia, we were more comfortable with each other. Like during the first meeting: 'Oh! Fellow Asians!' I think it would've been very, very different if another person or say two or three (Canadian) students were there. I'm not sure if anyone would get intimidated by that, but I think (…) that person would have an edge over speaking because that person could be, could be the one who would do most the talking in the meeting, probably. (Tia, interview 1)

Communication from the outset was friendly, indirect, and somehow natural:

> It's so good because everyone was…I don't know, every time we had a meeting and…it wasn't that much of conflicts that we had, or if there was, it just gets solved, I don't know how, it kind of gets – just gets solved naturally. I don't know how. (Tia, interview 1)

For Tia, the interpersonal dynamic that emerged at the beginning of term emerged somehow implicitly and invisibly from the interactions of the team members, possibly thanks to the teammates' common origins in East and Southeast Asia, their similar circumstances as international students or recent immigrants at CU, and the absence of native English speakers. These factors appeared to shape the team's emerging practices and culture.

Secondly, Tia was most familiar with lecture and textbook-based study and she began second year ECE with a preference for this mode of study because she could avoid unpleasant conflicts and control her time. CU's second year programme was more integrated and involved team-based design projects, something that Tia began to find appealing, despite her early experiences:

> Like, I was really excited to start these ECE courses because it makes me feel more engaged on the career that I want to go in. Because first-year courses are like 'Rrrrrryyeah, OK, I'm doing math, I'm doing physics (i.e., gestures like she's bored).' But this - because we have to deal with electrical circuits hands-on. I was excited about (it). (Tia, interview 1)

Accompanying this change was the expectation Tia felt to become a more self-directed learner.

The identifiable changes in external conditions for Tia stemmed from focusing mainly on traditional science and math study as a transfer and unclassified student to joining the second year ECE programme as a full engineering student. Specifically, she 1) went from an isolated learning context at CU as an unclassified student into a comfortable Pan-Asian team in Design I, 2) moved to team-based project work from traditional math and science study which had allowed her to control her time and avoid interpersonal conflict, 3) came under new expectations to do hands-on work and be self-directed. Observations and interviews suggest that Tia's inner contradiction was essentially how to do the right thing, which involved her balancing her need to attend to the emotional life of her new team (e.g., maintain harmony, avoid conflict, create community), to respond to the expectations and rules of authority (i.e., the team's experts, the instructors, TAs), and to do engineering (e.g., be self reliant, figure things out for herself, build and test circuits, move people and the project forward). Each of these placed interesting tensions on Tia, which will be discussed in the next sections.

6.5.4 Stage 3: Emergence of New Dispositions and Thinking

The engineering dispositions and thinking that emerged in Tia are introduced in this section. First, Tia came to realize the value engineering communication as integral to technical knowledge. Tia immediately occupied a key role as team communicator and coordinator because she had good communication skills, liked to take care of people, and did not see anyone else stepping into the role: "I just think of myself as someone who talks a lot and kind of ask people what they like and then tells the rest of the group what this person is saying." Thanks to her first few technical communication lectures, she also reported an early shift in awareness of what engineers do from “OK, here’s my output - if it’s working, then it’s good” to “Ooooh, we have to communicate the project we did to another person!” She began facilitating the team’s internal (in-person, Facebook, email, phone) and external communication (professors, TAs). She was also the coordinator for the teams’ project 1 formal report following the demonstration in the third week of October. Her adjustment from independent, traditional math and science study in first year to functioning in a team-based project in second year was smooth and rapid perhaps because of her interpersonal and communication skills and the supportive team in which she found herself.

Tia played a key role in the team’s conflict in project 1 (Sections 6.2.4, 6.3.4), which stemmed from factors such as the lack of clear and explicit communication, poor time management, lack of explicit task delegation, Jay’s lack of buy in to the team, and Tony and Lee's control of the project. As noted in Jay’s account (Section 6.2), when it was time to evaluate peers and divide up marks. Lee, Tony, Tia, and Hyuna agreed that Jay did not deserve full marks and so they had to communicate this. Tia facilitated the team’s Plan A, which was to avoid any direct confrontation by having each student submit their evaluations of each other to Kelvin so he could average the scores. Tia consulted a TA, who told her the approach would not work, because the team had to agree on the scores: “if someone gets a low mark, he has to know why.” Plan B was to reduce the discomfort of direct confrontation with Jay by presenting his mark as a group decision. The four submitted scores by ballot, Tony averaged them and Tia called Jay over so the group could show him the mark. When Jay saw his 65%, he rejected it, asking for arbitration. As discussed, Kelvin met everyone individually and then recommended giving an equal share of marks. He also directed them to delegate tasks and communicate explicitly in project 2 so as to give each team member a chance to get a full share of marks. The team’s proposed solutions to the marks conflict seemed to stem from same underlying approach (i.e., conflict avoidance, indirect communication) that caused it in the first place. Tia reported that Kelvin had changed everything because he had made them aware of their collective need to communicate and explicitly delegate tasks. As such, the peer evaluation component of the assessment sparked change in the team's culture and practices and in Tia herself:

> It was kind of like the climactic point that changed everything and everyone realize that it was not just a Jay's fault, it was everyone's fault for not getting him really involved by saying "Can you stay and do this? Can you still do this?" (Tia, interview 2)

Through this experience, Tia and the team became increasingly aware that conflict avoidance and inexplicit communication comes with a price in engineering projects. Tia began to be aware that her tendency to "zip it" was not a desirable approach to communication in teams.

Through this experience, her natural disposition towards the importance of constructive collaboration became enhanced because she realized that avoiding conflict and indirect communication and collaboration came at a price. Tia was observed doing the most to initiate changes in team practices, starting with the early meetings of project 2. She made attempts to focus and structure meetings; facilitating communication by asking for updates and critical comment (what was working, what was not); clarifying project tasks, requirements, knowledge and material resources; and initiating and facilitated scheduling and task delegation. After the conflict, Tia noted that change had occurred:

> The thing we're doing right now is we're being organized for project 2, but we weren't like that for project 1. We would do this and then we stop and we continue tomorrow without thinking about what should be finished tomorrow. Something like that. (Tia, interview 1)

Observations suggest that the new approach was a distinct but incomplete change in the team's practices. They responded to some of what Tia was attempting to facilitate, but it was not the dramatic change at the team level that she had claimed. As Tia reports, the marks dispute had caused the change, but it was not mentioned again: “It was a big jump. I was thinking about, I don’t think…we don't talk about problems we had, right? I don't even think that Yao has an idea that we had that problem before because it is going so smoothly now.” Thanks mostly to Tia, the team had achieved a degree of task delegation and more explicit communication, although these goals were not achieved fully and inefficient use of time persisted in the team.

As part of her emerging role as communicator and coordinator, Tia was observed attending to the emotional life of the team and building a sense of cohesion among her teammates. She did this specifically by using light humour, commiserating with and cheering people on, acting as a figure of fun to relieve tension, positively characterizing others, expressing trust or admiration in others’ work and abilities, and monitoring and articulating people’s moods. Tia was observed throughout the project acting as the go-between and attending to teammates’ emotional needs at critical points. For example, the first meeting on November 2 was the day after the dispute was resolved and so Tia repeatedly asked if Jay was okay with going overtime in the meeting because he was going to meet his friends that day. She also complimented him on his knowledge and hinted at him inviting them out to socialize sometime. As a second example, on Yao’s first day on November 6, Tia was key in welcoming Yao by showing admiration for his machine shop experience, referring to common Design I experiences, including him in a ‘bonding night’ with the team, and welcoming him in the team’s increasing level of collaboration on homework assignments.

Tia noted her sensitivity to others’ feelings: “I take my feelings into consideration – sometimes I don’t think that they are important compared to what others are feeling.” Observations and interviews during project 2 show that good human relations was of primary importance to Tia's sense of well-being rather than being a teamwork strategy: "You know the problems we had with project 1, right? And then for project 2, everyone was always there, so it's kind of uplifting knowing that everyone was cooperating and everyone was just doing their part. Just really good!" The team also recognized her role in fostering cohesion in the team. Hyuna noted "she's trying to make our group kind of special, so it feels like we belong together or something." Li, a new team member who replaced Jay, also noted that "Tia was really good in, like, welcoming me in the group so that I don't feel strange …I feel like they are not hating me."

Tia had a tendency to defer to authority and as communicator and coordinator, confer it on teammates and also enforce it, on occasion. Project 1 had resulted in Tony and Lee becoming the respectively outspoken and quiet technical leaders or 'local experts' of the team, and Tia identified them as such to the team members on multiple occasions using characters from a teamwork video. On November 5, Kelvin had a guest speaker on teamwork in the lecture so as to encourage students to reflect on project 1 and improve their approach to teamwork. The speaker used a video from the early 1970s of a plant production meeting to present scenarios and provoke discussion about how Mac, the plant manager, should find a solution to a production problem from a team full of difficult personalities who challenged his authority. The video was paused at multiple points and the students discussed what Mac (aka "the leader of the pack") should do next to both move towards a solution and maintain his authority. A second, very knowledgeable engineering character, Ansel, was another leader in the all-male meeting of mostly Caucasian attendees. Tia began calling Tony "Mac" (aka "the leader of the pack") and Lee "Ansel" at times and frequently referred to both Tony and Lee as "super smart", reinforcing their technical leadership status. On November 14, when Yao, Jay, Hyuna, and Tia were in the lab preparing to discuss the project, Tia said aloud to everyone: "We have to wait - we can't start without them (salutes). They (Tony and Lee) are our bosses!" She was observed on several occasions being dependent on Tony and Lee to explain basic technical knowledge. Tia also began calling Jay The Solder King towards the end of project 2 as he worked to solder the project for the team.

Tia's characterizations of the local experts of the team also came with a fair amount of trust and faith in their abilities and their decisions, which occasionally had the effect of muting other team member's suggestions and ideas. Yao, for example, contested decisions Tony and Lee pushed forward without much explicit consultation that turned out to be time-inefficient. For example, when Yao questioned whether soldering was going to be easy. Tia dismissed his concerns, saying, "You're talking to the son of an electrical engineer!" and later repeated to everyone Tony's comment that there was plenty of time for soldering. When Yao questioned the need to spend time making the case, Tia sided with Tony and Lee. She also repeated incorrect information that they would lose marks if they did not do certain tasks because the instructor, Tony, or Lee had "said so". When Yao questioned the need to solder project 2, she repeated Lee's (incorrect) information that they would get zero if they did not. When Hyuna asked for a rationale for soldering, Tia's response showed she had not really examined if from a technical viewpoint: she simply said, "Because we have to."

Tia frequently sought out detailed information on what was expected in the projects. As there was so much information flowing among the teams about the projects, the techniques required to do the projects, the assessment criteria, and the relative importance of different project requirements were not always clear. Many students struggled to get and make sense of the information they needed in order to make hard decisions when they were under time pressure. Tia's information seeking was sometimes understandable, yet at times it was at odds with independent problem solving skills required of engineers that entailed thinking through requirements, criteria, conditions, constraints, resources, and methods. Information seeking in Tia’s case appeared to be linked to her drive to do the right thing and to feel secure. Several observations indicate that Tia did not at first understand that doing engineering was not always about satisfying external expectations but about what works best given the requirements, conditions, and constraints. During one brainstorming session on November 17, the male students in the team were exchanging concepts for a circuit design that would allow the multimeter to select the proper reference voltage when the sign of the input voltage (i.e., the voltage between two points in another circuit) to be measured was unknown. Lee was discussing how to take the difference across the device under test (i.e., the input voltage – a voltage difference). Tia interjected “Are we expected to do that?” which resulted in brief silence and stares. What ‘we are expected to do’ did not make sense: it was about ‘what would work best’. Tia tended to focus on what instructors and TAs were requiring rather than what would be a good idea or design. It was usually Tia who chased down TAs, instructors, and the lab technician to find the details of what was required, often on matters that were the team’s responsibility to figure out or decide.

Tia was rare among students in her team almost unstinting attempts to enforce the “No Food or Drink” rule in the lab to both her teammates and other students. It became a running joke in the team and Tony, Hyuna, and later Lee derived great pleasure from coming up behind Tia to crack open drink containers next to hear ear, sneak bits of food in her peripheral vision so she could see, or eat donuts luxuriously in full view. This deeply concerned Tia at first but she gradually began to play the enforcer in a more comical vein. Hyuna attributed Tia's tendency to hold fast to rules to her background. While she could communicate with Tia, she was unable to share and feel close to her because she was too strict about things:

> She’s really like religious. But she’s really like more her morality is like really high? (…) So if I go like “Oh, how about drinking (alcohol)?” and she's like “No, no drinking!” You know last time like really eating in the lab and then she's so against it (…) and then I ask her, oh, I ask her if she had a boyfriend before and then she said no. And then she said she doesn't want any. (…) and then she doesn’t even want to get married, so I don't know … it's difficult. (Hyuna, interview 2)

Tia began to grow technically in project 2 after having very little technical input into project 1. She confessed having very little hands-on experience before project 2: “I like it but I’m not comfortable with it yet. (…) It’s just not…I’m not used to it.” In early project 2 meetings, Tia was the most active in communicating and coordinating during non-technical talk in the meetings, but was far less talkative when the male students were addressing the project’s design challenges and sharing technical information. During these topics, she was far more engaged than Hyuna, but tended to take a monitoring role: listening, asking clarifying questions, following along with the technical talk, and discussing supplies. Yet, Tia did not contribute during whole group technical discussions because she thought others’ ideas were better.

Tia’s movement into a technical role marked the emergence of two new dispositions and thinking towards technical work. First was her beginning to trust her own technical knowledge and authority rather than trusting the experts of the team. Second was that she was beginning to like and value practical over theoretical application of knowledge. Tia became more engaged in technical talk after she stepped up to the task of building the power supply on November 6, upon which she began calling herself “The Power Ranger”, a Japanese TV hero. She sought out Tony and Lee's knowledge, advice, and recognition on technical matters. In the second project meeting, Tia engaged Tony with several specific questions about her power supply design in an unusually terse, fast-paced discussion. Her exchange with Tony was one of several one-on-one discussions she had with him about technical details and design that were distinct from their other more casual interactions: it was direct, clipped, and entirely technical. Tia clearly enjoyed engaging with and being apprenticed by Tony and Lee in the technical aspects of her piece of the project and took much time and pride building the power supply from November 17-27. Tia worked with Jay as he transferred and soldered the power supply onto a circuit board, all the while carefully checking and correcting because she knew the design best. The power supply worked very well and Tia announced proudly: “I build that! I build thaaaaaaaat!” At this time Tia, perhaps not by coincidence, took a caramel from Hyuna in the lab and said “Thank you! (to Tony) Look!” and ate it. Later, she mentioned that when the pressure is on, some rules “go out the window”. It is very interesting that for her, the involvement in building, testing, and soldering the circuit successfully had somehow broken her out of her usual rule-orientation at this time.

6.5.5 Stage 4: Turnover in Dominance

Tia grew into a new role as technical lead on a small part of Design II project 1 and also moved from conferring and deferring to technical authority to clarifying and questioning technical decisions in her team. The rather poor performance of project 2 in November raised questions for Tia. The team had held Tony, Lee, and then Jay up as the team’s experts and placed much faith in them for the project 2 decisions: going with Heisenberg’s dual slope ADC design when they had a functional version of their own, soldering the circuitry in a modular fashion before they had fully tested it as a whole on breadboards, soldering the circuitry in the first place when time was tight, and designing and making a purpose-built box when one could easily have been bought. These decisions were strongly influenced by Tony and Lee and some had never been explicitly and fully discussed. In hindsight, the team realized that their score of 6 out of 10 had resulted from making time-consuming choices during a period of overconfidence following Design I project 1. As such, Tia began to question her faith in Tony because his easy claims and confidence in project 2 choices had not matched the project results.

Interestingly, observations during in the first Design II project 1 meeting on January 15 and in later meetings and exchanges about the project, Tia was far more explicit and critical during technical talk than she had been before. For example, she questioned Tony's confident assurances about how easy the capacitive liquid height measurement design would be:

> Tony: We have module 2, we have THE capacitor – the cup with plates in it - we have the thermometer. We're going to get that, right? It's just a component, right? There is just a component and there will be a way of setting it up and it's just going to be a resistance.
> Tia: The way you say it sounds so easy.
> Tony: I mean, at the moment, the electronic one is just going to be a resistor, right?
> Tia: Mmmm. Is it? (audio recording, field notes)

Tia also became more centrally involved in defining the technical requirements and analyzing the tasks for the project, which was a first for her. She was persistent in clarifying the exact requirements for project 1 in the first project meetings, distinguished between requirements and extras by focusing on the assignment wording, and helped to identify and delegate the key tasks. Her enthusiasm during Design I project 2 of devising "extra features" (i.e., extra functionality in the project for bonus marks) had been replaced by an interest in eliminating unnecessary work. Tony's overconfidence in Design I project 2 had made Tia reconsider what a leader was:

> I realized that, being a leader is more than just being talkative and social, because Lee is definitely not the most social person in the group. But then I realize that being a leader also you need to be very knowledgeable, of the material that you're doing….and that's Lee. (Tia, interview 3)

The task delegation was more decisive than in Design I project 2. They had learned that teammates moving between parts of the project was time inefficient and discussed this explicitly in the meeting. Tia and Hyuna were in charge of the capacitive liquid height measurement design and Tia took the lead on design. Tia had assisted Jay in soldering her power supply because she knew the design and had built the circuit. After building her design with Hyuna, Tia mentored Hyuna in soldering parts of project 1 in Hyuna's bid to become more central to the team.

Tia was observed continuing in Design II project 1 in her role as the team's communicator and coordinator until she took leave from the programme due to stress-related health reasons in early March 2013. Once she had left, her teammates were quick to recognize the central role she had played since Design I project 1 in September 2012. Lee, who had taken over the role, contrasted their working style and flows before and after Tia had left:

> She'll ask 'OK, when are we going to be done with this part and when can we…?' This kind of stuff. What we had (after she left) was OK, Tony is there working on his part and like Yao is also working slowly (…) I think it slowed down quite a bit. (Hyuna, interview 3)

Tia was key in cultivating the team's emotional life and motivating and building team confidence in order to move forward. Hyuna recognized the team's loss: "She was so energetic and then she was always like cheered up for us – it's kind of like, feel empty after she left." Lee also noted that when Tia left the team, it was "the biggest loss" because she coordinated the technical report writing for the projects: "I, I don't know how she does it but, but all the three reports she managed to pull them all together. For this, the last five of us worked together. (laughs)."

6.5.6 Stage 5: Restructuring Process Leading to a New Trajectory

There is evidence of substantial change in Tia through her six month second year engineering study in the team-based design projects. Tia came to immediately inhabit a communication and coordinating role and was still in the process of consolidating and stabilizing a central technical role and becoming technically competent as a central member of the team. Firstly, her appreciation of her new capabilities in teamwork was pronounced:

> I appreciate it, I have this, a better higher regard on teamwork. (…) I love it now because well, we had a good experience, a great experience and I guess before high school stuff, we have just little things to do that I was thinking "Oh I can do that by myself" But for (Design I) and (Design II), I realized that in the future I will be doing huge stuff that I know that I won't be able to do it by myself and it kind of opened my eyes to what could be my role be in a group. (Tia, interview 3)

This role became dominant early in the academic year and matured through the projects. In particular, Tia had come to understand that such communication and coordination was crucial to engineering and that conflict avoidance and indirect and inexplicit communication had its price in engineering projects. Secondly, she had transitioned effectively from traditional study in math and science to applying science and engineering principles and knowledge to produce functional projects. She also came to prefer hands-on work in the lab far more to lectures and exams, which she came to consider boring. She reported moving from theory into practice:

> I thought of myself because I came from math, and before I went to engineering, so I was more like a theoretical person, than the practical and then when is it? So, right now I realized that I think I'm more, I'm more inclined to do engineering stuff than just sticking inside a box of theories. (Tia, interview 3)

Further observation was needed to determine how stable this change was and whether it had given her a new direction in central technical roles. Thirdly, Tia had also moved away from her deference to authority and embraced self-reliance in figuring out problems and engaging in technical work. This change was emergent and related to her move into a more central role:

> It's the first time that I've had a course where it's not just lectures and exams, and it's really about (…) building that project – it makes you feel proud and feel more like an engineer. (…) It feels great that you know something and you just don't know something but you can do, you know, you can do things, you can create products, you can…yeah, you can create an output out of what you know. It's not just writing an exam and passing it. (Tia, interview 3)

Tia departed early from the team before Design II project 2 was fully underway and so further observation was not possible after project 1. During Design I, she had one less course than the other students and her full course load in the second term was a possible factor in her health problems. She noted: “Aside from the headaches that I had, the tension migraines that I had, the time, the time management was rough, a bit rough. Because midterms, they come, they don’t just come up, on separate times. They sometimes go in a block so it’s kind of hard.” While Tia was quite attentive to her teammates’ wellbeing, she was less attentive to her own. Despite growing stress-related health problems in Design II project 1, she chose not to say anything until taking leave. It was a surprise to the team because Tia had remained silent until the end: “I don’t (didn’t) want them to get worried.” She continued monitoring the team on Facebook and email, giving them moral support, and acting as a resource person for the final report.

While workload as a contributing factor to her stress-related illness, Tia was still determined to be an engineer and to continue second year in the 2013-2014 academic year. She recognized the importance of having difficulties and challenges in her engineering study: “What I’m thinking now, school is training ground for the workplace, and I’d rather experience some hardship now than experience it later after graduation, so I wouldn’t mind having a hard time in my courses.” Tia did come back the following year and rejoined the programme.

6.6 Yao – “Getting Past/Passed” Versus “Aiming High”

“It’s more like trying to get past/passed instead of trying to aim high - and after a few more rounds I see some of my friends they just don’t show up in the exam, and even one guy he looks at the exam and he stand and rips it in half and just walks out.”

6.6.1 Section Summary

This section gives an account of how Yao, a student who aimed for academic survival learned to regulate his thinking, emotions, and body in a demanding engineering programme while working in a team who tended to aim for perfection rather than just a pass (Figure 25). The real historical conditions relevant to Yao's trajectory (Stage 1) were that he:

1) disliked high pressure schooling because it did not encourage effective learning;
2) had the highest English ability and the most experience living in Canada in team Z5;
3) chose engineering because of his peer group, his subject interests, good job opportunities, and his engineering uncles;
4) had an extreme fear of failing and believed students was being consciously 'weeded out' in the programme; and
5) was consciously sacrificing himself now for a better future.

The identifiable changes in external conditions from first to second year for Yao (Stage 2) were:

1) there was increased pressure on him because of the newness of the content, the workload, and new assessment practices that made him more fearful of passing;
2) the move into project work motivated him because it was more like engineering;
3) his early experience in his first team was negative due to lack of communication and accountability;
4) he joined team Z5 from project 2.

Yao's inner contradiction can be expressed in the question: How can I balance my approach towards time/mark-efficient activity to "get past/passed" with my need to maintain harmony as a new member of a team that is "aiming high"?

Yao's status as a newcomer in team Z5 made it difficult for him to go against project decisions that he considered inefficient from a time and marks point of view, but that were largely dictated by Tony and Lee. The tension between Yao's "getting past/passed" and Tony and Lee's "aiming high" perspectives on project 2 became manifested in the building of a box for their multimeter in Design I project 2. Tony was very attached to the idea of having a well designed, purpose built box tightly housing a soldered, perfectly functioning multimeter. This box came to drive many decisions that Tony and Lee were in the position to influence (i.e., compacting circuitry, soldering the project in 'the 11th hour' so it fit, targeting bonus marks on the basis that basic functionality was assured). Yao preferred simple design decisions and a focus primarily on basic functionality. Yet he felt it best to let go of his ideas when they were dismissed. Lee was aware that Yao was doing so, noting that he was "good at controlling his anger." Yao also showed solidarity with his new team by matching them hour for hour in the lab despite disagreeing with many of the decisions that kept him there. Yao's behaviour serves as examples of how he regulated his own thoughts and emotions to maintain team harmony. Project and programme demands also led Yao to a conscious process of regulating his mind by adopting strategies for coping with the heavy content.

The change in Yao's engineering dispositions and thinking proceeded to Stage 5 (restructuring process/new trajectory observed). In general, the nature of Yao's evolution was that, as a new member, he came into a team that had a perspective on projects, which was mismatched to his disposition towards basic functionality and getting passed in the course. His Z5 teammates wanted the kind of perfection they had achieved in Design I project 1. Through his technical contributions in project 2, Yao gained status as a technical leader with Tony and Lee. Once Design I project 2 failed to deliver the expected results and the Design II project got underway, the gap between Yao's "getting past/passed" and Tony and Lee's "aiming high" narrowed: team practices were changing.

The failed project 2 prompted the Tia and the team to more explicitly analyze and delegate project tasks and aim for basic project functionality over perfection. The team also adopted some of Yao's ideas, particularly to mitigate potential risks (e.g., producing a spare breadboard prototype). The specific engineering dispositions and thinking Yao developed through his enculturation, that reached Stage 5, were:

1) Seek simple, functional solutions.
2) Engineering thinking: i) Find a method to solve problems, ii) Don't waste time or energy, iii) Know how to find answers.
3) Be consistent, reliable, and resourceful.
4) Regulate emotions: Don't panic, control anger, maintain harmony.
5) Discipline your body, delay gratification.

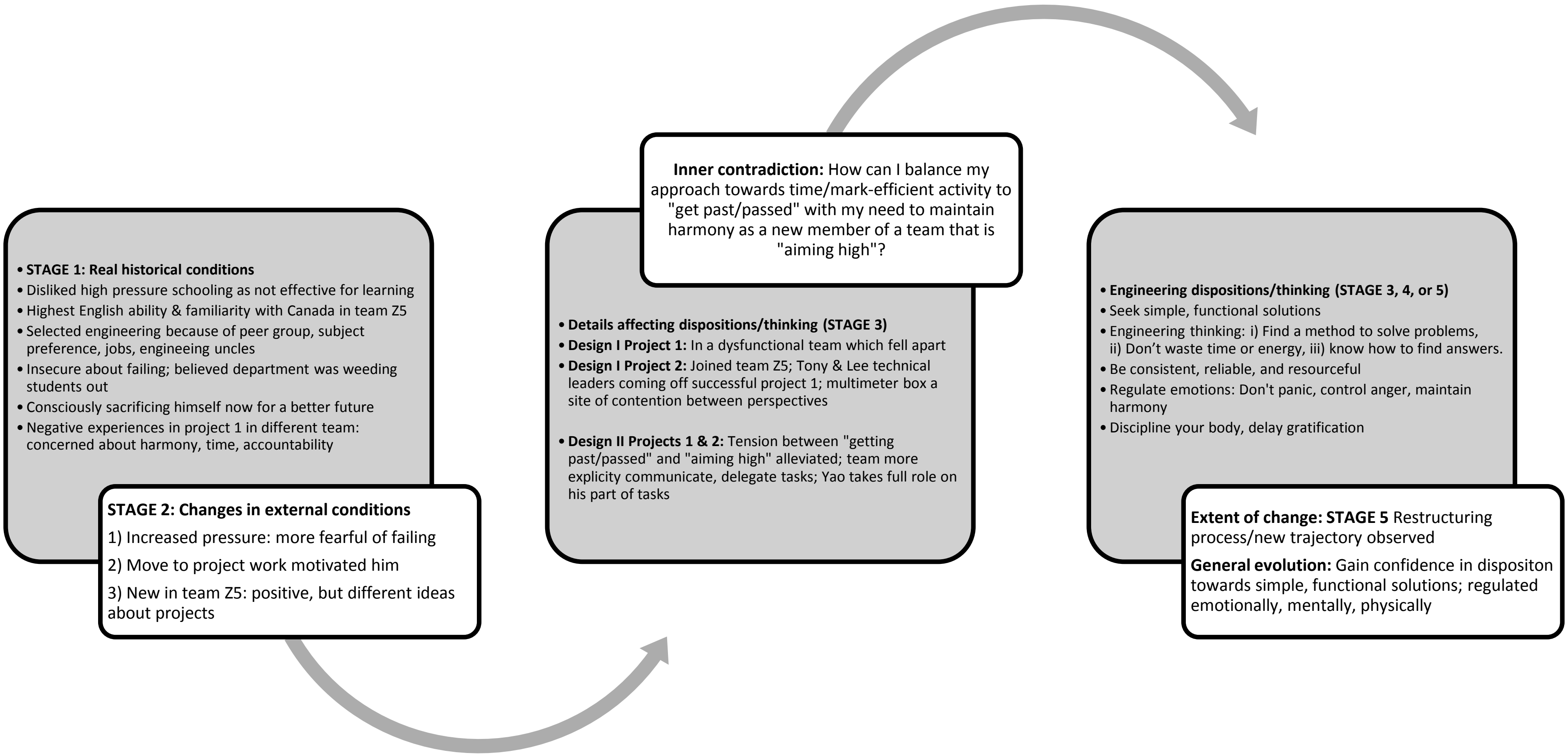

Figure 25. Summary of Yao's Trajectory

6.6.2 Stage 1: Real Historical Conditions Relevant to Yao's Trajectory

Yao grew up studying in very different K-12 school systems in Hong Kong and Canada, but preferred the latter. Although born in Canada, Yao returned to Hong Kong as a toddler and spent K-6 in the Hong Kong school system. To Yao, education in Hong Kong was "really harsh to student - we don't really learn much like that, because we (were) not mature enough to understand the material and they just forced the material in." In Hong Kong, Yao reported that long hours and private tutoring to drill the material into kids was seen as necessary for success at school, but something that he did not think resulted in effective learning: "you're basically like a robot and you just write the exam." Yao intensely disliked his time in his Hong Kong school because "basically they want you to compare and compete with other students." Schools publicly disclose grades and Yao claimed "if you don't do well you'll be embarrassed in front of classmates" to the point that poorly performing students are made to feel bad, bullied, or even excluded from higher education as early as primary school. Yao returned to Vancouver, Canada in 2005 for the rest of his K-12 schooling. As such, he had the highest English language competence and the greatest familiarity with life in Canada of those in team Z5.

Yao's interest in engineering grew from grade 10 because of his peer group, early awareness of job opportunities, subject interests, and family influence. First, he did not study much until grade 10, when he joined a hard-working, mark-focused peer group, which made him reticent to slack off. Second, Grade 10 Planning exposed Yao to a lot of career information on technical professions and to a survey, which recommended engineering or business as Yao's best options. Third, engineering fit Yao's interest in math and science and his desire for a good career where he could work indoors. Math and science came naturally to Yao and so he focused on these subjects in grades 11 and 12, taking Math 12 in the summer after grade 11 and AP Calculus in grade 12 in preparation for university. Third, Yao's two uncles were both engineers, which influenced his decision. His "big uncle" worked for a Hong Kong construction company, was very knowledgeable, and became a distant idol. Yao's second uncle owned a toy company and got him interested in computers and computer engineering. While applying to universities, Yao knew admission to computer engineering was more difficult and so he went for the harder option, thinking he could switch to computer science if it did not work out.

Yao reported an extreme fear of failing and believed that students were being consciously weeded out, both of which partially drove his approach to study. He felt "unprepared and scared" when he first came to CU and knew he had no choice but to work hard. He had the impression from his high school teachers that first year math and science would be a review, but this with the exception of math (he had taken AP Calculus) this proved to be false. In his first chemistry class, for example, the professor started talking about quantum theory in an attempt to appeal to students, but Yao found this intimidating. He saw many students giving up in exams because it was too hard: "I see some of my friends they just don't show up in the exam – and even one guy he looks at the exam and he stands and rips it in half and just walks out." The number of people dropping or switching to easier universities or faculties contributed to his idea that engineering departments were trying to "eliminate those who cannot handle the pressure and stuff like that." Yao's hard work paid off with low A's on his first midterms - class averages were in the 50-60% range. He came to realize that high school marks were highly inflated, engineering marks were very low, and so a huge drop was normal. Yao also came to view studying engineering as "more like getting past/passed instead of trying to aim high."

Yao's success in the first term made him feel he had gained some experience and could handle school without pushing himself too hard. He "slacked off" in the second term and his average dropped. The positive effects of AP calculus had worn off and he now started to go to classes unprepared. After the second term, Yao took careful notice of the drop in his marks and decided to get serious again because did not want to fail engineering and disappoint his parents:

> I want to work for my future, so I know if I work hard now, my future will probably more comfortable and so it's just a decision. If I go to arts it might be easier now, but do I get a job after I graduate? (Yao, interview 1)

Yao demonstrated this by sketching a graph (Figure 26) of happiness by year and major.

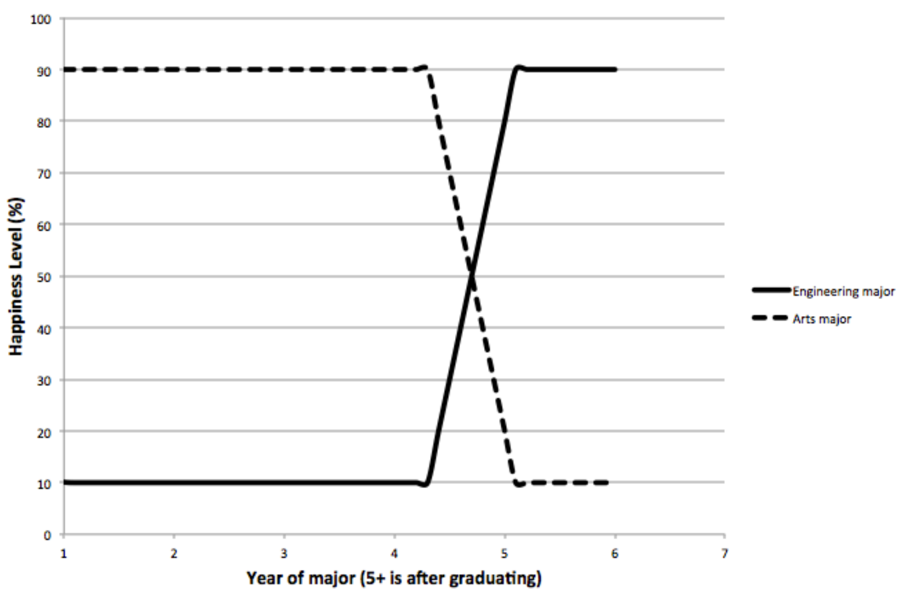

Figure 26. Yao's Happiness Versus Year by Programme Graph

He explained that though he was suffering in his degree, he would actually be better off long-term compared to those in arts because of the job opportunities in engineering. Yao was sacrificing short-term happiness for long-term gain and began second year at ECE determined to do better. The real historical conditions relevant to Yao's trajectory were: 1) he disliked high pressure schooling because it did not encourage effective learning, 2) he had the highest English ability and the most experience living in Canada in team Z5, 3) he chose engineering because of his peer group, his subject interests, good job opportunities, and his engineering uncles, 4) he had an extreme fear of failing and believed students were being consciously ‘weeded out’ in the programme, and 5) he was consciously sacrificing himself now for a better future.

6.6.3 Stage 2: Identifiable Changes in External Conditions Relevant to Yao

Yao found early second year a shock even compared to first year and saw himself as subject to his department’s conscious process of eliminating students: “second year for ECE is another round of tests.” This made him feel vulnerable. In his mind, the positive effects of his advanced high school study had worn off, course content was difficult, and assessment practices in some courses were unfamiliar, which all heightened his fear of failure and reinforced his focus on marks. As an example, for the Circuit Analysis I midterm, students needed to get the correct answer in order to get full marks and would get no part marks on exam questions: “they don’t look at your steps, so it’s a bit of a new style we need to learn.” Yao loved the course but got zero on the midterm. He noted that in several of the problems on the 21-question midterm, he was on the right track but made silly mistakes, such as forgetting minus signs after using his calculator. He was “really shocked and scared” by his early marks in second year.

Yao was initially positive about teamwork and the chance to design and build projects in Design I and Design II: “First year, I don’t feel like I’m studying engineering and second year I feel more like – ‘This is the stuff!’” He saw first year as effectively a continuation of high school study: “It felt like we were in science for the first year.” Yao saw the benefits of project work and engineering co-op as going beyond grades: learning how to talk and use vocabulary like an engineer, making contacts through school and industry that would later serve his career, and learning how to function professionally. Yet, despite his initial enthusiasm, he had a very negative experience in project 1. While originally happy to find himself with friends from first year and high school in team Z7, ECE's decision to run the integration pilot that displaced Jay from his original team also displaced Yao two weeks after the start of term:

> I got forced into Z13. Before I was with my friends, I was happy and stuff and then suddenly I got into this group of strangers, I didn't know them, so it's hard to communicate with them because before, with my friends we know each other, we can communicate well and it's kind of peer pressure thing if you don't do your work you'll get, like I mean, other friends would ban you from the group. (Yao, interview 1)

Yao labeled his new team as dysfunctional: it had no natural leaders and teammates did not communicate well and had too many extra-curricular demands. Two were "seriously avoiding work" while another willing teammate was too dependent on them. Yao and Kor, his only friend on the team, decided to take control and design and build a multimeter without much support. They had problems achieving a functional design and ended up days before the demonstration desperately debugging it. It began to work, but when they gambled on a teammate's solution to the remaining problems, the multimeter failed to work at all. They demonstrated and got 5.95.

Yao and Kor realized they were in trouble. Project 2 would be more demanding and complex and they lacked the people and knowledge to make it work, because one of their team switched faculties, the second was too involved in sports and "not willing to make sacrifices", and the third cared more about himself than the team. Yao lamented that "I know if we continue with this group, we're doomed" and Yao and Kor approached Kelvin with their problem on October 22 after his Monday lecture. Yao was downcast and almost teary-eyed and described their situation to Kelvin, who arranged a team meeting. Kelvin reported, "one of them (Yao) is 'cracking' and the group is suffering." Yao requested reassignment to team Z5 because of their reputation as a strong, functioning team and Kelvin agreed after their November 1 meeting. Tia, Hyuna, and Tony had also heard of Yao's team breaking up, knew that someone was going to join the team, and were hoping it would be Yao because he too had a good reputation.

The identifiable changes in external conditions relevant to Yao were: 1) there was increased pressure on him because of the newness of the content, the workload, and new assessment practices that made him more fearful of passing, 2) the move into project increased his motivation because it was more like engineering, and 3) his early experience in first team was negative due to lack of communication and accountability in the team, 4) his first team broke up. Coming off first year, Yao was focused on surviving in the programme and so his inner contraction as he joined and came to know team Z5 at the beginning of project 2 was between his need to balance his "getting past/passed" approach to engineering study with the need to build good relations and maintain harmony with his new team mates who were "aiming high".

6.6.4 Stage 3: Emergence of New Dispositions and Thinking

During the November 6 project meeting, team Z5 welcomed Yao warmly. Tony solicited ideas from Yao on project 1 and showed flexibility in task delegation. Tia suggested that Tony invite Yao to an "ADC bonding night" so they he could get to know them and the design and signaled the team's openness to collaborating on non-Design I work: "Why don't you work together? That's what the best friends are for!" Yao signaled respect, competence, and flexibility by acknowledging their design ("Yeah, yeah, you guys got the idea (of attenuating and then amplifying voltage) already!"), identifying his skills, and offering to do menial tasks ("I have some experience in machine shop…maybe you guys can give (the box) to me to polish it or something."). By all reports and observations, Yao quickly blended in and became an asset to the team. He was very attentive to harmony, particularly over the first two weeks of the project.

Before being unavoidably absent for the first hour or the November 8th meeting, he posted apologies in advance to Facebook saying, "I am willing to do extra work to make up for this mistake – again, I am extremely sorry, guys - please forgive me!" Unavoidably traffic before another early meeting resulted in Yao giving a very formal apology with his head bowed when he arrived 40 minutes late: "I can assure you this will never happen again." The team members found this entertaining because he seemed so serious, but told him everything was fine.

While welcoming Yao, members of the team also signaled roles and expectations. Tia began Yao's first encounter with the team by identifying them as "Mac" and "Ansel", engineering leaders in a teamwork video shown to students by a guest lecturer on November 5 (described in Section 6.6.4). Tia continued calling Tony "Mac" (aka the leader of the pack) and Lee "Ansel" at times and frequently referred to both as "super smart", reinforcing their technical leadership status. Tony also appeared to be asserting his position as the leader through a rather formal, authoritative summary about the way forward on project 2, something that was observed neither prior to nor after this first meeting with Yao:

> We decided on a couple of deadlines just so that we know. Try and meet those deadlines. The machine shop has to start working on the chassis (multimeter box). We have to finish testing all the breadboards, because the breadboard are the same shape, as the, as the circuit boards, right, so we finish testing the breadboards first so soldering the next day. This one is, this one will be done at…but the ADC. Soldering is Lee. Umm. VHDL has to be done within this week or next week. This week being all the logic that you already know and next week based on the new ADC, whatever changes happen. You're (i.e., Jay) in charge of…transistor-beta conversion so that has to be done this week, basically all the thinking and planning we try to finish and then see how you're doing. (audio recording)

Tony, Lee, and Tia also signaled the team's standards by talking at length about the beautiful multimeter box that Tony had already designed, referring to their successful project 1, and declaring the level of competence of the team mates ("Our friends are, like, state-of-the-art!").

Once the project meetings focused on project 2 design challenges, Yao demonstrated his capacity for developing solutions. Tony, Lee, Jay, and Yao first discussed the voltmeter and auto range designs. Yao was central in contributing ideas to the challenge of selecting the proper reference voltage when the sign of the voltage to be measured was unknown, for which he garnered the team's immediate respect. His engagement with problems on many occasions was well informed and insightful with a tendency towards simple and elegant solutions. Yet, despite being technically capable, Yao as a new teammate was not in a position to assert his "getting past/passed" approach to technical decisions. Until Yao arrived, Tony and Lee had been setting the technical agenda and controlling the design and decisions so as to "aim high." The difference in approach described differently by Lee, who inevitably sided with Tony in disagreements:

> I can also see, like disagreements between Yao and Tony. They're just always, quite often… like conflicting ideas, like Yao usually goes for more – I don't know – more, more sort of 'Do it simple, but it may not be the best solution, but do it simple' but Tony is like doing 'If you're going to do it, do it correctly.' (Lee, interview 2)

Tia, Lee, and Yao reported independently that Yao had to be careful not to cause disharmony by voicing concerns about the team's "aiming high" approach because it had led them to a successful project 1.

Yao spent time tuning into the environment to be mark and time efficient:

Yao:	I think every student treat marks as money and you're… so when you are in that position you try to maximize your use of time.
Researcher:	Yeah so they treat marks like money, that's interesting. Do you talk about it like that with the other students or…?
Yao:	No, but I think everyone does the same, like they think 'Yeah, so I only have limited amount of time so how can I distribute it to maximize my marks?'
Researcher:	It's a complex calculation in a way? But it goes on - it's almost subconsciously or…
Yao:	Like I won't bring out a calculator and say 'OK, I have that many hours and divided up by that many courses or maybe I, oh this course is worth more so. I won't do that.' But I think the first project first term, I didn't have that

> to plan anything ‘cause the team were struggling to put the thing together and I spent way too much time. (Yao, interview 1)

Yao perceived Tony and Lee’s “aiming high” approach in terms of marks: “(Tony is) more aggressive – I think he focused a lot on the marks and he wants to make sure we get all the marks that we can get.” Yet, Tony and Lee talked about marks far less than Yao, who talked about them in almost every meeting. Yao often told mark crisis stories; for example, about how he had missed marks, made careless mistakes on assessments, misinterpreted what was required on assignments and tests, or was denied marks by instructors. Yao was often the protagonist in these humourous stories that seemed to be told to relieve stress and to commiserate and connect with other students. Talk of marks irritated Tony at times. Once, he abruptly ended Yao’s questions and suggestions about how Tony could get more marks by blurting out “I don’t care!” On another occasion, Yao told the team one of his mark crisis stories and asked Tony whether he should contest a grade he got on a midterm: Tony replied “I wouldn’t bother – it’s done.” As such, Tony and Lee appeared to be oriented to high quality work, from which good marks would naturally flow. This tension in between “getting past/passed” and “aiming high” manifested itself most clearly around the purpose-built box that Tony and Lee were so keen on and a number of other important decisions around it that had unexpected negative impacts on Design I project 2.

6.6.4.1 The Multimeter Box as a Site of Contention

The multimeter box became a key site of contention between Yao’s orientation to “getting past/passed” and Tony and Lee’s “aiming high” on projects. Like all project 1 and some project 2 decisions, the decision to make a multimeter box was strongly influenced by Tony, Lee, and Tia without much explicit discussion. The project 2 requirements stated:

> All the circuitry must be built using solder boards and properly packed in a metal or nonflammable plastic box. You can buy a pre-made box from the electronics stores in town or you can build your own box in the EECE metal shop.

At the beginning of the project 2 kick-off meeting on November 2, Tony wrote down “chassis” (i.e., multimeter box) on the project room whiteboard as the second item on a list of key tasks to be delegated that day. Two days later, Tony posted a sleek design for the box on the team's Facebook page that he had made using SketchUp, a simple version of AutoCAD. The box’s dimensions were calculated to house the DE2 board and two solder boards with connecting wires and multimeter probes so as to minimize empty space. On November 6, when Hyuna asked if they were going to make it, Tony teased her in a way that bordered on ridicule:

> Hyuna: So you need to make this in the machine shop?
> Tia: Cool guys!
> (Tony draws in his breath, imitates them by pulling an innocent, surprised expression)
> Tony: Where do you think it’s going to come from?
> (intonation suggests her question is ridiculous)
> Hyuna: I thought, I don’t know, if I…
> Tony: Dollar Shop? Home Multimeter Cases?
> (making up fictitious retail names; all laugh) (audio recording, field notes)

When Tony teased or called people out, it appeared to be good-natured banter, but it also seemed to carry the implicit message that he was right. He inserted “right?” at the end of his rapid-fire sentences containing technical content, propositions, and ideas. He tended to present his decisions as obvious, and used humour and his position as technical leader to reduce or eliminate dissent. Consciously or not, his easy confidence, his humour and his rapid-fire, sometimes incoherent Malaysian-Indian accented English were observed to have the effect of disarming less knowledgeable or confident team members so they would come around to his ideas.

Tony suggested through the exchange that it was ridiculous to think that they can buy a box. Yet, in fact, electronics shops sell them. Shortly after, Tony led a discussion about the details of the box, including whether they should have a square hole in the top to see the readouts, what colour it should be, and how aerosol sprays work. Such detailed discussion around the box, which was not an explicit project requirement, suggests that Tony and Lee underestimated what was ahead. Making a box may have seemed a matter of course to some in the team because conditions in the environment. It appeared in the project requirements as an option, the team had aimed high and succeeded in project 1, students had undergone machine shop training, and the box was discussed in lectures and among Design I students, which may have led to making a box being a fait accompli.

Yao questioned the value of designing and making a box but was dismissed:

Yao:	Do we get bonus marks if we made our own box, or what if we just buy it? I mean…
Tia:	I don't think they care.
Yao:	Then what's the point? I mean - it's just for fun.
Lee:	Yeah, I didn't want to buy it for fun last time. (laughs lightly)
Tia:	Yeah.
Tony:	We didn't really discuss about it.
Tia:	Yeah. No buying.
Tony:	Who wants to buy a box? (i.e., no)
Tia:	Better to make it. (draws in breath) A better question is: who takes custody? After…
Lee:	Taking custody! (laughs)
Tia:	I'll bet Lee will apply for his right.
Hyuna:	What is custody?
Tia:	Who will own it afterwards? Who would…
Hyuna:	Me. (Tia laughs)
Tony:	She's right.
Tia:	Yeah.
Researcher:	You use the word custody when you talk about a baby: who has the baby.
Tia:	Yeah, kids. It's our baby! (laughs)
Tia:	We're all the parents.
Hyuna:	Let's just destroy it. (audio recording)

With Yao's challenge dismissed, they had, de facto, decided to make a box. Interestingly, Tony and Lee's "aiming high" perspective towards the project is apparent: Lee "didn't want to buy it for fun last time" and Tony agrees, asking, "Who wants to buy a box?" This question is presented as having only one correct answer. In addition, Tia dismissed Yao's question as less important than "Who takes custody?" - language normally used with respect to guardians and children. She points to the emotional meaning Tony, Lee, and Tia harboured for project 1, which was not necessarily shared by the others. Hyuna joked, "Let's just destroy it!" Jay remained silent.

On November 15 Tony, Lee, and Tia discussed when to build the box and whether they should build it before building the circuits on breadboards. Yao asked them how they will fabricate it and mainly Tony explained how they would do it in the machine shop. At this time, two weeks before the demonstration, the only hands-on work done was the DE2 board 'modding' on November 8 and modules 5 and 6. Time was limited, very little core work had been done on the project, and yet, the box remained a priority. Tony and Yao eventually built it over a three-hour period in the machine shop on November 21, eight days before the demonstration at a time when the power supply, the beta meter, autorange, and voltmeter were only partially built. The now-build box also became entwined with other contentious decisions.

The next contentious decision around the box was whether or not to transfer the circuitry from the breadboards after prototyping to the circuit boards for soldering. For Tony and Lee, in order for the project to fit into the tightly designed box, it had to be soldered onto two circuit boards. On November 27, Hyuna asked openly about the original rationale for soldering anything onto a circuit board (Section 6.5.4). This was a very good question given the limited time available and because the industry standard is printed circuit boards (PCBs). Tony responded with light ridicule and the topic was dropped. On November 28, Yao also questioned the value of soldering the project so it would fit in the box so close to the demonstration. From his discussions with other teams, he had identified the potential danger that soldering a functional prototype onto circuit boards would render it non-functional:

> Tia: Is doing an all-nighter out of the question?
> Tony: Yeah.
> Tia: Out of the question?
> Tony: What's wrong with it? We won't be doing one. We won't need one.
> Yao: Do you, like, for, if we don't solder it, is it like do they just deduct 5% or something like that? Many people, after they solder it, their circuit is not working.
> Tia: They fail.
> Tony: If we don't solder it, it won't fit in the case. Yeah. (firmly, intonation down, like it's the final word)
> Tia: Mmmmmm.
> (Lots of crosstalk: Jay, Lee, Tony, Tia)
> Lee: If you don't solder it, if you don't solder it….
> Tia: They get a failing grade. (audio recording)

Several points suggest that the team had neither discussed their priorities directly nor assessed time constraints effectively. First, there was a fair amount of misinformation as to whether a project would get zero if it remained on the breadboards. The assessment criteria were unclear on this and students were making their own interpretations and also circulating conflicting information. Interestingly, while Lee states firmly to the group on several occasions that teams will get zero if they do not solder, Heisenberg noted later that teams could easily demonstrate a functional project on the breadboard and accept a loss of one or two marks. This was not known by all students. Second, this discussion happened two nights before the demonstration, which suggests that the team was overconfident in Jay's ability to solder the project perfectly. Third, Tony noted that if they did not transfer the circuit from the breadboard to the solder board and manually solder it, it would not fit it into the box. That Tony presented the need for the project fit into his tightly designed box as a reason for soldering suggests that he was neglect priorities during a time of crisis, likely because he had not realized that a crisis was unfolding. Another example of a surprising waste of time was when Hyuna painted the box pink in the workshop on November 26, three days before the demo.

Another contentious decision occurred on November 28, when Tony, concerned about the tight dimensions of the box, proposed to “compress” the voltmeter and other circuitry on two of the three breadboards to fit onto one breadboard for soldering. Yao suggested compressing and soldering the circuit would make it prone to mistakes. Tony was observed in the lab dropping the issue. He put the breadboards and tools down until Yao left to do something else. After talking with Lee and then checking over the workbenches for Yao, Tony picked up the breadboard and tools and did it. Lee later reported that he had agreed with Tony’s decision, despite it being prone to error. Yao returned and was surprised, but said nothing and went back to his VHDL. A chat with Yao later shows his disagreement with this move:

Yao:	(comes over, opens the topic) Like, today’s decision was kind of wrong.
Researcher:	Yeah?
Yao:	To compress the board so that we can fit it onto two boards.
Researcher:	Oh, I see.
Yao:	I mean to compress the circuit, right?
Researcher:	Oh, I see. Because it was working better on the breadboard?
Yao:	I mean, with this kind of project, when it’s working, just keep it that way. Don’t mess around with it.
Researcher:	He (Tony) wanted to do that for the extra compactness and..
Yao:	Before we only had two soldering boards so…and our box design is so compact. He wanted to achieve minimal amount of space.
Researcher:	So it results in more work, eh, that decision.
Yao:	Yeah.
Researcher:	Were you hoping not to do that?
Yao:	Yeah, we learn from this this time and next time we know what to do.

(field notes, audio recording)

The last sentence suggests that although Yao could see the downside of such decisions, he did not have the power to stop them and let them go. Another contentious decision arose when the height of the capacitors on Tia’s soldered power source circuitry exceeded the box's dimensions. Tony and Yao proposed different ideas for fitting the boards into the box. Tony suggested cutting the capacitors off and resoldering them so as to be parallel to the face of the board in order to achieve a lower profile. Yao suggested adding more screws to the top of the box to suspend the cover at a higher level, something that would not require changing anything. Tony presented these to Lee without naming the author of the idea. As Tia later noted, Lee sided with Tony's anonymous idea, to Tony's delight:

> Then you could see Tony smile like "See! I was right!" and then he told Yao that and then it was never officially resolved. I mean there wasn't…. (Researcher: It was never officially resolved?) There wasn't a closure like, there wasn't a time when Yao said, "OK, OK let's have it your way" and then I don't know what happened, but we just let it pass and then one time I think Tony was finding something to do so he asked me to come over to his work station and then – "Can you hold on to this?" and he did what he wanted to do. (Tia, interview 2)

Yao reported why it was difficult to say anything about Tony's refusal to engage in explicit discussion and decision-making in the team during project 2:

Researcher:	OK, when did you start feeling like this was a problem? (…)
Yao:	I think I noticed the problem…more than half way through. (November 17)
Researcher:	More than half way through. So was it difficult for you to say something about it?
Yao:	Yeah because I know they got high marks for the first one, so if I came on forcing them to go the safe way they need to sacrifice on marks, so if they don't use the prototype board they use the breadboard, they might lose half a mark or so but for me it's worth it, but for them because they got so high the first time, I know it's kind of hard for them to accept it so…
Researcher:	Right yeah. Why couldn't you tell them that?
Yao:	I think it's because from what I see like because Lee and Tony they're smart and they know their stuff so even if I say "Go the safe way!" they, like Lee and Tony I don't want to make them to lose marks like before they try it. So if they try it and it doesn't work then it's OK but if they haven't tried it and then afterwards it works and then you lose some marks they might blame me for that.
Researcher:	Yeah that's true, so you have to make that calculation and not really bring it up in a way.
Yao:	Yeah.
Researcher:	So were you thinking about how it might affect the relationship in any way or?
Yao:	Yeah I was scared that if we go the safe way and we get like eight or something.

Researcher: Yeah.
Yao: And then they might say if we had gone for the prototype thing we'd have gotten a nine and if we colored the box and it we could have gotten ten or something like that. (Yao, interview 2)

Design I project 2 was for all intents and purposes, a failure for the team. The team recognized this after the demonstration, although they did not engage in a full post-mortem in subsequent project meetings. Right after the demonstration, Yao noted to all present that the team had not even shown Kelvin and the TAs the multimeter box they had invested so much time in. In the chaos of the demonstration, it lay at the end of the bench, forgotten in their panic. The team agreed, downcast. Yao later reported:

> Even for the box, like, which they put so much time in it, like, even during the last day they still want to add more stuff to it, but I was saying…they wanted to recolour it (on the last day)! Coloring doesn't worth anything and even at the end we didn't even show them the box even though we put some much time in it! (audio recording, field notes)

6.6.5 Stage 4: Turnover in Dominance

Yao's need to balance his drive to "get past/passed" in the programme with his need to maintain harmony with team mates who were "aiming high" drove him towards greater self-discipline. Beginning with emotional self-discipline, Yao accepted the decisions of the team even though he did not agree because he would not risk the harmony of the team. It was difficulty for him, but he let things go. He also displayed solidarity by accepting the long hours in the lab doing things that he personally felt were neither efficient nor meaningful in terms of rewards. Tia, Lee, and Yao recognized he was not in a position to strongly disagree with Tony and Lee on the contentious decisions that contributed to the poor result in project 2. Lee praised Yao's response to disagreements with Tony, saying "He is good at controlling his anger" and noted how, along with tolerance and organization, that "anger management" was a top quality of a good teammate because "like, for small things that leave us in anger, and we'll just, we'll just spoil everything." Yao also reported managing his emotions so as to maintain harmony and bore no resentment towards Tony and Lee as he enjoyed their optimism and technical knowledge. Yet, he felt had "no role" in the team, despite his contributions to the designs and his work on VHDL. He felt marginalized and unable to fully voice his ideas, but hid his dissatisfaction.

Yao also disciplined himself physically to meet the demands of the projects and programme: "I think that the programme makes me to understand myself more, my capabilities, my abilities and my, how my body functions – you kind of find out how much you can handle" Yao cut out his free time activities as the projects started (i.e., napping after school, watching TV dramas, computer games) "because if I don't do those actions, I wouldn't be able to survive." His lifestyle changed and the pressure and stress caused him to lose weight, something his parents noticed: "My dad keeps on whining to me not eating lunch sometimes." Yao "learned to cherish the stuff that I can have – like even sleep and food, really basic stuff, became a luxury to me. Having five or more hours of sleep – it's like heaven." Yao accepts the discipline:

> I think it's something that I signed up for. I know it's tough, but **I signed up for it**…I got some advice from my friends for five years, before I signed up, like, to apply for engineering and they just say you need to **man up** (Researcher: What does that mean?). Like you need to be able to just sustain the pressure and the stuff that they correct you and just - they tell me to **suck it up**. (Yao, interview 2)

Interestingly, Yao sometimes referred to heavy assignments and difficult courses as "torture" or "the torturing time", envisioning engineering study as corporeal punishment. Yao also frequently talked to teammates about how tired he was and how much he was pushing himself, another brand of story that sometimes accompanied his 'mark crisis' stories. An example of such an exchange was a short discussion two days before the project 2 demonstration:

Yao: I think this computer is like me. Always drain it down to zero – the juice.

Lee: Then charge it back up.
Yao: Ah, take charge. For stress time only like 30 minutes of sleep and...
Tia: Wow. Thirty minutes.
Hyuna: Why? You sleep only for 30 minutes?
Yao: For stress time (i.e., periods of high workload). I don't get, like for Wiley, sometimes I stay overnight right? (laughs)
Hyuna: Oh, yeah, yeah, yeah. How can you do that?
Tia: For Wiley?
Hyuna: How?
Yao: Sometimes.
Lee: You can wake up?
Yao: I couldn't sleep.
Lee: Half an hour.
Hyuna: It's like a nap.
Yao: Half an hour is like, just to refresh myself.
Hyuna: But are you OK the whole day?
Yao: For that day I also need to finish my Design I – my lab right? Yeah, that day, I can finish my block and do good so I was OK for that day but…
Hyuna: How about after you go home?
Yao: Normally, I always (take the) trip myself, but, I mean, mentally I was OK, but physically I wasn't OK and after that I got sick for... it was the long weekend and then I got sick on the long weekend.
Hyuna: See? You should be, you should sleep.
Yao: I only do that… occasionally…it's not like I can do it every day.
Hyuna: But you look so healthy. No?
Yao: I hope I look healthy? Which one (to Tony) we just changed R, right? (to Hyuna) ...actually I lost so much weight. (audio recording, field notes)

Yao's self-discipline was one way he alleviated his inner contradiction between his orientation to "getting passed/past" and his need to maintain harmony in a team that was "aiming high."

The poor project 2 result and changes in the nature of Design II design projects and assessment practices contributed to a greater acceptance of Yao's perspective on projects and shaped the team practices. For Yao, this alleviated the inner contradiction he faced working in a team who was "aiming high" rather than "getting past/passed". He moved into a more central technical role with tasks that he was more in control of. The team as a whole also began to aim differently. Far more explicit and open discussion on how to approach the Design II projects was observed in both projects. As noted in Tia's account in Section 6.6.5, the kickoff meeting of

Design II project 1 on January 15 and later observations showed Tia clarifying and questioning technical decisions than she had before. Yao had also earned a place at the centre of the team and a right to more directly express his ideas. Team members were unanimous in privately admitted that where Design I project 1 yielded unsuccessful teamwork and a successful project, project 2 failed on both counts. A clear post-mortem on Design I project 2 never fully happened in later project meetings, but change nevertheless emerged. Interestingly, Yao noted of project 2 that:

> It was stressful, but it was valuable. I mean we actually learned from it and we evolved and…improved on our techniques and our strategies. So even though we didn't discuss directly or extensively, but we, somehow we just collaborate better, yeah.
> (Yao, interview 3)

Improved collaboration in the team took the form of: 1) more complete and reasoned task delegation, 2) a primary focus on securing a basic, functioning project, 3) greater decision-making power for those leading specific tasks, and 4) the adoption of Yao's idea of building and testing of two copies of any analog circuit on breadboards prior to soldering. The team recognized that although tasks in Design I project 2 were delegated more completely than in project 1, they did not sufficiently think through how to divide tasks effectively. Yao reports:

> We shouldn't split it up as VHDL and stuff like that. We should actually do it something like voltmeter, ammeter or ohmmeter and just separate parts instead of a part of the voltmeter is VHDL so we split the VHDL into half. That way it's harder to combine instead of each piece is one part. (…) Modularizing in the right way. Like if you modularize it as software and hardware is kind of harder because the hardware has to work with software but the software person cannot communicate effectively with the other guy. So it's conflicting each other and…if you do that part, you do it all… and second term we split it up as mostly through parts. First project we had a mechanism, me and Li took up that part, Tony took up the temperature sensing himself and Lee took up the logic and Hyuna and Tia took up the cup…the capacitor on cup. (Yao, interview 3)

“Modularizing” became a key concept for the team in Design II projects 1 and 2 and made sense because these were concrete projects with easily identifiable parts that lent themselves to clean division and task delegation, unlike the more abstract Design I projects.

The second change in team practices followed from the first. Now that the projects could be modularized effectively, decision-making power naturally devolved more fully to those working on the different parts. The technical lead on each part had complete control over the task and while others might make suggestions, the other team members accepted the decisions of those in charge. This arrangement prevented some of the inefficiencies that occurred from people moving between tasks that were observed in Design I project 2. Less movement of people between tasks and less interference with decision making was observed in Design II, with the exception of Lee, who had a special role in drawing the project together.

Third, project 2 made the team aware of compounding errors that can occur when functional parts cease to work when integrated, as described by Yao:

> We were struggling to get this thing working and they wanted a perfectly functional project, like, but, it was functional on main part by themselves – when we put it together is not working. So, we shouldn’t take the risk to combine the thing because many other groups had encountered that problem when they put it together, because when you combine stuff together, I remembered there is a term for that kind of complication of error or something…so, you can’t, you can’t foresee the problems when you combine it. (Yao, interview 2)

As such, the team agreed to focus efforts on achieving basic functionality first before they discussed additional functionality and bonus marks. While additional features might come after securing a working project, they became less of a priority to the team.

Finally, Yao drew on an idea circulating among students of building and testing two identical copies of the analog circuits on breadboards in order to mitigate problems encountered in soldering in Design I project 2. In the event that a soldered project ceased to function, the team would have a fully functioning spare available for the demonstration. This idea was accepted and implemented by the team in the Design II projects:

> It's something that we learned from that project, so by doing that all the Design II – project 1, project 2 – everything was OK. So basically, Design II projects, we spent a bit extra time and did more effort to do the circuit – the second one – but then we save on the debugging time. That's a huge save – you know, of time. (Yao, interview 3)

Additional changes shaped the team's evolving practices in Design II. As mentioned, the two Design II projects were far more modular and concrete to students. They were also technically easier compared to Design I project 2, which was recognized later by instructors and TAs as too advanced for the students at that time. Kelvin and Heisenberg had also changed their assessment practices in the course, which relieved some of the mark pressure students experienced in the run up to project demonstration. The instructors allowed three days to demonstrate the project and did not assign specific times to teams. In addition, they allowed groups to redemonstrate if things did not go well. As such, students could no longer complain "it was working 30 minutes ago." The team's response to the new regime was to demonstrate on the first day with the rationale that "if we present the first day, they (i.e., other students) say you have a higher change of impressing the professor." The change in regime also opened the potential for students to game the system because, as Yao said: "On the first day, many groups couldn't get the thing to work. After someone present (i.e., demonstrated) they might be able to (…) because they already completed the project, they might disassemble some parts and give it to you."

6.6.6 Stage 5: Restructuring Process Leading to a New Trajectory

Yao's experiences in Design I project 2 and subsequent Design II projects shaped his evolution and change. The inner contradiction in Yao between "getting past/passed" and the challenges of functioning harmoniously in a team that was "aiming high" contributed to Yao's evolution and change over the 6 months which placed Yao on a new trajectory. Through his experiences in team-based design projects, Yao gained more confidence in his general disposition towards simple, functional solutions to problems and in his capacity for disciplining himself emotionally, mentally, and physically to function in a team. He learned to manage his thoughts and emotions and discipline his physical needs in order to maintain harmony in the team and keep up with the time demands of the projects.

Yao was highly self-aware of how his mind works and reported substantial change over the second year. In Yao's final interview he articulated in great detail five ways in which he had consciously worked on controlling his thoughts and emotions. His description was prefaced by the comment "a tutor (in first year) told me that I have too much going on in my mind, that's why I can't focus…I need to limit my thoughts so I can't just go wild." First, he reported that through the programme, he was learning to regulate his thoughts by developing thinking habits. These included finding a method to approach problems. One example was to break problems down into steps: "I break it down to steps … focus on your the and just get it done no matter what. So if you are assigned that task, like nobody should look at other people's part until they are done with their part." He also noted how to work efficiently by not wasting time and effort. For example, he noted: "I figure out a pattern that if I'm stuck at a thing and I check it for two times, don't check that part anymore. It's usually not that part - it's usually something else. If I have to debugging, I would have followed that procedure and take it step by step."

Second, Yao recognized the huge amount of engineering knowledge as being hierarchically structured and difficult to remember. As an example, he discussed how knowing how to find the answers was more important than recall: "If you ask me now about the courses I took last term, I might be able to recall, if you give me a problem and that is related to that, I might be able to bridge the connection, but I won't remember all the details … (but) I can just look it up … I think that's part of being resourceful … I think I'm able to program with resources." Third, Yao reported that he was learning to regulate his emotions. He was very conscious of his own emotional state, particularly when faced with an overload of information: "If I, like, try to either know it all … it's too much for me - I need to limit my thoughts so I can't just go wild and take in every, any information and process it." He also noted how he had to limit his emotional reactions when his ideas were not taken up by the team. As Lee said of Yao, "He is good at controlling his anger." Fourth, Yao articulated the need to stick to basic functionality on projects: to "keep it basic" and "get it right": "I think it's better to play safe now that aim for 100% every time. I think the group were aiming for too high and instead it backfires." Fifth, Yao identified being self-reliant, consistent, and resourceful as important: "you need to try one more on your own before you ask…if you don't put any effort and then you ask, people might just think that you are too lazy…so think through your question before you ask it." He prized being resourceful above all for students graduating and going into industry: "I think being an engineer, you need to be resourceful. Like the knowledge that we gained from school combined with connections that we gain in industry and the people that we know from school will be an asset for our future and so this is just building blocks for us to become a real engineer."

6.7 Engineering Disposition and Thinking Manifest Through Themes

This study took Vygotsky (1978) and Leont'ev's (1978; 1981) challenge of conducting research in a non-reductive manner by adopting activity as an irreducible, self-moving unit of analysis and attempting to focus on holistic processes and their effects from the standpoint of the student. In Sections 6.2 to 6.6, the particular manifestations of engineering dispositions and thinking, brought about by the inner contradiction in each student-within-the-team-within-the-activity-over-time, were tracked to produce five trajectories. These five trajectories are thought of as “particular instance(s) of the possible” (Bachelard (1949) in Bourdieu and Wacquant (1992, p. 233)), meaning that they are examples of generalized possibilities that exist in the activity system (Holzkamp, 2013) for culturally diverse students. For this section, these five student trajectories were considered side by side and themes drawn out which underlie the emergence of culturally diverse students' engineering dispositions and thinking. Evolution in these five students’ engineering dispositions and thinking was manifest through:

1) Being willing to buy into working as part of a team
2) Being willing and able to claim a viable role as an engineer
3) Grappling with competing identities in becoming an engineer
4) Navigating different perspectives on engineering projects
5) Being able to self and co-regulate while under a complex, heavy workload

This means that within this overall activity system of the team-based engineering design courses, change in a culturally diverse student’s engineering dispositions and thinking is influenced by their capacity to meet these five conditions, given their particular circumstances. Findings for each of these will now be presented and these five key findings will form the structure of the discussion in Chapter 7.

6.7.1 Being Willing to Buy Into Working as Part of a Team

Analysis of the five students’ trajectories revealed the importance of a willingness to buy into working as part of a team as a minimum condition to develop engineering dispositions and thinking towards constructive collaboration and a capacity for communicating interpersonally and interculturally. This is exemplified by two cases out of a team of six (Hyuna, Jay, Lee, Tia, Yao, and Tony): Hyuna, who had a willingness to buy into teamwork and Jay who initially did not and later came to realize its importance.

On one hand, as noted in Hyuna's trajectory (Section 6.4), she was socially central and technically peripheral in the team during the Design I projects, but nonetheless benefitted fully from the marks of a very successful project 1. She was sociable, had good interpersonal and intercultural communication skills, was liked by her teammates, and contributed to the positive climate of the team. Interview and observational data from the early life of the team indicates that Hyuna and her teammates Tony and Tia were the most active in shaping the team's social climate. They shared informal history, told stories, made jokes and comments, discussed Asian Pop Culture and teammates' resemblance to Asian celebrities, and made statements about what kind of team they were. An emergent team history and culture became manifest. Hyuna began inhabiting a technically peripheral, assistive, and social role and relying heavily on others to do the technical and coordination work on the projects. Hyuna sought ways of contributing indirectly or pretended to work in exchange for her apparent lack of technical project work.

On the other hand, Jay (Section 6.2) began as both socially and technically peripheral in the team. Several factors contributed to Jay apparently not buying into working as part of the team. These include his late arrival in the team; his limited teamwork experience; a preference for controlling his time and working alone; his undemanding first year study at an engineering college transfer programme; his tightly-knit group of Chinese friends; and his ability to function academically in a traditional mode of study with limited English ability. While Jay had a minor technical role in this project, he appeared to lack presence in the team because he did little to engage socially and his attendance was unpredictable. This is especially when the observational and interview data indicate what it meant to be a valued team member – being present, interacting harmoniously, and demonstrating solidarity with the team. These, more than technical contributions, appeared to be the primary criteria for mark division. Hyuna, Tia, and Lee saw Jay as “cold”, not “really being there” for the team, and not willing to “tell people things”. In the project 1 evaluation, and unlike Hyuna, he was punished by the team members, who scored his contribution at 65% of what they expected of him. A conflict resulted from this decision and was brought for arbitration to Kelvin, the instructor, who divided their marks up equally and told them to communicate and delegate tasks. The conflict was a critical event for Jay: he gained a new awareness that he could no longer remain minimally involved at the periphery of the team. Expectations weighed upon Jay to buy into working as part of a team and contribute in project 2.

Interestingly Jay made five claims around the building of projects 1 and 2 that were either untrue or obscured events. For example, he claimed he could not contribute to project 1 because the team members had not invited him to the design meeting (they had) and that Tony and Lee took project 1 home to design and build it (they did not). In project 2, Jay had some success in claiming a more central technical role as the solder person and in helping to define the design of the voltmeter and β meter. He claimed to Lee that he had made a functioning β meter from a design he found on the Chinese Internet. Yet, Tia reported observing Jay dismantling it and Lee could not find it in the locker where Jay claimed he had put it. Despite the instances observed of Jay making false claims and obfuscating events, the teammates and Jay alike generally dropped the topic, presumably to maintain harmony in the team.

Jay faced challenges with his English competence. Despite having the required IELTS score of 6.5, he was observed to have relatively low communicative competence in spoken and aural English, especially sociolinguistic, functional, and strategic competence (Bachman & Palmer, 2010). He had difficulty communicating during project meetings. His teammates, all English Language Learners, employed strategies (e.g., simplifying language, restating questions, paraphrasing, asking for clarification, code switching) to facilitate communication with Jay. Tia in particular, identified Jay specifically as "having a language barrier" and Hyuna identified him as being the most difficult to understand. Interestingly, Jay reported not seeing his English as a problem, presumably because it had served him in the lecture and textbook-based mode of study in his first year of the college engineering transfer programme. He seemed either unaware of or did not admit to difficulties in functioning in a team in English. Jay noted that it was just a code that could be translated in Google, which points to a lack of awareness for what it meant to be functional in English teamwork. Unlike Hyuna, Jay's capacity to buy into working as part of a team appears to have been hampered by cultural factors and his attitude towards and ability in English language.

These two cases, Hyuna and Jay, exemplify the minimum condition (willingness to buy into teamwork) for students from cultural backgrounds and contexts where collaboration in teams is not a common mode of study.

6.7.2 Being Willing and Able to Claim a Viable Role as an Engineer

Similar to Section 6.7.1, analysis of the five students' trajectories revealed the importance of a willingness and an ability to claim a viable role as an engineer to developing engineering dispositions and thinking towards technical work. This is exemplified by four cases out of a team of six (Hyuna, Jay, Lee, Tia, Yao, and Tony): Lee, who claimed an early technical role and, though quiet, came to be recognized as the team's technical leader; Jay who claimed a key technical role through his knowledge of electronics and skill in soldering; Tia, who grew slowly into a technical role through self- and peer-tutoring; and Hyuna, who failed to secure a technical role until the Design II projects.

In this study, the question of what led particular students to inhabit particular roles is important because evolution of students' engineering dispositions and thinking was found neither to proceed uniformly in lockstep nor in the same direction, but rather along multifarious trajectories (i.e., Sections 6.2 to 6.6). The entry points for particular roles for particular students are coined herein as *critical decision points* along the life of the project (or their trajectories) which led to the differentiation of roles and hence, outcomes for students engineering dispositions and thinking. Such critical decision points became initially manifest in often inexplicable and yet-to-be-knowable ways (Roth, 2013) in observed or reported instances or events which marked new directions for the development of their engineering dispositions and thinking. In this section, four critical decision points are described for Lee, Jay, Tia, and Hyuna. Then, as noted in the paragraph above, each students' role is discussed in relation to the importance of students being willing and able to claim a viable role as an engineer.

As noted in Section 6.3, Lee claimed a central role in the team through his work in defining the dual slope ADC in the first real project meeting, which Tia and Jay were unable to attend. The combination of absent students, the pro-active work of Lee and Tony, and the time pressure of the project placed Lee in a provisional role at the centre of the project. This can be thought of as a critical decision point that led to role differentiation in a team that had largely functioned as a study group until one month into the project. A second critical decision point for Lee, Hyuna, and Tia appears to have led to Lee's building role in the project and to the technically peripheral roles of Tia and Hyuna, who served as support in building project 1. This decision point appears to have been shaped by Lee's investment of time in the design and the tendency for Tia and Hyuna to defer to Lee and Tony's technical leadership. A degree of role gendering in the team was interpreted from the observational and interview data and is exemplified by Lee's own comments when he noted that it seemed automatic for the "two girls" to be "on the side" anticipating what support was necessary and to do it without asking for Lee and Tony, who were building the dual slop ADC.

A third critical decision point occurred for Jay when three team members tried their hand at soldering while modding the DE2 board early in project 2, just days after the project 1 conflict. As noted in Section 6.7.2, Jay demonstrated his skill in soldering after Lee and Hyuna had tried it, which led to his role as the team's soldering person. Jay had identified with engineering through his easy confidence and skill with soldering and his engineering father and the team recognized the indicators (i.e., Jay's bearing, skills, invocation of engineering father making him believable as an engineer). Jay was able to shift rapidly from a peripheral to a central role in the team: according to Tia, he became "The Solder King".

A fourth critical decision point was when Tia became "The Power Ranger", which was seemingly the co-occurrence of three factors in the first project 1 meeting: her endorsement of Tony and Lee to work on the voltmeter (dual slope ADC), her engagement in the discussion of the required voltages, and the seemingly random act by Tony, who, standing by the list of tasks on the whiteboard, wrote her name next to "Power Supply" rather than next to the β meter or the autorange. Hence, the decision points that led to the claiming of viable roles as an engineer appeared to be shaped by the perception and reality of students' technical knowledge and skills, indicators or being believable as an engineer that came to hold currency in the team, and random chance.

Now that four key critical decision points have been identified that were significant for role differentiation, the rest of this section will focus on the claiming of roles for Lee, Jay, Tia, and Hyuna. First, Lee's claiming of a hands-on technical role in the team - by building the central voltmeter in Design I project 1 - reveals the importance of being willing and able to claim a viable role as an engineer (Section 6.3). Lee began second year with very little hands-on experience, but was able to rapidly transfer his disposition towards perfection and attention to detail in schoolwork to building tight, clean circuitry on breadboards in project 1. The voltmeter design was critical because it was the core of both projects 1 and 2. In taking the time to carefully build a voltmeter in a highly successful project 1, Lee knew its intimate details and hence garnered a central role in project 2 which extended through his growing knowledge and experience, to the Design II projects. Lee became central to the core of the four projects through his methodical and patient approach to building circuits and through his sheer dedication – he invested more time in the projects that his team mates.

Lee's technical role led to unexpected consequences for the evolution of his engineering dispositions and thinking. Through his central role and connection to the physical project, Lee was afforded a social role in the team and opportunities to develop teamwork and communication skills. Though a self-confessed introvert, sitting in the lab with the project's tools, parts, and materials afforded him a comfortable mode of communication with others, which can be described as object-centered. Lee's role in project 1 grew though his efforts, technical knowledge, position near the core, and his orientation to perfection into being the undisputed, quiet technical leader of the team. Lee came to know who he is socially and technically in the team through this knowledge, his skill, his effort, and the materiality of engineering, importantly, from his capacity to claim a viable role.

Following the conflict in project 1, Jay quickly claimed a technical role in Design 1 project 2 (Section 6.2). He employed his knowledge of electronics, his knowledge of Chinese and Chinese circuit designs on the Internet, and his skill at soldering for the team at the beginning of project 2. Jay demonstrated his soldering skill (Section 6.2.3) and became the team's lead solder person (aka The Solder King). Lee and Hyuna, who also tried soldering, did not seem to have the bearing and skills and were not chosen, even though they could probably have eventually done equally well in the role. Jay's electronics knowledge, easy confidence and skill with soldering, and his engineering father were recognized in the team as the indicators of Jay *as* an engineer. Jay was able to shift rapidly from a peripheral to a central role in the team in Design I project 2.

Yet, while Jay had gained an awareness of teamwork and had contributed technically in the meeting two days before, Jay in project 2 was not a completely different person. It was the change in the conditions between project 1 (not modular) and project 2 (highly modular) that had partly afforded him an opportunity to claim one of the many roles available. Luckily for Jay, soldering was a high status activity because good soldering meant that projects prototyped on breadboards would be functional once transferred to solder boards. It also afforded him opportunities to work with other team members such as Lee and Tia when he soldered their projects at the end of Design I. As such, project 1's modularity, combined with him not buying into working as part of the team relegated him to a peripheral role in that project. Project 2's modularity and its soldering requirement afforded Jay his opportunity to claim a more significant role.

Tia was initially less successful than Tony and Jay at claiming a viable role (Section 6.5). Lee and Tony had taken the initiative in designing project 1 in early October and when it came to build it days later, she began assuming an assistive role. Project 1 was a relatively simple design that could be built on two breadboards and both Tia and Hyuna assumed supportive roles. Lee had reported the decisions about the roles in building project 1 were not discussed. Role differentiation was somehow recognized as “automatic” by Lee, Tia, and Hyuna: when they sat down to build the project, the “two girls (were) by the side” and without asking, they just anticipated what Lee and Tony needed and did it. Hyuna and Tia tended to defer to Lee and Tony’s technical authority and expectations with respect to roles appeared to be gendered to some degree. As the team moved into project 2, the multiple requirements of the design afforded Tia her opportunity to design and create the project’s power supply. During the first project meeting of Design II project 2, Tia was designated as the sole person who would produce a power supply that would provide the reference voltages to the voltmeter. Interestingly this happened through a combination of her nominating Lee and Tony to work on the central part of the project, her persistence in discussing power requirements, and the random chance that Tony just wrote her name down next to “Power Supply” on the list instead of the other two options that were there (β meter, autorange). She had claimed the title “The Power Ranger” shortly after the meeting and was active in seeking knowledge about the best design from Tony. Lee also tutored her in building analog circuitry. Through a blend of self and peer-apprenticeship she built a successfully functioning power supply for project 2 and had garnered a technical role alongside her coordinating and communication role in the team.

Hyuna’s trajectory (Section 6.4) also indicates that she was technically peripheral as a result of Design I project 1. This persisted through until the end of project 2. Hyuna had expressed an interest in soldering and attempted to solder during the DE2 board modding; however, Jay assumed that role until he left the team. Hyuna was assigned to work on the digital block (DE2 board and VHDL code) with Yao, but there was little for her to do because Heisenberg had provided much of the code necessary in mid-November, the team had decided to pursue an analog solution to the auto range requirement, and Hyuna did not learn how to code in VHDL because she had dropped the course. As such, Hyuna remained in a peripheral technical role until Design II, which might explain the slow evolution observed in her engineering dispositions and thinking (Section 6.4). Hyuna finally garnered a viable role in Design II as a solder person for the team.

These four cases (Lee, Jay, Tia, and Hyuna) exemplify a key condition (being willing and able to claim a viable role as an engineer) for students from educational backgrounds where the practical application of disciplinary knowledge to technical work is not a common experience.

6.7.3 Grappling with Competing Identities in Becoming an Engineer

Similar to Section 6.7.1, analysis of the five students' trajectories revealed the importance of grappling with competing identities in becoming an engineer to developing engineering dispositions and thinking towards one's early professional path. This is exemplified by one case out of a team of six (Hyuna, Jay, Lee, Tia, Yao, and Tony): Hyuna, who reprioritized becoming an engineer from among the competing affinities, goals, and drives across the multiple spheres of her life.

Hyuna's trajectory (Section 6.4) exemplifies why some students may fail to realize opportunities to develop their engineering dispositions and thinking until they grapple with competing affinities, goals, and drives, and begin to conceive of or see themselves as engineers. Hyuna was the least interested and invested in engineering in team Z5 and had the largest time commitments outside of her study. She did little or no technical work on the Design I projects and compensated the team by being present, socializing, pretending to work, and acquiring or doing assignments for her teammates. Hyuna, unlike Jay, was effectively forgiven for not engaging in much of the technical work until later she became more technically active in the Design II projects. Somehow she had the freedom from the team not to engage in the technical knowledge that the projects were intended to foster, yet garnered equal marks on the projects.

Hyuna's peripheral role in the team was functional enough from the team's perspective, but it was certainly not functional for the evolution of her dispositions and thinking. She both disidentified with engineering and was part of a team culture that appeared to expect less of female students, with men tending towards technical and women towards assistive roles. Lee noted of Hyuna in Design I: "I don't know if I should say this, but I don't think she knows well most of the stuff. So if there's a decision, I'll make the decision and then she'll do something else." Hyuna came to be peripheral. She disidentified (Pesheux, 1982) with engineering and so was not taken seriously as an engineering student by her team. She reported a dislike of design to her team; appeared to lack technical initiative, effort, and engagement during modules and projects; tended to play inappropriately and idly with equipment; and often voiced ideas during meetings that were perceived to be naïve or off-based.

As noted in Section 6.5, Hyuna functioned in and across more life activities than her teammates, who reported that by early Design I that they had curtailed most outside activity to prioritize their engineering study. Initially in second year at least, actually being an engineer was low on Hyuna's priorities. It is highly likely that cultural values around gender roles contributed to the low status of engineering itself in Hyuna's priorities. Hyuna harboured traditional gender values about her future:

> And then one more thing about being a woman in engineering: I feel kind of pressured too, because guys – they have more strength – and physically they can, I don't know, work

> more and stuff. So, and for girls, I don’t know, it’s kind of different because in future, girls being, like, mom, and they do houseworks too, so I don’t know, I think it’s kind of different with guys. When I look at guys they are like: “Oh, they’re engineers!” But for girls, even though we have to graduate and then get a job and after we get married and like women get married then they might just stick in the house. (Hyuna, interview 2)

She volunteered and disparaged a stereotypical image of a female engineer: “What I imagine is like, stiff face…and then looks not that…pretty, but just looks more formal.” She asserts that she will not become like that: “I doesn’t like being, like, stiff because that’s horrible.” She could also not feel close to Tia because had not had a boyfriend and “she didn’t even want to get married.”

Hyuna gradually chose to cut out her social activities and outside friendships that had remained strong in first year in preference for long hours in the lab day after day. She declared this to be a depressing choice made towards the end of Design I. As described in her account, she began seeking a more central technical role at the end of Design I through soldering. In particular, she had been seeking opportunities to demonstrate her soldering skill throughout Design I project 2. Hyuna finally gained an opportunity to solder in front of Lee and Jay. She demonstrated proper respect for the equipment; spoke in a clipped, professional manner; and soldered with careful, efficient movements. Jay and Lee recognized her skill for the first time and through this event, she identified as an engineer and was recognized as an engineer. She was not observed playing inappropriately with equipment again and adopted a role in the Design II projects as a solder person in the team. By participating differently in the team’s activity, Hyuna's competence was noted, which signaled the beginning of a shift towards being more recognizable as an engineer.

This case of Hyuna exemplifies a key condition (grappling with competing identities in becoming an engineer) for students who have not invested themselves in their early professional path.

6.7.4 Navigating Different Perspectives on Engineering Projects

Similar to Section 6.7.1, analysis of the five students' trajectories revealed the importance of navigating different perspectives on engineering projects to develop engineering dispositions and thinking towards constructive collaboration on engineering projects in complex environments. This is exemplified by one case involving two cases out of a team of six (Hyuna, Jay, Lee, Tia, Yao, and Tony): Yao and Tony, who had an extended disagreement on Design I project 2 within a complex and sometimes confusing context. Before discussing the extended disagreement between Yao and Tony, the relevant contextual background is drawn together here from previous sections: the individual students, the early culture and climate of team Z5, and the complex environment of Design I and Design II.

Beginning with the individual students, this study focuses on the evolution in culturally diverse students' engineering dispositions and thinking and has identified students' individual inner contradictions and tracked how students changed over time through their experiences in an engineering design team (Sections 6.2 to 6.6). As noted in Section 3.4.2, inner contradictions are defined as tensions that emerge in individuals in complex activity that drive their evolution (Leont′ev, 1978). In order to capture each student's inner contradictions and represent their trajectories, these contradictions were expressing in the form of questions for Sections 6.2 to 6.6. These inner contradictions - expressed as questions - are unique to individual students and orient them to what they are doing and why they are doing it as they collaborate on projects (Table 16). They also shape what Holland and Reeves (1996) refer to as "team perspectives" as they play out locally in decisions and actions in teams working on projects. Team perspectives are used to explain how different teams working toward the same project requirements create different intellectual tasks and develop different takes (hence, perspectives) on doing the project because they have some degree of freedom in controlling and directing their work. Navigating competing team perspectives on projects has been identified in this section as critical to develop engineering dispositions and thinking towards constructive collaboration in teams.

Table 16. Individual Students' Inner Contradictions Expressed as Questions

Person	Problem
Jay	How can I apply my technical talents in the most time-effective way in an inefficient, socially oriented English speaking team to get an equal share of the marks?
Lee	How do I function comfortably in a diverse team and achieve high quality work with teammates who have different ideas about what is 'good enough'?
Hyuna	How do I maintain my outside activities and my place in engineering and satisfy my teammates without engaging in much project work?
Tia	How do I 'do the right thing' cultivating the team's emotional life, following the rules, and doing engineering well?
Yao	How can I balance my approach towards time/mark-efficient activity to "get past/passed" with my need to maintain harmony as a new member of a team that is "aiming high"?
Tony	How can I maximize my enjoyment of the design and problem solving process and produce an attractive, perfectly functioning project my way? *

*Tony's consented to participate in the study but did not consent to being interviewed. Based on observations, the problem driving him might have been worded as shown.

Moving on to team Z5, the early team culture and climate that emerged was identified as generally friendly, cohesive, and somehow familiar (Sections 6.4.3, 6.5.3). There was a general atmosphere of optimism and goodwill among team members (Sections 6.5.3, 6.6.4) and the team members tended to avoid conflict, communicate indirectly, and foster harmony among team members (Section 6.2.3, 6.5.3). In addition, the team perspective on projects was strongly influenced by Tony and Lee, who aimed for high quality and perfection (Section 6.6.4). Evidence for the foregoing description of team Z5 culture comes from observational and interview data. Yao, Tia, Lee, and Tony reported separately on the indirect communication patterns with respect to decisions and conflicts; echoing Yao's comment that "even though we didn't discuss directly or extensively, we somehow collaborated better." Tia reported her tendency to "zip it!" to avoid conflict in teams. Interestingly, Lee highly praised Yao's capacity for not expressing his disagreement or anger with the decisions over project 2, which Tony tended to control, as necessary for working in teams (e.g., "He's good at controlling his anger."). There are clear indicators that these students tended to communicate indirectly and placed a premium on team harmony. The recognized leaders in the team at the end of Design I project 1 were Lee and Tony on the technical side and Tia who both deferred to their authority and conferred it upon them. In project 2, their team perspective to aim high and achieve perfection appeared to dominate.

Team perspectives, as they emerge as part of team culture and history, can be thought of as serving a potentially effective organizing and orienting function. Given the complex and information dense environment of team-based design projects, they can be seen as a way of reaching some agreement on what it means to be doing the project that serves as a basis for decisions and actions. Three points are made about the early team perspective of Z5 during Design I project 2. First, it was a provisional but dominant perspective from project 1. At that point in the team's history, the orientation towards high quality and perfection appeared to match the way the team functioned and the results it produced (i.e., an exceptional score of 9.2 on project 1). Second, the team perspective, as part of emergent team culture, was not always explicit and available for open discussion and change, being as it was an aspect of their team culture oriented to conflict avoidance, indirect communication, and harmony. Third, it was the dominant rather than the only perspective, being that it emerged mainly from people (i.e., Tony with Lee's silent backup, Tia) who had the power to tell everyone what kind of team they are, what they do, and how they do it. It did not dictate how students responded because each had their individual subjective reasons for their actions: as Holzkamp (2013) astutely notes of individuals; "they do not simply live under conditions, but produce the conditions under which they live" (p. 19). The team's perspective, so described, points to the possibility that they can be an asset when they make the team adaptive to changing circumstances or a burden when they make the team less responsive to a complex and changing environment.

Finally, the complex context around the projects is relevant to Yao and Tony's extended disagreement because it was challenging for students at times to take the necessary cues when taking decisions and actions on projects. As noted in Chapter 5, the environment of the Design I/II courses was dense with people, things, and information - there was a diversity of interactions there (i.e., student-instructor, student-student, student-tool, student-assessment). Culturally diverse students are doubly challenged in teams when discerning what is expected and important, how to orient themselves in activity, and how to anticipate how decisions and actions will affect project outcomes. Hence, they need to discern cues in a complex environment and cultural factors and language ability potentially mediate their capacity to do so.

Four examples from team Z5 illustrate challenges of culturally diverse students in discerning and responding to cues in the environment. First, Yao amusingly based his soda drink delivery design in Design II project 1 on his mistaken perception that because "Heisenberg likes flashy stuff" he would give them extra marks. He may have seen Heisenberg across cultures and ages as being the kind of person who would be influenced in this way. Luckily, Yao was proactive in checking with Kelvin and decided to repurpose the design partly because of resistance from his team and because they could not be sure who would assess them. Second, the team was observed carefully reading the project requirements aloud at the kickoff meetings of the Design I project 1 and Design II projects and discussing them. They observed misinterpreting requirements, such as the power supply requirement – at one point, they thought that they had to provide an independent power source for the DE2 board. Tia worked on it, only to drop the idea after investing valuable time

Third, in project 2, the team had a functional project 1 voltmeter that they were about to use. When Heisenberg provided all students with his design to place teams that had failed in project 1 on an even footing, the team doubted their design and abandoned it saying "Better to be safe – use the one HEISENBERG made!" What was meant as an affordance and help mid-project, made them drop a functioning design because they trusted Heisenberg's authority. Fourth, Design I project 2 and the Design II projects had manual soldering and mechanical design requirements. Manual soldering became a threat in some cases to project functionality. As discussed in Section 2.6, Newstetter's (1998) makes an interesting distinction between hard prototyping (i.e., production-oriented: building the physical project at the end) and soft-prototyping (i.e., knowledge-oriented: representing, ideation, paper work, model building) and argues against and overemphasis on hard prototyping. With their recent move from textbook and lecture modes of science and math study, students reported an eagerness to build things (i.e., hard prototyping). The soldering and building requirements were discussed in lectures, students did safety training, and they grappled with the details of fabrication. Such conditions may have primed Tony, Lee, and Tia to pursue building the optional multimeter box (Section 6.6.4.2). Taken as a whole, these four examples suggest that cues, discerned well or poorly from a complex environment, shape the following in turn: i) the team perspectives by virtue of what students come to understand is important and expected, ii) what they focus on, and iii) what engineering dispositions and thinking evolve in them as a result.

Yao and Tony's extended disagreement over a multimeter box in project 2 exemplifies how competing team perspectives can play out in projects (Section 6.6.4.1). The disagreement came down to a disjuncture between Yao and Tony's inner contradictions, which can be thought of as competing team perspectives on the project (Table 16) and focused on a multimeter box, which would house Design I project 2 (Section 6.6.4.1). While the project 2 requirements clearly stated that a multimeter box could be store bought, the team designed and built one, which consumed valuable time. Yao had just experience a very difficult project 1 in another team, where poor relations, lack of buy in to teamwork, and heavy workloads had consumed valuable time and "doomed" the project. He had little interest in investing energy in project tasks that were not explicitly required and lightly contested the decision to make a box during his first meeting with the team: he suggested buying one from an electronics shop. Tony, coming off an almost perfect project 1, was confident and determined to continue the team's record of high quality work. While he understood a purpose-built box was optional, making a sleek box in which the project fit to tight tolerances seemed to represent the high standards he saw as being the hallmark of the team.

Once built, the box significantly shaped many of the decisions around building the project that Yao felt he was not in a position to resist. Six points of disagreements arose over the box between Yao and Tony. While Tony got his way on each disagreement, the decisions arguably contribute to a loss of time, loss of functionality, and a poor result on the project. One example was Tony insisting on soldering the circuits in the last days of the project so that it would fit in the box. As noted in Section 6.6.4.1, it was common knowledge at the time that transferring functioning projects from breadboards to solder boards had rendered many teams' projects not functional. Other disagreements included the repainting of the box in the last days at a time when the team was struggling to get the project functional, Tony compressing functioning circuits on breadboards so they would take up less space and fit into the box, and cutting capacitors on the power supply and resoldering them so that the power supply would fit into the box.

Given what Tony knew at the time, his actions were quite reasonable to him. The team had done an exceptional project 1 and believed Jay could solder project 2 quickly so as to be bug free. Even though parts of the project were not yet working in the last three days before the demonstration, Tony had a natural disposition towards optimism. He had not perceived that project 1 and 2 were qualitatively different in complexity and scope. As noted in Section 4.4.5, project 2 (a system-level project) was different from project 1 (a transistor-level project) and required a change in mindset toward hierarchical structuring of project activities, prioritization, task delegation, and the use of time, knowledge, and human resources. Yao at the time did not have the status in the team to influence Tony's preferences and endured quietly until the team received a poor mark. The explicit sharing of cues from the complex environment and a discussion of the team perspective on the project did not occur for this team in project 2. However, the team shifted to a more practical, cautious, and communicative approach: their team perspective on projects had evolved, albeit late after a poor showing.

This case of Yao and Tony exemplifies a key condition (navigating different perspectives on engineering projects) for students who have difficulties collaborating constructively on engineering projects in complex environments in which cultural factors are significant.

6.7.5 Being Able to Self and Co-Regulate While Under a Complex, Heavy Workload

Similar to Section 6.7.1, analysis of the five students' trajectories revealed the importance of being able to self-regulate to developing engineering dispositions and thinking towards work in team-based engineering design. This is exemplified by two cases out of a team of six (Hyuna, Jay, Lee, Tia, Yao, and Tony): Yao, who was challenged by the demands that the second year engineering was placing on his mind, heart, and body and managed to cope; and Tia, who went beyond her capacity for self-regulation, got sick, and took leave of the programme.

As described in Sections 5.5 and 5.6, many second year students saw the workload as substantial, complex, and sometimes uneven, which led to many experiencing a great deal of pressure and stress. When asked about the workload and stress in the programme, one instructor identified that "engineering is a rite of passage" and that while stressful, students learn "basics and a way of thinking". Intended or unintended, and for better or for worse, the substantial workload in engineering appears to be an important aspect of the enculturation process.

Yao and Tia were determined to become engineers, but responded to the workload and stress in different ways. Of all the team members, Yao reported most extensively and expressively about how the programme was affecting him physically, emotionally, and mentally (Section 6.6). He referred to accepting a place in CU engineering as "signing up", as if he were joining the military, and discussed the need to "man up" and "suck it up" to get through the programme. Yao was very motivated in engineering and wanted to become "a dictionary of technical knowledge". He articulated in the second interview that he was conscious of, on the one hand, doing school (i.e., doing what he needed to get enough marks to "get past/passed") and, on the other, becoming an engineer (i.e., focusing on things that would benefit his professional career), which he sometimes considered as two different things. His drive appeared to be interest and fear in equal measure: excitement and trepidation, being upbeat, and being dragged down. He referred to schoolwork as “torture” at times and was happy taking short summer courses to clear off his required credits because “the torture time is not too long”.

Yao’s way of describing his engineering study is highly interesting because he explicitly articulated that some kind of mental, emotional, and physical discipline is implied in becoming an engineer. He talked specifically about how his body and mind were affected by the programme: “I think that the programme makes me to understand myself more, my capabilities, my abilities and my, how my body functions – you kind of find out how much you can handle.” Yao reported cutting out his free time activities as the projects started (i.e., napping after school, watching TV dramas, computer games) “because if I don’t do those actions, I wouldn’t be able to survive.” His lifestyle changed and the pressure and stress caused him to lose weight, something his parents noticed: “My dad keeps on whining to me not eating lunch sometimes.” Yao noted “I learned to cherish the stuff that I can have – like even sleep and food, really basic stuff, became a luxury to me. Having five or more hours of sleep – it’s like heaven.” Yet Yao accepted the discipline for the long-term benefits, as evidenced by the graph he drew (Figure 26) of his happiness level over the next few years (very low) until he would graduate (increases, reverses places with that of arts students).

In Yao’s final interview he articulated in great detail five ways in which he had consciously worked on controlling his thoughts and emotions. His description was prefaced by the comment “a tutor (in first year) told me that I have too much going on in my mind, that’s why I can’t focus…I need to limit my thoughts so I can’t just go wild.” First, he reported that through the programme, he was learning to regulate his thoughts by developing thinking habits, which included finding a method to approaching problems, breaking big problems into small problems, and not wasting effort. Second, he recognized the huge amount of engineering knowledge as being hierarchically structured and difficult to remember and considered knowing how to find the answers as more important than having good recall. Third, he reported that he was learning to regulate his emotions (e.g., “You turn off when you panic…if you just relax…you will get a better result.” Lee: “He is good at controlling his anger.”). Fourth, he articulated the need to be cautious, to “play it safe” on projects by making the basics solid and not changing things at the last minute. Fifth, he recognized the value of being persistent: “focus on your task and just get it done no matter what.” into focus on tasks and get them done “no matter what”. Sixth, he identified being self-reliant as important: “you need to try one more on your own before you ask…if you don’t put any effort and then you ask, people might just think that you are too lazy…so think through your question before you ask it.”

While Yao went to great lengths to articulate how the programme was affecting him, Tia said very little about her internal struggles until she left. Tia was observed through the projects as having a balance of both non-technical skills (e.g., her key role as team coordinator, communicator) and emerging technical skills (e.g., her building a functional power supply in Design I project 2). In her interviews, she rarely voiced how the experiences were affecting her mentally, physically, or emotionally, but instead preferred to focus on monitoring and supporting the team and the project. She did this by communicating, coordinating, and motivating her teammates. Tia abruptly took leave from the programme once Design II project 1 was complete, citing health reasons. She later reported not being able to endure the migraines that she had been having for months that were partially the result of the workload:

> Aside from the headaches that I had, the tension migraines that I had, the time management was rough, a bit rough, because midterms, they come, they don’t just come up, on separate times. They sometimes go in a block so it’s kind of hard. (Tia, interview 3)

While Tia was quite attentive to her teammates' wellbeing, she appeared far less attentive to her own. Despite growing stress-related health problems in Design II project 1, she chose not to say anything until taking leave: "I don't (didn't) want them to get worried." The team was very surprised and concerned, but they were unaware she had been having difficulties.

Yao was able to self-regulate, cope, and get through - also known as signing up, manning up, and sucking it up to get passed/past. Tia's capacity to self-regulate did not enable her to complete the term – she had somehow exceeded her elastic limit for taking punishment. While workload was a contributing factor to her stress-related illness, Tia was still determined to be an engineer and to continue second year in the 2013-2014 academic year. She appeared to accept the difficulties and challenges in her engineering study: "What I'm thinking now, school is training ground for the workplace, and I'd rather experience some hardship now than experience it later after graduation, so I wouldn't mind having a hard time in my courses." Tia came back the following year and rejoined the programme.

As reported and observed in this study, the workload is second year appears to have enculturating effects on engineering dispositions and thinking. Many students coped with the workload and produced many excellent projects that met or exceeded the requirements. In many cases, Heisenberg's comment that "the value of something is in that it is difficult", is well taken:

> Project work is hard, but when things work, it's a hook - if they get something that works and looks good after 3 days of solid work, they forget all the tough times they've had - things working is like an addiction. So, this model is good as long as I can keep them motivated, prevent frustration, and help students get unstuck when they are stuck. I want them to try stuff. (Kelvin, instructor interview)

Benefits potentially emerge from being pushed up against challenges: students develop their dispositions and thinking in ways that they could not have imagined possible. Accordingly, they gained a new understanding of their capabilities.

On the other hand, a potential result of the effects of the workload on engineering dispositions thinking is that it can narrow or exclude perspectives (through enculturation) and people (through attrition) in ways that is not fruitful for the profession. Tia, in the final interview in 2013, was determined to get over her health issues. While she questioned why the workload and stress was necessary, she still voiced an affinity for engineering and a desire to continue:

> It feels great. It feels great that you know something and you just don't know something but you can do, you know, you can do things, you can create products, you can, yeah you can create an output out of what you know. It's not just writing an exam and passing it. (…) (Researcher: So do you still want to be an engineer?) Definitely, yeah. That's because right now that's how I see myself in the future…as an engineer. (Tia, interview 3)

Tia took the year off and returned in January 2014. At the time of writing she had completed third year and reported doing well.

These cases of Yao and Tia exemplify a key condition (having an ability to self-regulate while under a complex, heavy workload) for students who are challenged in managing complexity and difficulty in team-based engineering design.

6.8 Summary of Chapter 6 Findings

This chapter has presented five trajectories of culturally diverse students' evolution in team-based engineering design projects over time and identified change in their engineering dispositions and thinking. These are summarized in Table 17. As noted in Section 6.7, an additional level analysis was conducted to identify five conditions that culturally diverse students are required to meet in order to benefit from opportunities in team-based engineering design projects to develop their engineering dispositions and thinking. These conditions appear after Table 17. Their discussion in Section 6.7 will become fodder for Chapter 7.

Table 17. Summary of Engineering Dispositions and Thinking from Student Trajectories

Student	Stage Reached (Roth, 2009)	Engineering Dispositions and Thinking Developed
Jay	Turnover (Stage 4)	Be technically proactive Mobilize skills and knowledge for team Be more reliable by prioritizing time for team Be socially engaged
Lee	Restructuring (Stage 5)	Be hard-working, persistent, detail-oriented Do engineering through hard-prototyping Lead through technical knowledge Assess tradeoffs and compromise on perfection Be socially engaged in diversity Seek quality through team monitoring and backup
Hyuna	Emergent (Stage 3)	Be dependent on others to do technical work Compensate for technical weaknesses with unrelated work Value hard-prototyping skills as engineering work Demonstrate team solidarity through sacrifice
Tia	Restructuring (Stage 5)	Value engineering communication Value constructive collaboration Trust one's own technical authority Value practical application of knowledge
Yao	Restructuring (Stage 5)	Seek simple, functional solutions Engineering thinking: i) Find a method to solve problems, ii) Don’t waste time or energy, iii) know how to find answers. Be consistent, reliable, and resourceful Regulate emotions: Don't panic, control anger, maintain harmony Discipline your body, delay gratification

1) Being willing to buy into working as part of a team

2) Being willing and able to claim a viable role as an engineer

3) Grappling with competing identities in becoming an engineer

4) Navigating different perspectives on engineering projects

5) Being able to self and co-regulate while under a complex, heavy workload

Chapter 7: Discussion

7.1 Introduction

This chapter discusses the findings reported in Chapter 6 by elaborating upon the interpretations and meanings ascribed to how engineering dispositions and thinking of culturally diverse student evolve in the team-based design courses. The emphasis in this chapter is on the five conditions (Section 6.7) that potentially manifest along students' trajectories, whose effects are mediated by other factors (cultural, contextual, personal) in activity to shape culturally diverse students' engineering dispositions and thinking. This study's research questions (Section 1.3) were not directly focused on culture. Rather than being embedded in the research questions, culture and cultural diversity reside in the choice of context and participants and emerges in the findings.

Researching how engineering dispositions and thinking of culturally diverse students evolve through their experiences in this study meant entertaining Tolman's (1991) insight that "a thing is best understood as to what it is by examining how it got that way" (p. 10). It is clear that *how* in the wording of the main research question - how do the engineering dispositions and thinking of culturally diverse students evolve (Section 1.3) - contains a dual meaning. The first meaning is: what engineering dispositions and thinking emerged and to what extent? The second meaning is: what is the nature and dynamics of the process by which this change occurs? Chapter 6 has addressed both these meanings of *how* inherent to the research question. This chapter discusses the general underlying conditions of "how it got that way" (Tolman, 1991) so as to provide insight for what it means for culturally diverse students participating in team-based design projects and, indeed, what it means for all students.

This study took up Vygotsky (1978) and Leont'ev's (1978; 1981) challenge of conducting research in a non-reductive manner by adopting activity as an irreducible, self-moving unit of analysis and focusing on holistic processes and their effects from the standpoint of the student. In Chapter 6, the particular manifestations of engineering dispositions and thinking, brought about by the inner contradiction in each 'student-within-the-team-within-the-activity-over-time', were tracked to produce five trajectories. These five trajectories are thought of as "particular instance(s) of the possible" (Bachelard (1949) in Bourdieu and Wacquant (1992, p. 233)), meaning that they are manifestations of generalized possibilities that exist in the activity system (Holzkamp, 2013) for culturally diverse students. In Chapter 6, these five student trajectories were considered side by side and five conditions were drawn out which underlie the emergence of culturally diverse learners' engineering dispositions and thinking. Evolution in these five students' engineering dispositions and thinking was manifest through:

1) Being willing to buy into working as part of a team (Section 7.2)
2) Being willing and able to claim a viable role as an engineer (Section 7.3)
3) Grappling with competing identities in becoming an engineer (Section 7.4)
4) Navigating different perspectives on engineering projects (Section 7.5)
5) Being able to self-regulate while under a complex, heavy workload (Section 7.6)

This means that within this overall activity system of the team-based engineering design courses, change in a culturally diverse student's engineering dispositions and thinking is influenced by their capacity meet these five conditions, given their particular circumstances. This chapter discusses these five conditions, in the sections labeled above, for what they mean for culturally diverse students in team-based design project modes of engineering study. The chapter's discussion leads to implications for theory, curriculum, and practice, to be outlined in Chapter 8.

7.2 Being Willing to Buy Into Working as Part of a Team

As discussed in Section 6.7.1, analysis of the five students' trajectories revealed the importance of a willingness of students to buy into working as part of a team as a minimum condition to develop engineering dispositions and thinking towards constructive collaboration and a capacity for communicating interculturally and interpersonally. The findings of this study point to a high possibility that there are gaps in the preparedness of second year students from cultural backgrounds and contexts where collaborating in diverse teams is not a common mode of study. Based on careful consideration of this study's participants, there appears to be: i) a gap between the intercultural awareness and skills (Weber, 2006) that students have and what is required to function effectively in a diverse team and ii) a gap between the academic English preparation that students like Jay undergo and what is required to function in team-based engineering design. This section first discusses constructive collaboration as it emerges in teams and then discusses the factors around culture and English language that potentially mediate students' meeting the minimum condition of being willing to buy into working as part of a team.

The intellectual and physical work of producing a project in a team is embedded within socially and materially organized activity (Holland & Reeves, 1996). From the moment students meet, they begin engaging in a process of jointly creating a team. Meaning becomes manifest through interactions in the team that serve as a basis for future collaboration. With successive interactions, these meanings evolve and come to serve as something members can point to for understanding what they are doing and why they are doing it together. Such meanings can be thought of as the emergent culture and history that manifests and evolves in teams (Carroll et al., 1992).

Team Z5 was comprised of students of diverse cultural backgrounds. They were from different Asian countries and spoke different languages. All students functioned in the team in English as their second or third language, although Jay and Lee (English-Mandarin) and Lee and Tony (English-Malay) occasionally code switched. Hence, rather than being socialized into North American engineering disciplinary norms, as characterized in Vickers (2007), there was no dominant culture or language in the team. A majority did not rule. As noted in Section 6.7.1, Jay's social engagement in shaping the team's early culture and history was minimal. He did not initially contribute to a pattern of constructive collaboration between its members and became socially and technically peripheral. On the other hand, Hyuna had the interpersonal and intercultural skills to engage with other team members to become central to the team's social functioning. It is highly possible that Jay lacked the intercultural and interpersonal communication awareness skills to fully function in the context. Hyuna was fluent in English and had the capacity to relate to team members from other cultures. Socially, and later technically, she functioned unimpeded in the team. The dynamics within team Z5 can be viewed as a "hybridity" of cultures (Gutiérrez et al., 1999) that exists in between the diverse personal cultures and histories of students in the team. Implicit in this hybridity is the need for the team members to participate in the medium of English across diverse personal and cultural backgrounds. The degree to which the team's constructive collaboration emerged is seen as a function of the team members' willingness to buy into working as part of the team by employing their individual capacities for interpersonal and intercultural communication.

The first cultural factor that potentially mediates students buying into working as part of a team relates to how students see the nature of their relations with their teammates. Jay's late arrival and his sickness, which limited his early contact with the team, are recognized as factors in him being peripheral in the team. However, Jay's background in a highly competitive Chinese school system, where student achievement tends to be prized over collaboration, and his experience in mostly homogeneous Chinese social groups before and after coming to Canada may have predisposed him to not buying into teamwork in this culturally diverse team. It is plausible that individual students' capacities to buy into working as part of a team in the early life of the team is substantially mediated by how strongly lines has been drawn between in-groups and out-groups in their experiences. As noted in Section 6.7.2, Hyuna was regarded by other team members as being easy to talk to – she was quick to engage with her new team members. On the other hand, Hyuna, Tia, and Lee all reported in the first interview that Jay separated himself from the other team members and tended to speak only for functional purposes. They saw him as initially cold, hesitant to share, and difficult to talk to.

Cultural notions of in-groups (insiders) and out-groups (outsiders) potentially mediate students' willingness to buy into working as part of the team. All cultures carry with them concepts of proximity in human relations, which influence communication and relationship patterns. Yet, Gao (1998) reports that the notions of insiders and outsiders are an integral part of the Chinese self-conception and that "(while) a person with an insider's status often enjoys privileges and special treatment beyond an outsider's comprehension…Chinese are less likely to initiate interactions or to be involved in social relationships with outsiders" (p. 49). The insider-outsider distinction prescribes specific rules of interaction in Chinese communication and interpersonal relationships, which include not interacting with outsiders, not sharing information, not expressing emotions, and seeking third-party mediators of relations (Gao et al., 1998). The notion of insider-outsider in Chinese culture is recognized as a broad guideline and subject to substantial variation among individuals from Chinese cultural backgrounds. Yet, it is plausible that Jay's experience in mostly Chinese groups before and after coming to Canada caused him difficulty relating to diverse others who he might have seen as outsiders. Cultural notions of insider-outsider and the associated interactional patterns, which manifest differently in individuals, are recognized as a potential factor influencing the willingness and capacity of students like Jay to buy into working as part of a team.

The cultural factor that potentially mediates an individual student's willingness and capacity to buy into working as part of a team relates to how students construe themselves with their teammates. As noted in Section 6.7.2, Hyuna was fairly explicit in her communication and transparent about what she did or was capable of doing on the project. On the other, Jay made five claims around the building of projects 1 and 2 that were either untrue or obscured events. For example, he claimed he could not contribute to project 1 because the team members had not invited him to the design meeting (they had) and that Tony and Lee had taken project 1 home to build it (they had not). In project 2, Jay claimed to Lee that he had made a functioning β meter from a design he found on the Chinese Internet. Yet, Tia reported observing Jay dismantling it and Lee could not find it in the locker where Jay claimed he had put it. Despite the instances observed of Jay making false claims and obfuscating events, the teammates and Jay alike consistently dropped the topic. It is interesting to note as well that Yao had come only a day after the project 1 conflict was resolved, yet he was unaware that the conflict of project 1 had occurred until the researcher brought it up during an interview.

The related concepts of face and facework in Chinese culture are relevant to the foregoing discussion that focuses on understanding Jay's challenges in buying into working as part of a team. Ting-Toomey and Kurogi (1998) define face as "a claimed sense of favorable social self-worth that a person wants others to have of her or him…a vulnerable identity-based resource because it can be enhanced or threatened in any uncertain social situation" (p. 187). These authors identify the importance of face as "insurmountable" in Chinese culture, quoting Hu's (1944) point that face "represents the confidence of society in the integrity of ego's moral character, the loss of which makes it impossible for him to function properly in the community" (p. 45). Ting-Toomey and Kurogi (1998) define facework as "referring to a set of communicative behaviours that people use to regulate their social dignity" (p. 188). While the phenomenon of face as being embarrassed or losing integrity in the eyes of others is common in all cultures, Chinese face has been described as having particular manifestations in social interactions, particularly in contexts of embarrassment, shame, and conflict (Gao et al., 1998).

The concept of face is relevant to the incident where Jay hid his failure to produce a functioning β meter, because it makes sense in light of his context - he was in the process of claiming a more technical role in the team in project 2 and likely felt vulnerable at that time. The topic of his failed β meter and his denial over the failure were quickly dropped and never mentioned again by his teammates. It is likely that while Jay kept his face by denying that it had failed, Lee (Chinese-Malaysian) and Tia (Filipino) preserved the silence, Jay's integrity, and hence, the harmony of the team. They did facework around Jay, including other moves such as Tia's sharing of the blame over the conflict in project 1 and concealing that part of team history from Yao, a new team member. While Jay had nominally bought into working as part of a team following the conflict, he still appeared to be experiencing challenges behaving in ways that were congruent with the team's social and work practices.

Moving from cultural factors, the third mediating factor in students' willingness to buy into working as part of a team is their attitude towards and competence in English. Recall from Section 8.6.1 that Jay seemed either unaware of or did not admit to difficulties in functioning in a team in English. With an IELTS score of 6.5, Jay had satisfied the English language admission requirements of the programme, but was observed having difficulty engaging effectively in the informal and formal communication around the projects. He also had challenges approaching and responding to instructors/TAs, doing demonstrations, and making informal social contact comfortably. At the beginning of term, he was observed only engaging in discussion when there was a functional reason to do so. On the other hand, Hyuna was observed from the beginning to be fluently engaging in English with the team members. She was aware of her limitations in English, which had factored into her decision to pursue a degree in engineering. Compared to Jay, Hyuna was more realistic about her English ability; yet, it was clear that she had sufficient English ability to interact in the team.

The difference between Jay and Hyuna is potentially the result of a disjuncture between the predominant focus of academic English language preparation programmes and what is required in professional academic programmes. Outcomes-based professional programmes like engineering, which follow professional accreditation frameworks (Engineers Canada, 2014), are now requiring students to have and develop teamwork, communication, and professional skills. Yet traditional English academic preparation for international students has traditionally focused on English language and literature rather than on broad communicative application in the target genres and contexts (Campbell, MacPherson, & Sawkins, 2014). Immigrant students such as Hyuna, who have attended high school, come with one or more years of academic English usage in content courses (e.g., math, physics, English) and more likely understand the general educational context in Canada and informal interaction in these contexts. Second, academic English programmes such as the one Jay attended, are often slow to adopt new conceptions of literacy to their programming, such as multiliteracies (Cazden et al., 1996), situated literacies

(Barton & Tusting, 2005), and corpus-based genre studies (Biber, 2006; Biber & Conrad, 2009; Nesi & Gardner, 2012). Third, there is a preoccupation with the gatekeeping IELTS examination for international students like Jay, which focuses on iconic academic genres and tasks so as to get students past the gate, but not necessarily fully prepared for what lies beyond it. In summary, there is far more to being functionally literate in English in the formal, informal, and non-formal learning contexts of engineering teamwork and design. Students must have the language awareness and ability to engage in cultivating constructive collaboration in the team. Students such as Jay who lack requisite language awareness and competence may be impeded in their capacity to buy into working as part of a team.

In summary, cultural and language factors appear to mediated students' willingness to buy into working as part of a team, particularly for students from cultural backgrounds and contexts where collaborating in diverse teams is not a common mode of study. The first cultural factor is that students must entertain the possibility that their new team is to become their in-group. The second cultural factor is that students need to influence and adapt to the team's emergent culture and practices so as to collaborate constructively on projects. Finally, students require the language awareness and competence that allow them to cultivate constructive collaboration in the team. The findings of this study point to a high possibility of the need to consider how to best prepare students to function in diverse teams through the development of intercultural awareness and skills and interpersonal English communication skills.

7.3 Being Willing and Able to Claim a Viable Role as an Engineer

As discussed in Section 6.7.2, analysis of five students' trajectories revealed the importance of being willing and able to claim a viable role as an engineer to developing engineering dispositions and thinking towards technical work. The findings of this study point to the critical importance of claiming a viable role as an engineer so as to shift from being a de facto math and science student to become a pre-professional engineering student. Based on careful consideration of the cases with respect to how students claimed their roles and how that factored into the evolution of their dispositions and thinking, the claiming of roles in team-based engineering design was found i) to occur through a combination of perceived and real technical knowledge and skills, indicators of being believable as an engineer, and random chance and ii) to result in a tight linking or fusion of person, role, and project that lead to unexpected evolution in students' engineering dispositions and thinking. This section discusses four critical decision points of Lee, Jay, Tia, and Hyuna which can be thought of as entry points for their particular role differentiation that led to differentiated evolution of their engineering dispositions and thinking. It then discusses factors that influence student's claiming of roles and hence, the evolution of their engineering dispositions and thinking towards technical work.

The critical decision points identified in Section 6.7.2 that led to the claiming of roles appeared to be mediated in equal measure by technical knowledge and skill, indicators of being believable as an engineer that came to hold currency in the team, and random chance. This study focuses on the evolution and change of engineering dispositions and thinking among cultural diverse students, and so gender, which emerged as important, is taken as a subset of cultural diversity. Yet, the findings of this study invite a discussion on gendered roles in engineering teamwork, particularly the work of two researchers (Kittleson & Southerland, 2004; Tonso, 2006a; Tonso, 2006b). As discussed in Chapter 2, Tonso (2006b) argued that belonging as an engineer student entailed both identifying and being identified as having a viable, locally produced engineering identity. Tonso (2006a) further argued that, unlike men, women may identify themselves through effective performances as engineers (i.e., show/have the abilities, bearing, appearance, behaviour etc. of engineers) but may not be identified by others as engineers making it harder for them to gain access to viable engineering student identities and garner equitable opportunities to learn. This has also been substantiated in other studies not explicitly focused on team based project modes of study in engineering (e.g., Phipps, 2007; Powell, Bagilhole, & Dainty, 2009; Powell, Dainty, & Bagilhole, 2012).

In this study of team Z5, there is sufficient evidence to claim that the indicators of being an engineer through the process of identifying and being identified as an engineer were partly gendered. This is exemplified in the data by how it seemed automatic to Lee that Tia and Hyuna were in peripheral supportive roles in building project 1. What Lee described as automatic, if viewed on a micro-interactional scale, likely involved a mutually consenting process of signaling and positioning of self and others from the time that they had first met (Davies & Harré, 1990). Such behaviour was observed in actions and talk during the study. Certainly, the male students were technically knowledgeable, but on this count, Tia and Hyuna were not necessarily far behind Tony and Lee when they first met in the team. Moreover, none of the students except Jay and later Yao had superior hands-on skills. Yet, somehow, being male tended to be synonymous with technical roles, with Tia emerging later as the only exception.

As Kittleson and Southerland (2004) note, there is a layer of knowledge and skill that appears to interact with beliefs about gender in shaping the claiming of roles. They found that in order to pull off being engineers, students had to i) enact particular discourses associated with ways of thinking, acting, valuing, and using tools and technologies that help other people recognize them as engineers; ii) have and be recognized as someone who has shared engineering knowledge; iii) have status within the team as defined by participation (i.e., time spent on project) and access to resources, technical authority; and iv) have recognized abilities, experience, or strengths. Tia had, or was enacting, this layer of knowledge along with her predisposition towards gendered roles in ways that did not preclude her from growing into a technical role through coordinating, communicating, and then building the power source in Design I project 2. She did so with the full support and appreciation from the male members of the team. On the other hand, Hyuna disidentified (Pesheux, 1982) with being an engineer throughout Design I projects 1 and 2 and also failed to engage in the knowledge and the discourse around the knowledge that would allow her to gain a positive result of claiming a viable role at critical decision points along the life of the project. She managed; however, to begin claiming a soldering role for herself at the beginning of Design II by practicing and then demonstrated her competence (Section 7.4).

Once roles were claimed, it was interesting to observe how a fusion of person, role, and project occurred in role specialization and led to unexpected change. As discussed in Section 6.7.2, Lee became central to the core of Design I projects 1 and 2, which drove the emergence of his engineering dispositions and thinking in the projects. Through his position at the core of the projects, his continued effort, and his growing knowledge and experience, he became central in the Design II projects as well. Lee was also afforded a social role in the team and opportunities to develop teamwork and communication skills over time by sitting in the lab with the project's tools, parts, and materials and communicating about and through these objects to other team members. His knowledge at the centre of the projects also led to project management, coordination, and communication roles. Though quiet, he emerged as the recognized leader of the team. Jay similarly claimed a role as " The Solder King", which gave him a stable and high status position in the team from which he contributed technically and socially. Tia overcame her initial peripheral role in project 1 by claiming a role as “The Power Ranger” and producing the power supply for Design I project 2, which led to a growing technical role to complement her coordination and communication role. The opportunities had important consequences for her engineering dispositions and thinking.

On the other hand, Hyuna came to inhabit a social loafing role, which Borrego, Karline, McNair, and Beddoes (2013) define as a phenomenon where individuals “exert less effort when working collectively than when working individually” (p. 487). Hyuna remained unattached to an identifiable part of Design I projects 1 and 2. Though provisionally assigned to the VHDL programming and DE2 board with Yao in project 2, she had not taken the co-requisite course and so did not know how to code in VHDL. Heisenberg had also provided basic VHDL code for the DE2 board and so she found herself without a viable role. Hence, she was not in a position to enjoy opportunities to develop her engineering dispositions and thinking towards project work. This may explain her eagerness to become involved in soldering projects, which would give her access to such opportunities (Section 6.4).

The examples of Lee, Jay, Tia, and Hyuna are illustrative of the concept of symmetry in Actor Network Theory (Latour, 1987). Symmetry describes how human and non-human entities “assemble collectives or ‘networks’ that produce force and other effects: knowledge, identities, routines, behaviours, policies, curricula, innovations, oppressions, reforms, illnesses, and on and on” (Fenwick & Edwards, 2011, p. 2). Lee and Jay were observed becoming connected to particular material objects in ways in which the person, role, and project became tightly linked, as if they were one, and in doing so became “capable of exerting force and joining together, changing and being changed by each other” (Fenwick & Edwards, 2011, p. 2). The explanatory power of the effects this tight linkage of person, role, and project on engineering dispositions and thinking; however, are directly related to Vygotsky's (1978) concept of mediation, which is to say, how people, by functioning as part of a cultural, historical, material, and social context, at once transform and are transformed by the world. As described in Section 3.4.1, Roth (2013) extends Vygotsky's notion in ways that informs the interpretations and meanings brought out in this section. He articulates the claiming of an identity in practice through engagement in collective, practical, material activity as a process of subjectification:

> First, the subject expends energy and therefore is materially transformed. Second, as a result of repeatedly producing the same form of movements (that realize actions), the body or bodies of the subject are transformed, becoming increasingly practically competent. Third, in praxis, the comprehension of the subject is changed, as it increasingly comes to understand praxis on the ideal level. Fourth, with increasing practical and ideal competence, the changes of the subject are recognized within the collective (community) writ large (i.e., not only within a specific groups that might constitute the collective subject of activity, but also within all those who are the subjects in other concretizations of the activity). (pp. 45-46)

Roth's (2013) articulation of the process subjectification is an informative account of how humans are transformed in practical activity by becoming practically competent, by gaining an understanding of praxis (i.e., the process by which theory is enacted, embodied, or realized) on the ideal level, and by being recognized in the collective as an engineer. Becoming fused as part of such networks of person-role-project, affords students critical opportunities to engage in real-world practical activity and to develop their engineering dispositions and thinking towards technical work through this process of subjectification. This opportunity was not available to Hyuna until the Design II projects when she was accepted as a solder person in the team.

Hence, a viable role linked to the materiality of engineering is critical to develop engineering dispositions and thinking towards technical work. A capacity to do so appears to be mediated by factors related to being believable as an engineer that come to hold currency in the team (gender in this case). It appears also to be critically mediated by perceived competence (e.g., contributions, knowledge, technical talk) that allowed students to pull off being an engineer (Kittleson & Southerland, 2004). The entry points to such roles are in the critical decision points that manifest inexplicably in the life of the project. Claiming a viable role as an engineer was observed to lead to the development of engineering dispositions and thinking in often unexpected ways when person, role, and project became tightly linked. It follows that students coming from a long experience in a traditional math and science mode of study must be willing and able to claim a viable role as an engineer if they are to develop engineering dispositions and thinking towards technical work. A viable role is a vehicle for evolution.

7.4 Grappling with Competing Identities in Becoming an Engineer

As discussed in Section 6.7.3, analysis of the five students' trajectories revealed the importance of students grappling with competing identities and investing in becoming an engineer as another minimum condition to develop engineering dispositions and thinking towards their early professional path. The findings demonstrate that students whose priorities lie elsewhere have fewer opportunities to develop their engineering dispositions and thinking. This section discusses Hyuna's trajectory because it exemplifies how competing identities can mediate students' investment in engineering and affect opportunities to develop engineering dispositions and thinking in students' early professional paths.

As noted in Section 6.7.3, Hyuna disidentified (Pesheux, 1982) with engineering, demonstrating a lack of investment in engineering which appeared to initially relegate her to peripheral technical roles in the team. Hyuna reported a dislike of design to her team; appeared to lack technical initiative, effort, and engagement during modules and projects; tended to play inappropriately and idly with equipment; and often voiced ideas during meetings that were perceived to be naïve or off-bases. Hyuna functioned in and across more activities across the spheres of her life than any of her teammates during Design I. In the first half of second year, actually being an engineer appeared to be low on Hyuna's priorities (i.e., affinities, goals, and drives). It was highly likely that cultural values around gender roles contributed to the initially low priority Hyuna placed on engineering in her life. As discussed in Section 6.7.3, she reported that as women, their role is to become moms and "just stick in the house", whereas the male students have a greater capacity for work and look like engineers.

Hyuna's lack of investment requires a nuanced understanding through Mead (1934) and Leont'ev's (1981) concepts of identity. As noted in Section 3.3.2, Mead (1934) saw identity as multifaceted and variant across the multiple activities in a person's whole life. Holland and Lachiotte (2007, p. 104) note Mead's concept of identity "as a sense in oneself as a participant in the social roles and positions defined by a specific, historically constituted set of social activities." The way forward in understanding Hyuna's disidentification with and lack of investment in engineering comes back through activity theory to Leont'ev's (1982) perspective on personality: "the real basis of human personality is the totality of the, by nature, societal relations man entertains with the world, precisely those relations that are realized. This occurs in/through his activity, more precisely, in/through the totality of his manifold activities" (pp. 175-176, translated by Roth, 2013). Leont'ev (1981) considered the substrate of personality as existing as a hierarchical network (aka 'knot-works') of activities and object/motives (Section 3.4.2.2) across the spheres of a person's life that "are tied not by the action of biological or spiritual forces of the subject which lie within him but by that system of relationships into which the subject enters" (p. 159). Roth (2014) explains:

> Within the unique individual, the object/motives, all of which are socially determined, exist in some hierarchical order that determine their relative priorities for the person as a whole

> (…) the study of personality cannot be conducted by looking at the individual itself, but one has to investigate the development of the systems in which the individual is part and which it, through its own development, develops in turn (p. 18).

Transitioning between a textbook and lecture-based math and science mode of study into a team-based design project mode of study in second year encounter increased workloads and new demands making time a scarce and valuable resource. Inner contradictions (Leontʹev, 1978) can thus emerge between competing identities, activities, and object/motives across a students' life in forcing them to grapple with what is to sit at the topic of this knot-work hierarchy of object/motives and identities. It is this hierarchy that influences how students invest in engineering and, accordingly, gain opportunities to develop engineering dispositions and thinking that are fitting to their early professional development. It was apparent in Design I that engineering did not sit at the top of Hyuna's knot-work hierarchy of object/motives – it was not her priority across the spheres of her life.

It is highly likely that Hyuna's cultural values and repertoires around gender roles and work contributed to the low status of engineering itself in her hierarchy of object/motives. Hyuna's notion that boys have greater capacity for work and girls become moms and "might just stick in the house" is likely an influence from prevailing views in South Korea on the role of women in society and the family (Sechiyama, 2013):

> A prominent feature of the South Korean model of patriarchy is its firmly rooted belief that social roles should be based on gender – a way of thinking set against the background of a Confucian tradition…it (is) pretty much the norm for women to quit working after marriage, and women were clearly placed in special work categories because they were women (pp. 160-161).

Interestingly as well, the original Chinese character for the Korean word couple or *naewe* (内外), transcribed into the Korean alphabet Hangul, is a combination of the meanings inside or 内 (i.e., woman) and outside or 外 (i.e., man), denoting a traditional separation of gender roles with men going out to work and women staying in the home. Finally, findings from the GLOBE Gender Egalitarianism dimension (House et al., 2004), defined as the degree to which a collective minimizes gender inequality, provide additional insight into values Hyuna has likely been exposed to while growing up for most of her life in South Korea (Table 17). High scores on the 7-point scale indicate greater gender equality. The findings indicate that South Korea's score of 2.50 is at the bottom of gender egalitarianism scale among 62 countries with a mean score of 3.37, a range of means from 2.50 to 4.08, and an average standard deviation of 0.37. The composite picture formed by observational and interview data and these additional sources (House et al., 2004; Sechiyama, 2013) suggests that Hyuna was strongly influenced by traditional Korean cultural values around gender roles and work.

Table 18. Mean Scores for Gender Egalitarianism

South Korea	China	US	Australia	Hong Kong	Malaysia	Philippines, France	England	Canada
2.50	3.05	3.34	3.40	3.47	3.51	3.64	3.67	3.70

Observations of Hyuna interacting in and outside her team also suggest that cultural schema around gender and work became manifest to some degree in her interactional repertoires. She acted playful, light, and sometimes helpless around the male students in ways that brought indulgence and light teasing and ridicule. She played with equipment inappropriately at times, showed her lack of knowledge, and made naïve, negative, or impractical suggestions for laughs. It is plausible that her behaviour, combined with her indirect support on projects and her positive social engagement with the team had the effect of excusing her from doing most of the technical work in Design I. The researcher's two decades of experience living in Japan and Korea prompted the interpretation from observational data that Hyuna was enacting some of the repertoires and interactional patterns associated with *aegyo/naesung*, Korean pop culture-inspired behaviour considered acceptable for young Korean woman socializing in mixed gender groups. Utz and Lau (2013) note:

> *Aegyo* literally means "behaving in a coquettish manner," a term frequently used in fan discourses to discuss the affectionate speaking and gestural styles of young female pop idols, encompassing their empowering function for women who use *aegyo* as a means to manipulate men (p. 279).

Puzar (2011) notes "*aegyo* entails acting charming yet…vulnerable and volatile, pretending sudden surprise or unmotivated sadness or anger…implying helplessness or confusion (p. 99). Someone using *aegyo* may utter, in an exaggerated way, the Korean word *oppa*, which literally means older brother, but is mostly used to address a boyfriend (Tudor, 2014, p. 24). Hence, a young woman invokes a kinship term (*oppa*) for an older male, who sits in a higher position in the family. *Naesung*, a similar cultural repertoire, means "pretending to be innocent, but in a negative way" (Tudor, 2014, p. 24). *Aegyo* and *naesung* extend beyond couple-related behaviour of young Korean adults and is often perceived as attractive and desirable. Hyuna was observed behaving in a manner that would be recognized as light *aegyo*/*naesung*, that positioned her with respect to the male students as helpless and often led them to either indulge her (Lee, Jay, Yao) or call her out (Jay, Tony). In harbouring cultural views on women and work and enacting these cultural repertoires, it is highly probably that Hyuna's disidentification with engineering was strongly culturally mediated.

Hyuna's case exemplifies how multiple competing identities across the knot-works of object/motives of a students life, mediated by culture and gender, can influence their investment and hence, their opportunities to develop engineering dispositions and thinking in their early professional path. Identities not commensurate with each other are likely to cause inner contradictions that will need to be grappled with lest they constrain opportunities for the student to engage centrally in the projects so as to develop engineering dispositions and thinking. The degree of congruence between an individual's knot-works of object/motives and the range of engineering identities available to culturally diverse students in engineering will also affect such investment.

In summary, cultural and gender factors potentially mediate culturally diverse students' inner contradictions (tensions) between the knot-works of object/motives and identities across the spheres of their lives. Congruence between the various knot-works of object/motives and identities across a person's life, including engineering study, is likely to result in investment in engineering and opportunities to develop engineering dispositions and thinking appropriate for early professional paths for students. Students who face inner contradictions across their identities and activities – mediated by culture or other factors - will need to grapple with competing identities in order to benefit from the development of students engineering dispositions and thinking in their early professional development.

7.5 Navigating Different Perspectives on Engineering Projects

As discussed in Section 6.7.4, analysis of the five students' trajectories revealed the importance of navigating different perspectives on engineering projects as a condition to develop engineering dispositions and thinking towards constructive collaboration on engineering projects in complex environments in which cultural factors are significant. The findings of this study point to a high possibility that challenges exist for culturally diverse students working in diverse teams in taking cues from the environment and navigating divergent team perspectives to arrive at sound decisions on engineering projects. This section discusses the complexity of the contexts of engineering design and the cultural factors that potentially mediate students' capabilities for navigating different perspectives on engineering projects.

Project requirements as communicated on assignment sheets, rubrics, and in lectures, viewed through an objective lens, might conjure up an image of teams proceeding down similar pathways towards the same goal. Yet, this study has illustrated that team-based engineering design projects are complex (Chapter 5), teams contain within them competing perspectives on projects (Holland & Reeves, 1996), and people working as part of this complexity have their own inner contradictions (Leont′ev, 1978) and their own subjective reasons for their actions (Holzkamp, 2013). Discussion of the extended disagreement between Yao and Tony in Section 6.7.4 exemplifies how dominant team perspectives (e.g., in this case, one oriented to high quality and perfection) and emergent team perspectives (e.g., in this case, one oriented towards simple solutions, basic functionality, getting passing marks) that manifest in complex environments, are mediated by cultural factors, and can lead to unanticipated outcomes.

As discussed in Section 2.6, Holland and Reeves (1996), employ Leont'ev's (1978), metaphor of a team of primeval hunters who, depending on their team perspective, made the hunt into either a masculine competition by chasing the biggest game or, alternately, into an opportunity to get out of the house and avoid domestic responsibilities by chasing game that fled afar. As noted in Section 6.7.4, the dominant team perspective these students inherited from project 1 (a transistor-level project) was arguably inappropriate for project 2 (a systems-level project): a change in mindset was required toward hierarchical structuring of project activities, prioritization, task delegation, and the use of time, knowledge, and human resources. The team either did not perceive the change or did not act on cues in the environment that things were now different.

A more complex hunt for larger game had emerged (Design 1 project 2), yet the team had remained stuck in an old team perspective that had been successful with smaller game (Design 1 project 1). In the collective hunt, Leont'ev (1978) notes that one hunter's role might be to perform the action of shaking bushes (i.e., actions within activity in Figure 5 in Section 3.4.1) to startle small game so others could catch it. Metaphorically speaking, in Tony's case, he became obsessed with shaking bushes, elevating an action (i.e. building a multimeter box) designed to accomplish the activity of hunting (i.e., creating a multimeter) to the level of activity itself (Figure 5 in Section 3.4.1). He had not attended to changes in the environment and hence, in the hunt. Tony's later comments suggested he had come to realize that this was the case, yet his realization was only possible after they had adopted a new team perspective of basic functionality first. Yao too could not see clearly at the time that his instincts were good. Given his recent arrival in the team, he was not in a position to push for an alternative team perspective. It was only with the poor showing of project 2 that the team was ready for the turnover.

Such events-in-the-making can only be understood once complete and available for discussion (Roth, 2013). Yet, the point is made here that the dominant team perspective that tended to shape these students' decisions and actions on the project was neither explicitly discussed at any time nor made available for renegotiation by new team members like Yao or new ideas emerged from other team mates. A candid and explicit sharing of information and cues from the complex environment around the new project 2 was largely absent. There is evidence that cultural factors mediated how Design I project 2 played out in the team. While it was noted earlier that teams contain within them competing perspectives on projects (Holland & Reeves,

1996) and people within teams have their own inner contradictions (Leont′ev, 1978) and subjective reasons for their actions (Holzkamp, 2013), people also bring their own cultures and histories to the team. Individuals' personal cultures and histories are fodder for the emerging culture and history in the team of which they become a constitutive part. Using the case of team Z5 as an example, cultural factors related to indirect communication and the maintenance of harmony, combined with Lee and Tony's authority as technical leaders, and Tia's power to confer authority to them, appear to have contributed to the Yao's ideas (e.g., buying instead of making the box, not soldering the project) being silenced.

GLOBE's Cultural Competencies (House et al., 2004) speak to the potential role of the cultural repertoires (Swidler, 1986) of indirect communication and maintenance of harmony in the team through their findings on in-group collectivism. They define in-group collectivism as "the degree to which individuals express pride, loyalty, and cohesiveness in their organizations or families the cultures in the participants' countries of origin" (House et al., 2004, p. 30). Table 18 lists the means for this dimension for the students' countries of origin with other countries selected from among the participating countries. High scores on the 7-point scale indicate greater in-group collectivism. The mean score for in-group collectivism across 62 countries was 5.13, the range was 3.53 (Denmark) to 6.36 (Philippines), and the average standard deviation was 0.73. The means of all students' countries of origin were between 0.3 and 1.7 of a standard deviation above the mean, suggesting that the team members, if representative, tended towards in-group collectivism. GLOBE's measure of power distance by country suggest that only Tia (Philippines) and Hyuna (South Korea) come from countries that scored as high power distance (House et al., 2004). Observance of hierarchy was only apparent in Tia: she often reinforced Tony and Lee as the authorities in the team and generally deferred to them.

Table 19. Mean Scores for In-group Collectivism

England	Australia	Canada, US	France	Hong Kong	Malaysia	South Korea	China	Philippines
4.08	4.17	4.26	4.37	5.32	5.51	5.54	5.8	6.36

House et al. (2004) make these claims about in-group collectivist national cultures:

> Members of individualistic countries tend to be direct and forthright in their communication, whereas members of collectivist cultures tend to be more indirect in their communication… (which) results from the desire in collectivist cultures to save face and the need to attend to contextual factors. (p. 452)

A number of studies also compared data taken from three countries identified as collectivistic (Hong Kong, Japan, China) with two countries identified as individualistic (US, Australia) and found that people in the collectivist samples had greater self-disclosure, more perceived similarity, more shared networks, and greater confidence in members of their in-group than in members of the out-group as compared to the individual sample (Gudykunst et al., 1992; Gudykunst, Gao, & Franklyn-Stokes, 1996). As noted in Section 6.7.4, many of these characteristics were observed in this team. It is highly probable that members of team Z5 naturally tended not to voice opinions on the project if they were viewed in the team as threatening to its social fabric or because they feared being called out by more knowledgeable team members like Tony. The team's tendency to sacrifice candid dialogue over team perspectives and take on board cues from the environment in the interests of maintaining social harmony (Anderson, Thomas, & Nashon, 2009) is very interesting. The case of Yao and Tony exemplifies how indirect communication and an overemphasis on harmony had consequences for the project outcomes and in the engineering dispositions and thinking it fostered, particularly since building the box slanted the focus of work to hard prototyping (Newstetter, 1998).

As Bucciarelli (1994) demonstrates, “design is a social process” (p. 20). It is difficult to predict how students will jointly create team perspectives and how these will orient the teams’ roles, activities, and expectations in complex environments that affect the project outcomes and the evolution of their engineering dispositions and thinking. Project task design, assessments, assessment practices, handouts, intellectual and physical resources, explicit learning of engineering design and project management (esp. task analysis, delegation), and communication about the project all shape the team perspective and students’ subjective reasons for action. As Holzkamp (2013) notes:

> The (societal) conditions which, in their environmental specificity, face the individuals (are) conceptualized as ‘constellations of meaning’ – that is generalized possibilities to act – which the individual can consciously related to by accepting or rejecting them as “premises” for her/his subjectively grounded actions. (p. 41)

The five examples (Section 6.7.4) of Yao’s flashy soda drink delivery design; the misreading of the power supply requirements; the adoption of Heisenberg’s dual slope ADC design; the emphasis on hard prototyping in project 2; and the multimeter box exemplify how cues read in the environment lead to particular outcomes and have implications for the nature of engineering dispositions and thinking. It therefore follows that it is essential that culturally diverse students in teams are able to navigate team perspectives, which implies interpreting and sharing information from a complex environment that informs team perspectives on the project and shapes the nature of the engineering dispositions and thinking that evolve in them through the projects.

This discussion points to the critical importance of culturally diverse students having an ability to navigate different team perspectives to develop engineering dispositions and thinking towards constructive collaboration on engineering projects in complex environments in which cultural factors are significant. A capacity to do so is potentially mediated by cultural factors and communication patterns for how they shape how cues are taken from the environment, shared and hence, how team perspectives manifest, are defined, and revised over the life of a team. This capacity has implications for what students focus on in projects, which in turn influences project outcomes and the shapes the nature of the engineering dispositions and thinking that evolve in students. Given that team perspectives orient what students do, how they do it, and why they do it, and hence how they evolve, it follows that the ability of culturally diverse students to engage in navigating team perspectives is essential to their evolution as pre-professional engineers.

7.6 Being Able to Self and Co-Regulate While Under a Complex, Heavy Workload

As discussed in Section 6.7.5, analysis of the five students' trajectories revealed the importance of being able to self-regulate to develop engineering dispositions and thinking towards work in team-based engineering design. The findings of this study point to a high possibility that challenges exist for students in self-regulating (Hadwin, Jarvela, & Miller, 2011; Zimmerman & Schunk, 2011) while under the complex, heavy workloads in this team-based project modes of engineering study so as to both cope effectively with the workload and also to develop engineering dispositions and thinking appropriate for professional engineering work. This section discusses how Yao and Tia's cases, which exemplify the link between the workload and context of team-based engineering design projects, the importance of self-regulation, and the development of engineering dispositions and thinking.

Section 6.7.5 discussed Yao and Tia's response to workload they faced in the team-based design projects. Yao reported that he developed thinking habits (e.g., finding a method towards approaching problems, breaking bigger problems into smaller ones, not wasting effort, knowing how to find answers versus recall); regulated his emotions (e.g., not panicking, controlling his anger); and tuned into dispositions appropriate to the work (e.g., being cautious, persistent, self-reliant). Zimmerman and Schunk (2011) define such self-regulation as "processes whereby learners personally activate and sustain cognitions, affects, and behaviours that are systematically oriented towards the attainment of personal goals" (p. 1). Yao provided the most explicit portrait of self-regulation and its role in the evolution of his engineering dispositions and thinking of all the students in team Z5. On the other hand, Tia was less communicative about how the programme was affecting her internally. As noted in Section 6.7.5, she rarely voiced how the experiences were affecting her mentally, physically, or emotionally. Instead, she preferred to focus on monitoring and supporting the team and the project through communicating with, coordinating, and motivating her teammates. Unlike Yao, Tia appeared to place a premium on the team rather than attending to her own needs in coping with the demands of the programme. Tia can be thought of as having more of a concern for engaging in socially shared regulation, which Hadwin et al. (2011) define as "interdependent or collectively shared regulatory processes orchestrated in the service of a shared outcome" (p. 67). Tia's orientation to the social and emotional life of the team and her lack of self-care may have contributed to her abruptly taking leave from the programme once Design II project 1 was complete because of her migraines. It is plausible that Yao was able to self-regulate, cope, and get through while Tia's capacity to self-regulate did not enable her to complete the term – she had somehow exceeded her elastic limit for taking punishment.

These two cases exemplify how students' responses, intentional or not, in the face of the heavy workload and complexity of the team-based project environment shapes their capacity to cope and hence, the nature of the evolution of their engineering dispositions and thinking. Leont'ev's (1978) concept of object/motive (Section 3.4.2) is informative for understanding how dispositions and thinking evolve through the collective practical activity of the team-based projects. Object/motive is one element of activity system defined as a collective societal need. Roth (2014) articulates object/motive as "the moving force that governs the processes of activity at the collective level; its image is a subjective product of activity that fixes, stabilizes, and contains it on the ideal plane (collective consciousness)" (p. 10). In this articulation of object/motive for an activity (e.g., producing an advanced multimeter) exists on a real plane (i.e., the physical project as it is at the moment) and the ideal plane (i.e., the project as it is envisioned by the collective once created). Drawing on Vygotsky (1978), working on the advanced multimeter is conceived as involving a mediated, dialectical process that occurs between the subjects (team members), through the tools and signs (project, equipment, tools) to the object/motive of the activity such that the real evolves to resemble the ideal (Section 3.3.1, Figure 2, 4: object/motive appears as object). The external outcome of this mediation (Vygotsky, 1978) is a physical project that hopefully evolves into how students envision it once created. Through his concept of internalization (Section 3.3.1), Vygotsky (1978) also conceives that an internal evolution is simultaneously occurring, which in this case is the evolution of engineering dispositions and thinking that emerge as critical to activity and are patterned on minds of the students. These concepts can be used as a lens to draw meaning from the findings in Section 6.7.5: self-regulation in the face of heavy workloads in complex environments is critical to the development of engineering dispositions and thinking.

Focusing at the activity system level, the gap or inner contradiction between the advanced multimeter (object/motive of Design I project 2) as it is on the real plane and as it is imagined on the ideal plane causes the activity system's self-movement (Roth, 2014). Students engaging as a constitutive part of activity inhabit roles in which they need to read and respond to cues or reference points in a busy and complex environment so as to close the gap between the project on the real and ideal plane. This is all subject to how the understanding of the object/motive is understood by the team.

Socially shared regulation of the team at the level of activity (Hadwin et al., 2011), in which Tia was deeply engaged, is essential to the collective goal of producing something such as an advanced multimeter. Recall that Tia's inner contradiction was expressed as: How do I 'do the right thing' cultivating the team's emotional life, following the rules, and doing engineering well? (Section 6.7.4). Her engagement at the level of socially shared regulation of the team may explain the shift in her disposition towards authority (i.e., rules in an activity system, Engeström, 1987; Section 3.3) Recall that by Design II project 1, Tia appeared to have lost trust in Tony's technical authority (Section 6.5.5) and began to question his confident assurances that did not produce the result expected in Design I project 2. Tia, through her engagement in socially shared regulation, her experience building a power supply, and her experience of the Design I project 2 as a failure may have led to a metacognitive awareness (Anderson & Nashon, 2007) with respect to her original deference to technical authority and Tony's capabilities to contribute successfully to the team. Tia's case exemplifies how her engineering dispositions and thinking become internalized through engagement in socially shared regulation of the team. It is possible that her substantial engagement at the level of team processes affected her own capacity to self-regulate at the individual level and engage in self-care so as to cope with the workload in a more sustainable fashion.

Recall that Yao's inner contradiction was expressed as: How can I balance my approach towards time/mark-efficient activity to "get past/passed" with my need to maintain harmony as a new member of a team that is "aiming high"? (Section 6.7.4). His orientation to "getting past/passed", which he regulated consciously by attending to marks, time, his physical, emotional, and physical resources (Section 6.6) is conceived as central to his self-regulation that led to the evolution of his engineering dispositions and thinking, as described earlier. While Yao appeared to be continually reading the environment for important clues to adjust the allocation of his resources in order to optimize his marks, Tia appeared not to have this mind-set. This may have contributed to his coping with the programme and her taking a leave of absence.

In summary, Yao and Tia's cases exemplify important enculturating effects from the workload and complex context of a team-based project mode of study on students' engineering dispositions and thinking. Students' individual capacities for and orientations towards self-regulation and socially shared regulation (Hadwin et al., 2011) in the intense activity of team-based projects shape the engineering dispositions and thinking they internalize (Vygotsky, 1978). Their individual capacities for self-regulation and socially shared regulation also influence whether such evolution is fruitful for them and the profession and whether it is sustainable or leads to attrition.

The five conditions that influence culturally diverse students' engineering dispositions and thinking have now been discussed (Section 7.2 to 7.6) for what they mean for culturally diverse students in team-based design project. The discussion in this chapter leads to several implications for theory, curriculum, and practice, which will be now be outlined in Chapter 8.

Chapter 8: Conclusions and Implications

8.1 Conclusions

Eight key conclusions are drawn from this study and derived from the discussion in Chapter 7. The first three are general conclusions related to the nature of team-based project mode of study as observed in this study. The five conclusions that follow the first three are drawn directly from the five conditions identified in Sections 7.2 to 7.6, which are relevant to the evolution of culturally diverse students' engineering dispositions and thinking. The conclusions extend the understandings from the findings (Chapters 5 and 6) and discussion (Chapter 7) that address the study's main research question: How do the engineering dispositions and thinking of culturally diverse students evolve through their experiences in the second year of an electrical and computer engineering programme?

First, student-student, student-instructor, student-tool, and student-assessment interactions are catalyzed by the nature of the project task and perceived competence and hence, roles claimed in the team. The nature of the project and the perceived competence substantially shape the object/motive of team-based projects. The object/motive is defined by Roth (2014) as "the moving force that governs the processes of activity at the collective level; its image is a subjective product of activity that fixes, stabilizes, and contains it on the ideal plane (collective consciousness)" (p. 10). The nature of the project task is its characteristics, such as the project requirements and criteria, project modularity, balance of hard and soft-prototyping, and required knowledge and skills. Perceived competence refers to the intellectual resources as they relate to the project, which are distributed among team members (Pea, 1993), and factor into the claiming of roles. This conclusion means that the nature of the project and perceived competence catalyzes, or activates and shapes, the dynamic interactions among students, instructors, tools, and assessments as teammates attempt to narrow the gap between the project as it exists physically in the present moment (object/motive on the real plane) and as they imagine it once completed (object/motive on the ideal plane).

Second, the structure and culture of the team were both fodder for and manifestations of team perspectives towards the project task. As Holland and Reeves (1996) note, when individuals jointly engage in practical activity, they develop different “takes” or “perspectives” on the project task as part of the team’s emergent structure and culture. Dominant team perspectives are prevailing and contingent understandings about project work - what the team does, how they do it, and why they do it - as they labour towards creating a successful project. As noted in the previous paragraph, the project task can be understood on two levels: as an idealized image in the collective consciousness once completed (i.e., object/motive on the ideal plane) and how it exists physically at any given moment (i.e., object/motive on the real plane). This conclusion means that the team structure and culture and the team perspectives towards the project mutually define each other and exist as a mediating layer between the project as it exists and the project as it is imagined once completed: between what it is and what it could be.

Third, critical decision points became manifest along the life of the project to shape the nature of students’ individual possibilities for developing engineering dispositions and thinking. Critical decision points are defined as entry points that present themselves to particular students along the life of the project and potentially lead to the differentiation of roles and hence, differentiated evolution in students’ engineering dispositions and thinking. Rather than necessarily being conscious decisions made with agential intent, critical decision points manifest in unexpected ways in the complex activity of the project. The occurrence and consequences of such critical decision points are not recognizable in the moment that they present themselves;

rather, they emerge as potential entry points for new directions for students to develop engineering dispositions and thinking in unpredictable ways.

Fourth, the degree to which constructive collaboration emerged and individual engineering dispositions and thinking evolved were a function of team members' willingness to buy into working as part of a team by deploying their individual capacities for interpersonal and intercultural communication. This is the first of five more specific conclusions drawn from the key conditions identified in Chapter 7. A willingness to buy into working as part of a team was identified as being a minimum condition - a price of admission - to develop engineering dispositions and thinking towards constructive collaboration and greater capacity for communicating interpersonally and interculturally. Meeting this condition was found to be mediated by culture and language competence, which represents a concern for students from cultural backgrounds and contexts where collaborating in diverse teams in English is not a common mode of study.

Fifth, the degree to which team members' constructive collaboration emerged and individual engineering dispositions and thinking evolved were a function of team members' willingness and ability to claim a viable role as an engineer by deploying their individual capacities for displaying perceived or real knowledge, skills, and attributes that held currency in the team to enhance their connection to technical project work. As identified in Chapter 7, a viable role is a vehicle for evolution. Being willing and able to claim a viable role as an engineer means students avail themselves of opportunities presented by critical decision points through the display of perceived or real knowledge, skills, and attributes. Success in becoming tightly linked to a part of the project and a more specialized role leads to the evolution of students' engineering dispositions and thinking in important and often unexpected ways.

Sixth, the degree to which team members' constructive collaboration emerged and individual engineering dispositions and thinking evolved were a function of team members' ability to grapple with competing identities in becoming an engineer by deploying their individual capacities for prioritizing engineering study and achieving a degree of congruence among the spheres of their lives. Grappling with competing identities in becoming an engineer was also identified as being another minimum condition (see conclusion four) - a price of admission - to investing in engineering to develop engineering dispositions and thinking towards one's early professional path. An individual's capacity to prioritize engineering study and achieve congruence among the spheres of their lives was found to be influenced by factors of cultural and gender as they played out in the dynamic of the team and in the students' lives.

Seventh, the degree to which team members' constructive collaboration emerged and individual engineering dispositions and thinking evolved were a function of team members' ability to navigate different perspectives on engineering projects by deploying their individual capacities for discerning and interpreting relevant cues in a complex environment and communicating interpersonally and interculturally. Engaging in the process of jointly discussing, defining, and revising the team perspective over the life of projects is a critical condition for a team's constructively collaboration. Doing so requires the capacity to effectively discern and interpret cues from the environment and jointly negotiate team perspective and practices on the basis of this information, both of which appear to be mediated by culture and language. Hence, a capacity for discerning such cues and employing intercultural and interpersonal communication skills is critically important for project outcomes and the evolution of students' engineering dispositions and thinking.

Eighth, the degree to which team members' constructive collaboration emerged and individual engineering dispositions and thinking evolved were a function of team members' ability to self-regulate and engage in socially shared regulation while under a complex, heavy workload by deploying their individual capacities for metacognitive awareness. The complex and heavy workload in engineering study has been described as a rite of passage and is recognized as potentially having both constructive and debilitating effects. These include effects on both the engineering dispositions and thinking students are enculturated into and the increased uniformity of the learning community that potentially occurs when students who resist or cannot sustain their participation in engineering study and drop out. In these ways there is a potential narrowing of dispositions and thinking through enculturation and attrition. Self-regulation was observed for its effects on thinking habits, emotional control, and dispositions adopted as appropriate to project work. Socially shared regulation (a form of co-regulation: Hadwin et al., 2011) was observed for its positive effects on the constructive collaboration in teams. A developing capacity for self-regulation and socially shared regulation enabled students to respectively sustain their personal wellbeing while coping with the workload and sustain the team's constructive collaboration so as to develop engineering dispositions and thinking relevant to their early professional development.

8.2 Implications for Theory

As noted in Section 3.4.3, this study employed a hybrid activity theory framework of Roth (2009), who drew from Leont'ev (1978) and Holzkamp (1991, 2013) to formulate an approach for tracking the emergence change and its accumulation and turnover to explain development in humans. The approach involves focusing on individual students' inner contradictions that emerge as they engage in collective practical activity over time and come to drive their evolution. As discussed, this framework is fundamentally different from many activity theory studies (Engeström & Sannino, 2010) that employ the second and third generation activity theory of Engeström (1987) and tend to focus on a system's eye view of activity theory (Section 3.3.2, Figure 4) as a framework for analysis. Roth's (2009) framework was chosen because it privileges a focus on the individual evolving as a constitutive part of an activity system that also contains within its own inner contradictions and self-movement. Roth (2013) notes of different versions of activity theory:

> There are two schools of thought that have developed. The first emphasizes the structural, synchronic aspects of an activity system, which is viewed from a god's eye perspective emblematically symbolized in triangular representations; the other emphasizes the dynamic, diachronic nature of activity from the perspective of the subject. (p. 44)

The "god's eye perspective" refers to second and third generation activity theory, which emphasizes the structure of the activity. Langemeyer and Roth (2006) note that following this approach effectively takes activity as static or invariant over time. As such, it was difficult to see how Engeström (1987) could be employed to research enculturation, which by definition, involves tracking change over time and to focus on units of analysis (i.e., consciousness and personality) such as identified in Leont'ev's (1978) work. Roth's (2009) was a very fruitful approach for framing this study. To the author's knowledge, this is the first study which has employed Roth's (2009) five stage framework to capture evolution in students over time from the standpoint of subject in a way that is not reductive (Roth, 2009), and as such, both the outcomes and process of the study make a unique contribution to our understandings of the theory in action.

This research is a unique contribution to the STEM education research field, specifically that cluster of studies that attempt to engage with complexity to understand student development at the lived level of the curriculum over time. As noted in chapter 2, several studies give nuanced accounts of engineering teamwork, but focus on static or steady state descriptions of individuals and teams (Holland & Reeves, 1996; Newstetter, 1998; Tonso, 2006b). Other studies researched students' change over time but tended to focus on generic evolution in programmes (e.g., Sheppard et al., 2010; Stevens et al., 2008). Vickers' (2007) language socialization study came the closest to tracking change in an ESL engineering student in a team over time, but ignored contextual influences in preference to language practices. Narrative inquiry studies also yielded descriptions of development over time of individuals in engineering (e.g., Carlone & Johnson, 2007; Hughes, 2001; Tate & Linn, 2005), but did not look into teams. Notable studies employing activity theory to give nuanced explanatory accounts of evolution and change in individuals over time: Roth (2013, 2014) and (2011) partly inspired the researcher to employ the hybrid activity theoretical and analytical framework of Roth (2009).

The use of Roth's (2009) framework in this study's context amounts to a decidedly ambitious engagement with complexity. The activity system chosen for the research was very complex given that it involved a culturally diverse team working on design projects within an already complex integrated second year engineering programme. Employing Roth's (2009) framework to focus more tightly on the emergence of specific dispositions and thinking, learning, or types of development in such a context may provide future researchers with more tuned balance of breadth and depth. A more contained focus on specific forms of development and learning is likely to result in greater depth, possibly at the expense of breadth and opportunities to capture unexpected evolutions in students. Similarly, maintaining a broad focus but choosing a research site characterized by less complexity than in this study may also be a healthy compromise between depth and breadth. Nevertheless, Roth (2009) is a sophisticated theoretical and analytical approach for practically guiding researchers to understand individuals' evolution from the point of view of the participants in ways that are highly interesting, being as they are, neither reductive nor overly simplistic.

8.3 Implications for Curriculum and Practice

Engineering design in industry has been recognized as a social process (Bucciarelli, 1994). However, while team-based design projects have been widely adopted in engineering education curricula, a research-based understanding of how to best cultivate students' professional development through this mode of study has been lacking (Borrego et al., 2013). The conclusions of this study (Section 8.2) offer food for thought for supporting culturally diverse students in early degree team-based design projects. The implications drawn from these conclusions relate to how team-based project modes of study are conceptualized, organized, and implemented.

The first implication relates to culturally diverse students' access to equitable opportunities to contribute to the technical work and social processes in teams to develop engineering dispositions and thinking. The requisite conditions for these opportunities are for students to buy into working as part of a team, claim a viable role that is linked to technical work, and grapple with competing identities across the spheres of their lives (i.e., conclusions four to six; Section 8.1). As a minimum, supporting culturally diverse students in meeting these conditions requires that they be explicitly and meaningfully oriented towards team-based project work as a mode of study because they cannot be assumed to all meet the three stated conditions.

Students coming into second year in this study's context were de facto math and science students in first year and had varying levels of awareness of the expectations of this mode of engineering study. Culturally diverse students are potentially doubly challenged if they come from cultural and personal backgrounds where this mode of study is unfamiliar. Furthermore, undergraduate students may also be balancing engineering study with the priorities and identities of the other spheres of their lives. As such, it cannot be assumed that students completely identify with and have bought into engineering study or teamwork. The factors of culture and gender were found in this study to substantially mediate students' capacity to meet these conditions. Orienting students explicitly and meaningfully towards team-based project work as a mode of study means establishing its congruence with their personal and academic backgrounds and experiences (Lee, 2005), meaningfully establishing its relevance to their future work in engineering (Bucciarelli, 1994), and making the academic and the general and disciplinary cultural expectations embedded within this mode of study transparent (Ecclestone, 2007). This first implication is offered as a minimum for all students.

Second, following from this minimum first implication, it is critical to foster metacognitive awareness and capacity to engage in the social processes of teams that influence technical work on projects (i.e., conclusions 2 to 6, 8; Section 8.1). Hadwin et al. (2011) defined such socially shared regulation as "interdependent or collectively shared regulatory processes orchestrated in the service of a shared outcome" (p. 67). It was apparent in this study that many of the social processes of team-based projects tended to operate below the level of awareness for students and to be dealt with by instructors on an ad hoc basis or when crises arose in teams. Engaging in socially shared regulation means having a specific metacognitive awareness of the dynamics and processes of teams. As outlined in the second conclusion (Section 8.1), the team structure and culture and the team perspectives towards the project mutually define each other and exist as a mediating layer between the project as it exists at the moment (object/motive on the real plane) and the project as it is imagined once completed (object/motive on the ideal plane). Students first require awareness that they are a constitutive part of a team (i.e., conclusion 4; Section 8.1). This means that their mere presence affects others and contributes to the development of the early culture and history of the team (Carroll et al., 1992) and comes to define its structures and culture. Second, meeting the minimum condition of buying into working as part of a team (i.e., conclusion 4; Section 8.1) means jointly contributing to the perspective on projects (i.e., conclusions 7, 8; Section 8.1). Engaging as part of the team effectively requires awareness that individuals and teams harbour perspectives on projects that significantly shape how the gaps are bridged between the project as it is at the moment and the project as it is imagined once completed. Third, beyond this awareness, it is also incumbent upon students to discern and interpret cues from a complex environment as input to defining and revising the team's perspective and associated practices. Hence, individual and team perspectives on projects must be made available for discussion and students made aware of their role in navigating team perspectives on projects. Meeting the conditions increases the probability of a successful project and opportunities for teammates to develop engineering dispositions and thinking towards constructive collaboration. Fourth, metacognitive awareness and capacity is also critical for the evolution of students' individual engineering dispositions and thinking. Discerning when critical decisions points make themselves available to students allows them entry points to viable roles as engineers, which lead them to develop engineering dispositions and thinking (i.e., conclusion 3, 5; Section 8.1).

Third, this study suggests there are opportunities for harnessing the potential that exists across culturally diverse groups in undergraduate engineering curricula. In this study, cultural factors were found to mediate culturally diverse students' willingness to buy into working as part of a team, willingness and ability to claim viable roles as an engineer, grapple with competing identities in become an engineer, and navigate different perspectives on engineering projects. Hence, there is an opportunity to introduce intercultural skills (Weber, 2006) needed for all students to function effectively in engineering programmes and the profession, which is increasingly characterized by cultural diversity (Laroche, 2012). In the context of this study, intercultural skills are implied in the graduate attributes of teamwork, communication skills, and professionalism (Engineers Canada, 2014), which derive from the Washington Accord. Many undergraduate engineering programmes of global universities in the English speaking world harbour high cultural diversity, which means that educating in diversity can no longer be thought of in terms of crossing untouched cultural boundaries or assimilation into a majority. In the context of this study, the presence of international, immigrant, and Canadian-born students in programmes means that students and faculty are increasingly functioning in a hybrid cultural space (Gutiérrez et al., 1999). Students come from varying backgrounds, whose attendant perspectives, practices, and cultural schema and repertoires are to varying degrees tacit or explicit and congruent or incongruent with the planned and lived curriculum of undergraduate engineering. Consideration is warranted for making intercultural competencies an integral part of the explicit teaching of teamwork, communication, and professionalism in engineering programmes. An orientation to applied intercultural skills in the context of cultural hybridity allows for possibilities to rethink how difference in engineering study and the profession can be conceptualized from the standpoint of credit rather than deficit.

Fourth, this study identified a potential gap in interpersonal communication skills between what some culturally diverse ESL students have and what they need to function in formal, informal, and non-formal undergraduate engineering learning communities. In this study, interpersonal communicative competence was found to mediate culturally diverse students' willingness to buy into working as part of a team, willingness and ability to claim viable roles as an engineer, and ability to navigate different perspectives on engineering projects. As noted earlier in this section, early degree team-based design experiences, greater cross-curricular integration, and greater focus on professional learning outcomes (Engineers Canada, 2014) are standard in undergraduate engineering programmes. As such, the English language competencies increasingly required to function in undergraduate engineering study are shifting away from what has traditionally been the focus of English academic preparation and related gatekeeping assessments. Specifically, students are now expected to collaborate in the formal, informal, and non-formal contexts of engineering design projects (Engineers Canada, 2014) and co-requisite courses. Functioning in these contexts implies a capacity for a variety of spoken genres (e.g., project demonstrations, problem solving presentations, interacting with instructors, employing and discussing representational knowledge: Biber, 2006; Nesi & Gardner, 2012; Roth, 2014b), multiliteracies (Cazden et al., 1996) and situated literacies (Barton & Tusting, 2005). The extent of the interpersonal communication gap begs to be verified and, as necessary, addressed before admission into and during undergraduate engineering programmes. The importance of English language as an implication in this study relates to culturally diverse students' capacity to access to engage in the technical and social processes of teams and gain opportunities to develop engineering dispositions and thinking relevant to their early professional paths.

Fifth, this study has implications for how assessment is employed to foster constructive collaboration and technical work so as to focus study on engineering dispositions and thinking relevant to students' professional pathways. The last two conclusions in Section 8.2 discussed the need for students to navigate different team perspectives on engineering projects and to engage in self-regulation and shared social regulation (Hadwin et al., 2011). Meeting these conditions implies the need to discern, interpret, and respond to cues in a busy and complex environment, which is made additionally challenging for culturally diverse students because of cultural and language factors. Improving classroom assessment practices in team-based project modes of learning holds potential for focusing and enhancing students' development of engineering dispositions and thinking. As Boud and Falchikov (2007, p. 3) note: "Assessment, rather than teaching, has a major influence on students' learning. It directs attention to what is important. It acts as an incentive for study. And it has a powerful effect on what students do and how they do it." The use of formative and summative assessment techniques and processes that are supportive of students' development of engineering dispositions and thinking are needed as important reference points to clarify the focus on team-based project work for both instructors and students. Some key measures are suggested here. First is the establishment of clear and transparent learning outcomes and their constructive alignment with teaching and assessment tools (Biggs & Tang, 2011). Second is the related work of designing project tasks and their assessment tools with an awareness of how they are likely to dictate the nature and equitable distribution of roles in the team, the formation of team perspectives on the project task, and the focus of the engineering dispositions and thinking the project task and assessment tool are likely to foster (Atman, Eris, McDonnell, Cardella, & Borgford-Parnell, 2014). Third is placing assessment literacy, learning outcomes and criteria, and processes in the hands of the students

(Black & Wiliam, 1998) by engaging them in a formative assessment process to make informed choices on how to bridge the gap between the project as it exists (object/motive on the real plane) and the project as it is imagined once completed (object/motive on the ideal plane). Sound assessment practices for team-based engineering projects are essential to directing culturally diverse students' minds towards the fruitful development of engineering dispositions and thinking. Such benefits hold for all students.

Sixth, self-regulation and socially shared regulation are critical to sustaining the success of the individual and of the team. The eighth conclusion (Section 8.2) has implications for how workloads and workflows affect development of engineering dispositions and thinking.
As noted in Section 7.6, workloads and workflows in engineering have enculturating effects on students' engineering dispositions and thinking. Namely, students' individual capacities for and orientations towards self-regulation and socially shared regulation (Hadwin et al., 2011) in the intense activity of team-based projects shape the engineering dispositions and thinking they internalize (Vygotsky, 1978). Early degree team-based design project experiences are welcome innovations. Yet, workloads and workflows can have punishing effects on some students' wellbeing and may lead them to the development of undesirable engineering dispositions and thinking (e.g., dispositions towards cheating/gaming the system, divide-and-conquer thinking). An environment where conditions tend to place students in their zone of proximal development (Vygotsky, 1978) which challenges and stretches their dispositions and thinking towards projects, deserves careful consideration. Excessive workloads and uneven workflows can be a threat to such balance and so a nuanced, holistic understanding and appropriate decisions that affect conditions at the level of the lived curriculum is key. Balanced workload and workflows at

the level of the lived curriculum is important for students to be physically, mentally, and emotionally receptive and capable of developing their engineering dispositions and thinking.

8.4 Implications for Research

This study has several implications for research. First, greater clarity is required regarding the evidence researchers need to claim that a given stage in Roth's (2009) five-stage framework has been reached. The first three stages (i.e., real historical conditions relevant to the subject [stage 1]; identifiable changes in the environment [stage 2]; emergence of change [stage 2]) were not found to be problematic because the researcher located a key place in the curriculum in which a transition in the mode of study was implicit (i.e., traditional math/science study to team-based design projects in second year). Stage 4 (turnover in dominance), and particularly stage 5 (restructuring process), were the most difficult to establish. Where possible, longer times in the field are desirable (eight or more months) to establish that turnover is complete and the individual has embarked on a new trajectory.

Second, greater clarity is required on how to establish the existence of inner contradictions from a large corpus of qualitative data collected on every student is required. This was approached in this study by hypothesizing an inner contradiction based on a close reading of the data and then checking back for disconfirming evidence. Establishing a student's inner contradiction that drove their evolution was challenging because tensions and conflicts are not always available for observation and can remain latent or unobserved. Inner contradictions in quieter and less demonstrative students such as Lee raise methodological issues around capture and verification from multiple sources that are not always easy to accomplish.

A third point is that some dispositions and thinking were more available for capture and verification than others. Observational and self-reported data from participants through semi-structured interviews gave the researcher access to dispositions and thinking that are more visible in the social realm. Researchers seeking a tighter focus on the evolution of particular engineering dispositions and thinking such as evolving approaches to team problem solving in design over time, for example, may require more targeted research designs to guide data collection and analysis over time. This study chose breadth and complexity in interaction, making the choice of ethnographic methods implicit.

Fourth, the findings in this study provide five sensitizing concepts or points of focus for future research on team-based projects in other contexts. These are the five conditions:

1) Being willing to buy into working as part of a team
2) Being willing and able to claim a viable role as an engineer
3) Grappling with competing identities in becoming an engineer
4) Navigating different perspectives on engineering projects
5) Being able to self-regulate while under a complex, heavy workload

These are highly relevant for focusing attention on how individuals in teams are challenged as they engage in and try to access opportunities for development and change in complex team-based contexts.

This study provides a departure point for additional research. At the time of writing, these include: research on "perspective negotiation" and how dominant team perspective on engineering design projects become manifest; research on the relations between how project task characteristics relate to the negotiation of roles; research on how classroom assessment practices shape the emergence of team perspectives on projects as it is negotiated in engineering design teams; and research on employing activity theory perspectives to research socially shared regulation (Fox & Riconscente, 2008; Hadwin et al., 2011) in team-based project. For now; however, the researcher must rest and take stock.

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Appendices

Interview Questions

First interview: Sample questions ('Trajectory interview')

I'm interested in how you came to engineering. Tell me a little bit about your pathway from high school and then to engineering here. (Lots of follow-up for basic information)

What do you think has the biggest transition for you?

Can you describe your transition from high school to first year?

What was the transition from first to second year like?

You've been on a long pathway into engineering. What things really supported you or sustained you to keep going? What pushed you back or discouraged you?

Let's talk about your team. Can you tell me what different people are working on in the team? Do you get along? Do you think people in your team have different roles in the projects? etc.

Do you notice anything about the way this group works? (For example: How decisions are made, rules, relationships, the way people work together)

(Additional questions as necessary about team makeup and how it affects these things: gender, ESL, being from E/SE Asia at times)

Do you like working with the tools and equipment on the projects? (Follow up questions: What's it like working hands-on? Does it affect the way you approach things or how you work?, etc.)

Do you get an image, feeling, or message about what an engineer does? How an engineer thinks or should be from this programme? How about your profs, TAs, other students?

(Follow up questions as necessary)

Second interview (All with follow-up as necessary)

How did project 2 go? (tap and follow themes identified in interview 1)

Let’s talk about your team. Can you tell me what different people are working on in the team? Do you get along? etc. (tap and follow themes about team dynamics, roles in interview 1)

Have the roles people have in teams changed since we last talked?

Can you think of another way of working that might have been better?

What do you think makes an effective team in terms of producing something? Learning something?

What things did your teachers or TAs do or say or demonstrate that you thought was useful to you as you prepare to be an engineer?

Is what you’re doing now in the programme similar to what you will be doing as an engineer?

I’m often thinking about how this programme affects engineering students in terms of what they learn and how they do things and how they think. Do you have any thoughts about that?

Addition questions to follow themes identified in interview 1 or came up today: the project 1 conflict, team dynamics, roles/division of labour, the rules/how decisions are made, working with tools, assessment, etc.

Third interview (All with follow-up as necessary)

What do you think has been the most memorable thing about this year? Have you changed in the last year?

Do you think the team member changes changed how your team worked? Did your role change? What about other people’s roles?

You heard about Design I being cancelled or changed, right? Do you think that is a good thing?

In your programme you’re being prepared to be an engineer. Is there anything in the programme that you think is helping you to become an engineer? Is there something you think is missing?

What things did your teachers or TAs do or say or demonstrate that you thought was useful to you as you prepare to be an engineer?

Is there anybody who stands out (instructor, TA, fellow student) as being an engineer? (i.e., when you look at them, you think: that’s what an engineer should be like?)

Has working in this team changed your ideas about leadership and teamwork?