“FINALLY, I CAN DO IT MY WAY.” STUDENTS’ EXPERIENCES OF PARTICIPATION, AGENCY, AND IDENTITY IN DISCIPLINARY AND INTERDISCIPLINARY UNDERGRADUATE SCIENCE

by

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Abstract

This study explores the learning practices that are valued and experienced by students who choose an interdisciplinary science degree, and how these practices contribute to the science-student related identities that are developed through participation in disciplinary and interdisciplinary learning contexts. The study objectives were to investigate undergraduate students' experiences of participation in disciplinary and interdisciplinary science degree programs.

To address these objectives, I carried out a collective case study of 9 undergraduate science students who transferred from the Mainstream science program to the InterScience program in the Faculty of Science at Large Research University. Specifically, between 2004 and 2006, I invited students to share their stories through semi-structured interviews and I listened to the stories that developed through students' interactions and relations during class. Using socio-cultural theories and narrative research methods, I sought to find, in the stories students shared, the practices in which they engage and through which they claim identity. I analyzed the data using open coding and the constant comparative method.

My findings indicate that the InterScience students who participated in my study value learning practices that lead to insights from multiple science disciplines and that facilitate interdisciplinary understanding. Further, these students wanted to approach their learning in a deep way, pursuing their interests and exercising self-determination in their science education. The students found that the structures and pedagogical strategies of Mainstream science *limited participation* in the practices of interdisciplinary science understanding, whereas the InterScience program structures and pedagogies *enabled participation*. Consequently, the students developed identities of exclusion and disengagement from Mainstream science and identities of belonging and legitimate peripheral participation with respect to the InterScience program.

This research provides evidence and examples of how disciplinary aspects of science learning environments can foster experiences of alienation for students who are oriented towards interdisciplinary ways of knowing. It also shows that by creating a community of integrated science practice, interdisciplinary science degree programs can enable bright and

keen, but deeply alienated students who seek interdisciplinary understanding to re-engage with their university and to become passionate advocates for their undergraduate education.

Preface

The following statements are requirements of the Faculty of Graduate Studies at The University of British Columbia (UBC) for research that has been partially published in articles and that required the approval of a UBC Research Ethics Board.

Publications arising from the work presented in the dissertation

Portions of Chapters 1 and 2 are published in Gerhard & Mayer-Smith (2008), ©2008 by Georgia Southern University, adapted and reproduced with permission from the publisher. This publication was based on ideas that I developed through writing my course papers and comprehensive exams, and I was the primary author of the article.

Sections of Chapters 1 and 5 are published in Gerhard & Mayer-Smith (2004). The data for this publication was collected by both researchers. I conducted the data analysis and was primary author of the article.

Approval of UBC Research Ethics Board

Ethics approval for this research was provided by the UBC Behavioural Research Ethics Board, certificate numbers: H03-80716, H03-80716(A001 – A006).

Table of Contents

List of Tables

List of Figures

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Foreword

February, 2000

"Wouldn't you rather ask the questions and let me hold the camera?"

We've just got back to camp from a pre-dawn hike up the volcano to watch the sun rise over the Pacific, and Ricardo has asked for my help interviewing students for his dissertation research. We're setting up in the bus in order to get out of the wind, taping blankets over the windows to block out the sunlight that's casting shadows and making us squint, and I'm not at all sure that I should be the one asking questions. Ricardo is a PhD student from the Faculty of Education, and his dissertation will be a "video-ethnography of students' experiences" during the undergraduate interdisciplinary science field course I'm co-teaching in Baja California. Despite Ricardo's patient explanations during long bus rides and hikes through the desert, I still don't understand what video-ethnography means or how following us around with a camera is research, but I'm happy to help. Christine, who is in her third year studying genetics and immunology, has volunteered to be my first interview. I'm feeling very much out of my depth, far from the (tenuous) comfort zone I've established as a mechanical engineer co-teaching this fourteen day field course with a geologist, a zoologist, and a botanist. I have never conducted research interviews before, but just as the wonder of watching desert colours emerge from darkness made me forget to worry about what the students were learning from our pre-dawn expedition this morning, the delight of engaging in conversation with Christine soon makes me forget my worry that I'm messing up Ricardo's dissertation.

It was wonderful to stop being a teacher and course coordinator for a moment and just talk to students, asking them about what they were studying, why they decided to take this course, and what they were learning. I think part of the reason I found our conversations so interesting is because the students seemed so … different. These weren't the typically exhausted students I see walking around campus by mid-term every year. These students were … dynamic, smiling, laughing, their words rushing out one on top of the other, thoughtful, critical, frustrated, delighted, enthusiastic, engaged. Their passion was infectious and wonderful. *This is how all students should feel about their university education!*

Back home I tried to describe the course to my colleagues and to convince them that all science students should take field courses, or at least interdisciplinary ones, but I struggled. I didn't have proof that there was something different about the learning that occurred in this course. I couldn't prove that I wasn't biased, and I didn't have anything to share except for my anecdotes. Eventually, I even stopped believing myself – maybe the students were just excited that they were on a beach in February.

Sometime in the fall Ricardo handed me a DVD saying, "this is my comprehensive exam." The video opened with a Mexican folk tune and a series of moving images: a line of students hiking through a landscape of pale green scrub brush, light brown rocks, and blue sky; an old green bus piled high with boxes and water canisters, surrounded by students gesturing to and talking around a piece of foolscap paper taped to its side; two students seen from behind, standing on a hill top watching the sun rise over a serpentine river as the colours of spring flowers slowly emerge into burgundy, yellow, purple and orange; a boat speeding over dark blue water and a young woman, red wind jacket on, hair blown back, talking to the camera with a huge grin on her face; a whale bursting from the water and falling back. The images faded and the title appeared: Processing the Experience. As the video continued we hear and see individual students, each one of them dynamic, engaged, reflective. At the end, Christine, talking to me, explains "that's my passion!"

After watching the film I still didn't understand what Ricardo was doing, how a video could be an exam, or how any of this was research, but I once again knew: something's going on here, something really important. *What is it? Why don't all science students feel this way about their education? What if they could?*

Over the next few years as I taught other interdisciplinary science courses I kept asking similar questions, trying to figure out what was going on and why the students we were teaching seemed to experience a sense of engagement in learning that was similar to what I witnessed with Ricardo in Baja California. Ricardo's comprehensive exam helped me experience the power of story and launched the final stage of my journey from mechanical engineer through interdisciplinary science lecturer to qualitative education researcher. The journey from engineering to education research has been mentally exhausting, but even though I find this work much harder than what I used to do, I wouldn't go back. I can't imagine working or thinking any other way. I now understand ethnographic research, interviews, and observations. I know that words, images, and feelings can all be data. I know that I am always, already biased and I'm okay with that. I'm even starting to trust myself as a research instrument. This dissertation is a result of my epistemological journey to a form of research that has helped me find a way to answer my questions, to figure out what is going on in interdisciplinary science education and what is it that makes it so engaging for students

Gillian

Chapter 1 The Problem and Its Context

1.1 Introduction

One doesn't have to go far on a university campus to hear concerns that students are passive, that they want easy answers, and that they care more about grades than learning. When 40-60% of students intending to declare science majors either leave science or drop-out of university altogether within two years of completing their first science course (Seymour & Hewitt, 1997), it is easy to question their ability and motivation. It is perhaps not surprising then that there is a persistent belief among many university faculty members that undergraduate science students are less-than-competent (Seymour & Hewitt, 1997; Tobias, 1990), and that those who struggle or fail would, as one anonymous blogger wrote, probably "never have mastered the material anyway" (PhysioProf, 2009). Research has shown, however, that students who leave science majors are high-achieving and that they entered university with a genuine interest in science (Seymour & Hewitt, 1997; Tobias, 1990, 1992). Something happens to far too many students between their first term on campus and their last.

> Ever since my first year at this university I was frustrated by the fact that I just didn't feel like I was getting the education that I wanted at an institution that claims to be so --- I don't know, just to --- scroll out really good students. … I was feeling like my education was too general and I wasn't studying the things I wanted to and -- I wasn't studying in the atmosphere that I wanted to. … I guess I kind of had a glorified view of the education I would get when I came here. <Sarah[1], 4th year student, interview>

> [At the end of second year I thought] there's nothing I want to do here that seems interesting. Then [I learned] about biopsychology and I was like "that's really interesting: what are the biological processes that determine how we are or how we behave?" [and I thought] that's really cool, that's a degree I want to do. So I started doing biopsych. … But at some point I realized that I'm not a psych person completely. … I think anatomy, physiology, and certain biology courses, like comparative neurobiology and developmental neurobiology, need to be a part of it … because it's about the brain, and how it develops, and how our behaviour is formed. … I think [it all] needs to be tied in together, instead of being so discrete. <Nancy, 4th year student, interview>

[1] All names used in this dissertation are pseudonyms, including the names of students, faculty members, programs, courses, and the university at which my research site was located.

> I had to find a really good reason [for] why I was getting an education. I'm not just going to University to get a -- degree, you know? There's [got to be] a reason for [being here]. <Keith, 4th year student, interview>

Students like Sarah, Nancy, and Keith are not passive and they don't want easy answers, but each one became disenchanted with their undergraduate science education. Keith started university when he was 15 but dropped out twice because he didn't know why [he] was going to school." Nancy felt boxed into programs that prescribed what, how, and when she should learn. Sarah felt removed from her teachers and her studies, unable to see "how things correspond and relate to each other."

We know that students' approaches to learning can be shaped by their learning environment and by faculty members' approaches to teaching (Cabrera, Colbeck, & Terenzini, 2001; Kreber, 2003; Trigwell, Prosser, & Waterhouse, 1999). It shouldn't be surprising, then, that students become passive when faced with the traditional post-secondary approach to science education.

> This is so classic of science – you've got a midterm worth between thirty and forty percent and then your final is worth the remainder. There are no assignments and if you have a lab you're lucky, because those are a rarity. It's just not conducive to --- retaining information. I mean, it encourages people to cram at the very last second and just stuff all this information in your head and I don't know anybody who learns that way. You can learn for a test, but you're not learning for yourself. So, sure enough, I fell right into that pattern. <Sarah, 4th year student, Interview>

Some students respond to traditional teaching approaches by adopting a survival mentality – maximizing their learning efficiency by minimizing their learning efforts (Biggs, 1987; Ramsden, 2003). These are the students who use rote learning strategies, who stare blankly at us when we ask them to recall first year calculus, or who share tips on what courses are "easy A's." Other students leave science or drop out of university altogether. In between are students who resist, wanting to engage but, like Sarah, falling "into a learning pattern" that they know is ineffective.

When students like Sarah, Keith and Nancy experience what Hurlock et al. (2008) describe as a "fundamental contradiction" between their beliefs about science and learning and "the reality of [their] … encounter" with undergraduate science teaching, they can enter a liminal space (p. 293). Homi Bhabha (1994) writes about the stairwell as liminal space, a passageway that is always in-between. Sarah, Keith and Nancy found themselves in the liminal space in-between survival and resistance, adaptation and withdrawal, science as discrete knowledge and science as an integrative process of interdisciplinary understanding. Hirshfield conceived of liminal spaces as entered into only briefly, “in a passage toward something else” (1998, cited in Hurlock et al., 2008, p. 293). The questions of concern here are why do students become disengaged from mainstream[2] undergraduate science programs, where do they move toward, and is there an alternative to acquiescence or withdrawal?

This dissertation looks at one program that appears to help students in these liminal spaces cross the threshold to engagement. This research matters because disengaged students may also be the very ones faculty members most want to teach and university science faculties aim to graduate – students who long to engage us in conversation, to ask questions, and to understand things; students who want to learn science as a holistic, interdisciplinary practice; students who, like Keith, are not in university to just get a degree.

1.2 The Study

The purpose of this study is to investigate undergraduate students’ experiences of participation in InterScience, an undergraduate interdisciplinary science degree program. The following research questions frame this study:

A. What learning practices are valued by undergraduate students who chose an interdisciplinary science degree?
B. How do undergraduate students experience their positioning in disciplinary and interdisciplinary science degree programs?
C. What identities do students develop through their participation in disciplinary and interdisciplinary science degree programs?

[2] I use the term *mainstream* to refer to the set of degree specializations that are typically offered through a university faculty of science and its departments (e.g. Biochemistry, Physics, Microbiology and Immunology, Psychology, etc…). These are the degree specializations that are spelled-out in a university calendar. They are listed by department and are differentiated by the required and elective courses that students must complete in order to earn their degree.

To answer my questions I conducted a qualitative case study focusing on students' experiences in two particular programs, the Mainstream and InterScience programs at Large Research University (LRU), between September 2003 and April 2007. Forty-four students and 5 faculty members from the program took part in the study. Nine students became the case study participants presented in this dissertation. My study data include interviews, course observations, historical documents, websites, course outlines, recollections and conversations. Drawing on socio-cultural theories of learning, these data allowed me to explore how a group of students undertake the pedagogical experience of becoming interdisciplinary science students, moving "through the liminal to a new sense of self" (Hurlock et al., 2008, p. 294). Theories of identity in post-secondary science, engineering, and math education particularly helped me to make sense of how these students (re)construct their education and themselves.

My study participants' stories, interpreted through a science identity lens, contribute to our understanding of how students who value interdisciplinary science understanding experience, make meaning of, and persist in post-secondary science. This research also contributes to our understanding of students' socio-cultural experiences of science as taught, learned, and practiced in post-secondary settings. The primary audience for this research will be post-secondary administrators, faculty members, and students interested in interdisciplinary learning in the sciences. The study should also be relevant to anyone interested in research on interdisciplinary or post-secondary science learning in general.

1.3 Significance of the Problem Area

> *"This class is different." It's November 2004, near the end of term, and I've asked Scott how the class on measurement and instrumentation he is co-teaching with a faculty member from Zoology is going. Scott is new to teaching explicitly interdisciplinary undergraduate science courses, and he tells me that students in this course seem more engaged than the students he is used to teaching in his home department of Physics, that the discussions seem livelier, and that he is really enjoying the experience. The conversation reminds me of some of the promises inherent in the stories we relate about student learning in interdisciplinary courses:*

engaged students, lively discussions across disciplines, something different going on. I had co-taught the same course a few years earlier, have since taught other interdisciplinary courses, and have told many of the same stories about what I believe students can and do learn in these contexts. "Yes," I think, "these classes and these students are different, but how and why?" <Gillian, personal reflection, 2004>

Since the early 1990s, undergraduate science education has been put under the microscope and been found wanting (Boyer, 1990; Seymour & Hewitt, 1997; Tobias, 1990). The traditional curricular emphasis on the transference of a body of knowledge from experts to individual students is no longer considered sufficient for engaging students, or for providing them with the skills they need to contribute to an "innovation economy" (Mandel, 2004). Graduates are expected to not only acquire disciplinary knowledge but also to learn how to seek different points of view, to look for connections, to put forward their own ideas with confidence, and to become lifelong learners (Conference Board of Canada, 2003; National Science Foundation, 1996). Passive reception of disciplinary information does not allow students to think critically, to tolerate uncertainty, to integrate knowledge across the boundaries of the disciplines, to collaborate, to communicate, and to become self-directed in their learning. Further, the traditional pedagogy and culture within undergraduate science has been found to alienate and even weed out many highly qualified students (Adamuti-Trache & Andres, 2008; Carlone & Johnson, 2007; Hughes, 2001).

In response to calls for improving undergraduate education, many universities have established interdisciplinary programs and developed integrated curricula (see for example Benbasat & Gass, 2002; McMaster University, 1996; Northwestern University, 2002; University of British Columbia, 2011; University of Western Ontario, 2003). Students in these programs are reported to gain critical thinking and problem solving skills, to become self-directed, to develop a higher tolerance for uncertainty, to learn to make connections across disciplines, and to become more engaged in their learning (Apostel, Berger, Briggs, & Michaud, 1972; Berlin & White, 1994; Meister & Nolan, 2001; Newell, 1992, 1998a; Van Kasteren, 1996; Wallace, Rennie, Malone, & Venville, 2001). However, since these claims are backed primarily by anecdotes and based on the opinion of faculty members, there is little compelling evidence to show that broad adoption of interdisciplinary approaches is either warranted or working (Wallace et al., 2001). There is a serious need for systematic empirical research that examines post-secondary interdisciplinary programs and courses (Franks et al., 2007; Lattuca, Voigt, & Fath, 2004; Lederman & Niess, 1998; Wallace et al., 2001). In particular, there is a need for research that examines these programs and courses from the perspectives of students themselves. My research addresses this need.

1.4 Delimitations and Limitations of this Study

My research project was confined to a single undergraduate degree program, 5 faculty members, and 44 students. Nine students became the case study participants in this study. I gave consideration to the larger Faculty and University structures only as they impacted this program and its students. In addition, the aspects of interdisciplinary education under study were limited to undergraduate integration of and within the natural and physical sciences (including biology, chemistry, computer science, earth and ocean sciences, life sciences, mathematical sciences, physics and astronomy). I did not examine the experiences of faculty teaching in the program, and I did not observe students outside of InterScience classrooms.

The generalizability of my study is limited in that the students in the InterScience program are all self-selecting – they apply to the program knowing that it has an explicitly integrated science focus. I also relied on convenience sampling to recruit the participants, some of whom, prior to the start of this research, had been students in a course I had taught. There was no control program designed to be explicitly uni-disciplinary in order to make comparisons. Further, I did not compare the experiences of students in the InterScience program with those of students who elect to pursue discipline-based degree programs or double-degree programs.

Finally, my research is interpretive, focused on the experience of individual students, and I have chosen to use a case study methodology and participant-observation research methods. These approaches limit the replicability of both the research process and findings. The knowledge claims I make are based primarily upon data that is self-reported via interviews, learning journals, and program application materials. When I discuss differences between students' experiences in the InterScience and Mainstream science programs, I rely on the students' perspectives supported by insights from faculty members, myself included, who have been teachers and/or advisors in the program. Further, when I discuss students' early experiences at LRU or their expectations for their undergraduate education, I rely on the students' recollections. My research provides an interpretation of students' experiences as recounted and observed during a particular moment in time, in a particular place and within a particular program. The experiences I relate are intended to provide insight for readers interested in how undergraduate interdisciplinary science degree programs can address the problem of alienation and disengagement for some students. I hope readers will be able to apply these insights to other students, programs, faculties, and universities in their respective settings.

1.5 Overview of the Dissertation

This dissertation is presented in six chapters. In this chapter I introduced the problem of student disengagement in undergraduate science contexts. I described the science education and university learning contexts in which the problem is situated and the significance of the study within these contexts. Finally, this chapter introduced the research questions, briefly described the research methods and limitations of the study design, and provided an overview of the dissertation as a whole.

In Chapter 2, I critically review the literature relevant to this study and position my research within this literature. I review the nature of learning and teaching in undergraduate science education, research on interdisciplinary and integrated learning and teaching, socio-cultural learning theories, and theories of identity in post-secondary science, engineering, and mathematics education. In Chapter 3, I present my research methodology and methods. I describe the study context and design, introduce the participants, outline data collection and analysis procedures, and address the validity and limitations of my research design. Finally, I discuss ethical considerations and my positioning as a researcher in this setting.

In Chapters 4 and 5, I present my data analysis and findings. In Chapter 4, I present narratives of students' pathways to and through undergraduate science education. In Chapter 5, I address my three research questions. I analyse how students position themselves and are positioned with/in the communities of undergraduate science education. I also analyze the participants' learning experiences and the meaning they make of interdisciplinary science. In the final chapter I summarize the research findings, discuss my conclusions, consider the implications of the study for the practice of post-secondary science education, and offer suggestions for future research and practice in undergraduate interdisciplinary science education.

Chapter 2 Review of Relevant Literature

This study examines the learning experiences of a small group of undergraduate students who became alienated from discipline-based science education, and who subsequently re-engaged through participation in an explicitly interdisciplinary science degree program. In this study I conceptualize learning as identity development through participation in social practice (Holland, Lachicotte, Skinner, & Cain, 1998; Lave & Wenger, 1991; Wenger, 1998). As I focus on students' experiences of alienation and engagement, I inquire into their sense of belonging and their identification with the purpose, values, and practices of two distinct worlds of undergraduate science education. In this chapter, I situate my study within the literature on post-secondary interdisciplinary science education and I review the literature relevant to my theoretical framework. I begin this chapter by defining interdisciplinarity. I then review claims about interdisciplinary learning in the sciences, and identify gaps in the research-based evidence used to support those claims. I end this chapter by reviewing literature on socio-cultural theories of learning, focusing particular attention on the theorizing of identity development in post-secondary science education.

2.1 Defining Interdisciplinarity

One of the challenges faced by anyone reading or reporting on the literature concerning interdisciplinary approaches to curriculum is a lack of consistent terminology (Berlin & White, 1994; Kockelmans, 1979a; Lederman & Niess, 1998; Venville, Wallace, Rennie, & Malone, 2002). Commonly used terms include: interdisciplinary, multidisciplinary, transdisciplinary, cross-disciplinary, connected, coordinated, and integrated. Two of the most frequently used terms are *curriculum integration* and *interdisciplinary studies*, both of which may be viewed as overarching categories describing curricula, programs, courses, projects, and/or processes that in some way involve interactions between two or more disciplines. The former term has been used more often in reference to school-based settings (see for example Beane, 1995; Drake, 1991; Hofer & Swan, 2008; Venville et al., 2002) and the latter in the post-secondary context (see for example Franks et al., 2007; Klein, 1990; Kockelmans, 1979b; Lattuca, 2001). Both terms are used and defined in multiple and often conflicting ways within and across the literature. For example, some researchers use the terms integration and interdisciplinarity interchangeably (Davison & Miller, 1995), while others clearly differentiate between the two terms (Beane, 1995).

To be consistent with most of the post-secondary literature, I have chosen to foreground interdisciplinarity as opposed to integration. Borrowing from Drake (1991) as well as Lederman and Niess (1998), I define a continuum, which I illustrate in Figure 1, from multidisciplinarity, through interdisciplinarity, to transdisciplinarity, each differing in the extent to which the disciplines are integrated. In multidisciplinarity, different disciplines are brought together and may be compared and contrasted, but they do not significantly overlap or interact. In interdisciplinarity, the disciplines remain identifiable, but they start to overlap and the overall goal is to initiate a dialogue across the disciplines and to integrate or synthesize disciplinary insights into a more conceptual whole. In transdisciplinarity the individual disciplines are fully integrated and no longer identifiable or perhaps even relevant, and the focus is on the overall problem or question at hand.

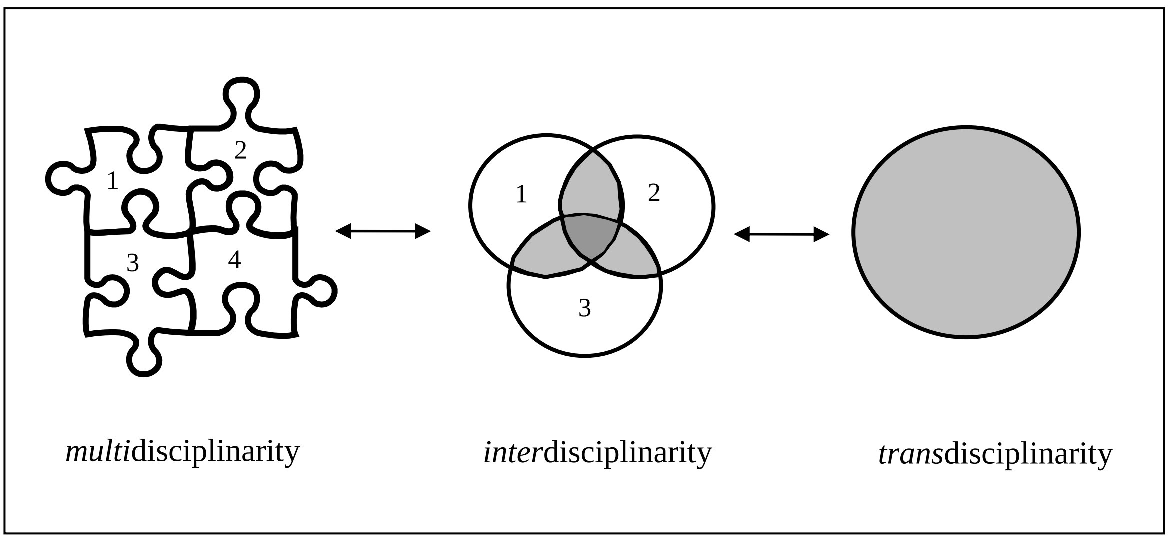

Figure 1: Visual representation of a continuum of integration of the disciplines (1, 2, 3, etc.) from multi- to transdisciplinarity.

I do not intend my definitions to imply a value judgement (i.e. that more integration is necessarily better), or to deny the complexity of the overall approach (Davison & Miller, 1995). Rather, I intend them to most clearly represent the definition of interdisciplinary science enacted through my research site, where students are expected to ground themselves in two or more disciplines and where explicit opportunities are provided to integrate the insights of those disciplines. I define integration according to Ernest Boyer (1990), as giving meaning to isolated facts, “making connections across the disciplines, [and] placing the specialities in larger context” (p. 18).

2.2 Post-Secondary Interdisciplinary Science Teaching and Learning

This section identifies and reviews the literature on interdisciplinary science teaching and learning and situates my research within this literature. My focus is on post-secondary interdisciplinary learning in the sciences, but, where relevant I have also drawn upon research on interdisciplinary teaching and from pre-university contexts. I begin by summarizing the claims about student learning in interdisciplinary contexts. This is followed by a review of how these claims have been supported, with a focus on the identification of methodological weaknesses. I end this section with an explanation of how my research addresses the methodological weaknesses of prior work and fills important gaps in what we know, from research, about learning in post-secondary interdisciplinary science settings.

Claims about post-secondary interdisciplinary science teaching and learning

Student learning is reported to be enhanced through interdisciplinary studies (Davis & Matlak, 1978; Gardner & Turner, 2002). Students are reported to identify interactions and interrelations between the disciplines (Armstrong, 1980; Dubowsky & Hartman, 1981; Ehntholt, 1977; Palmer, 1983; Van Kasteren, 1996; Vinson, 1975) and, through learning from other disciplines, students come to appreciate diversity (Newell, 1992; Van Kasteren, 1996). Students are also reported to develop the ability to synthesize and integrate knowledge (Newell, 1992), to think critically (Apostel et al., 1972; Newell, 1992, 1998b), and to identify and solve complex problems (Berlin & White, 1994; Newell, 1998b). The literature also claims that students come to view the world holistically and that they develop tolerance for uncertainty (Apostel et al., 1972). Further, the relationships between students and faculty is reported to be changed through interdisciplinary studies (Lattuca, 2001), with faculty and students co-learning and co-constructing knowledge (Apostel et al., 1972; Armstrong, 1980; Gardner & Turner, 2002). In the process of interdisciplinary learning, students reportedly become critically self-reflective learners (Newell, 1992), they enjoy their education (Davis & Matlak, 1978; Newell, 1992), and find it relevant and useful (Berlin & White, 1994; Van Kasteren, 1996). Finally, students are reported to learn disciplinary content at least as well as their peers in discipline-based programs (Berlin & White, 1994; Newell, 1992). In short, interdisciplinary studies are promoted as a feature of excellence in education (University of British Columbia, 2009). No single article identifies all of the outcomes mentioned above, and few if any make the same set of claims. Taken together, however, the literature on interdisciplinary studies presents a picture of a promising approach to undergraduate science teaching and learning. This picture, however, is primarily backed by anecdotes and claims made by faculty members, with little compelling evidence to show that the claims are warranted.

Figure 2 shows three dimensions of evidence used to support claims on interdisciplinary learning. The most convincing studies offer rigorous methodology and methods, multiple sources of evidence, and multiple types of data (studies indicated by the shaded/dotted quadrant in Figure 2).

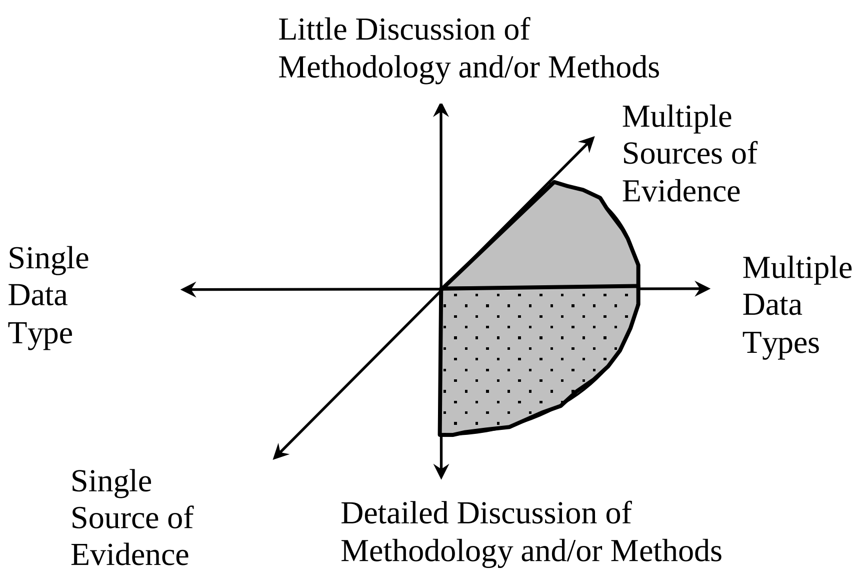

Figure 2: Dimensions of evidence in the literature on interdisciplinary learning

Research literature that presents compelling evidence for some of the claims about interdisciplinary learning has been increasing, particularly in the last decade, but remains relatively rare. The literature published prior to the mid-1990s makes little reference to the authors' research methodology and/or methods, and most often reports research based on a single type of data and a single source of evidence. More recent studies report the collection of more than one type of data and/or multiple sources of evidence, and some authors present thorough discussions of their methodological frameworks. In particular, researchers publishing in the late 1990s began turning their attention inward, examining the experiences of faculty members who teach and conduct research in interdisciplinary courses and programs (see for example Allendoerfer, Adams, Bell, Fleming, & Leifer, 2007; Borrego, 2007; Brew, 2007; Cranton & Carusetta, 2002; Gardner & Turner, 2002; Winberg, 2008). Most of these studies are theoretically grounded and based on at least two sources of evidence or types of data. These studies have found that faculty members can experience doubt and uncertainty when making a change to interdisciplinary teaching and/or research, yet they tend to find the experience positive and rewarding in the end. Teachers are also reported to teach differently within interdisciplinary contexts than disciplinary ones (Apostel et al., 1972; Lattuca, 2001).

While some research is being conducted on the experiences of faculty in interdisciplinary settings, other researchers are focusing their attention on students (Holley, 2006; Lattuca et al., 2004; Newswander & Borrego, 2009; Orillion, 2009; Russell, Dolnicar, & Ayoub, 2007). Much of the research on students' experiences, like that conducted with instructors, has been based on anecdotes and unexamined claims that interdisciplinarity is worth pursuing. Findings report "students rate the course highly" (Smith, Preer, & Brooks, 1975) and "students tend to…" (Newell & Green, 1998), with little or no support for how researchers came to these conclusions. Venville, Wallace, Rennie, and Malone (2002) write that part of the problem with finding out what middle school students are learning in integrated contexts "lies in the nature of the learning and the lack of measures for such learning", and part lies in a "dearth of close-up research into what [students] know and can do in integrated settings" (p. 60). Faculty testimony about what students are experiencing, learning, and practicing comes through multiple layers of interpretation – the reader is faced with interpreting the author's (or a faculty member's) interpretation of how students have interpreted the learning experience. Interpretation is a defining characteristic of this research, and the most convincing interpretive research presents the students' own voices, including direct quotes from interviews, samples of student work, excerpts from the researcher's field notes and/or reflections illustrated with supportive examples, and a discussion of issues of methodology and methods (Holley, 2006; Lattuca et al., 2004; Newswander & Borrego, 2009; Orillion, 2009; Russell et al., 2007). This transparency and "close-up research" is missing from much of the literature on learning in undergraduate interdisciplinary settings. My research aims to fill this gap by critically examining the experiences of students. Further, I aim to provide transparency in the way data are collected, to raise and discuss my methodological issues, and to present the voices of students themselves.

2.3 A Theoretical Framework for Researching Interdisciplinary Teaching and Learning

Constructivism is the theory that most often informs, either explicitly or implicitly, the approaches to researching interdisciplinary learning that are described in the literature. Constructivism is an umbrella term covering a cluster of related theories about knowledge and learning: theories about "what knowledge is," and "how one comes to know" (Fosnot, 1996, p. ix). Constructivist theories challenge the ontological view that reality is independent of its observers and that a complete understanding of reality can be achieved solely through direct, objective observation of the physical world. Proponents of constructivism contend that knowledge is tentatively constructed by those doing the observing (Phillips, 1995). From a constructivist viewpoint, understanding is dependent upon the observer since what is observed is interpreted through the lens of the observer's prior knowledge, and the learner's mind is the site for the formulation of new meaning. The unit of attention within constructivist theories ranges from individuals' cognitive processes to the interactions of individuals within groups (Cobb, 1994; Cobb & Bowers, 1999).

Reflecting constructivist theories, faculty report that in teaching interdisciplinary courses they shift their classroom role from being disciplinary experts who are the source of information to being co-constructors of knowledge with their students (Apostel et al., 1972; Armstrong, 1980; Gardner & Turner, 2002; Lattuca, 2001). Faculty in interdisciplinary programs have also noted that their students change, beginning to seek understanding rather than information (Barisonzi & Thorn, 2003) and to view knowledge as provisional (Gabella, 1995; Newell & Green, 1998). Constructivist theories have helped researchers focus their attention on learners and learning as well as on teachers and/or teaching, yet there are certain aspects of interdisciplinary learning that constructivist theories alone may not fully illuminate.

In much of the literature focused on interdisciplinary approaches to teaching, learning has been measured through students' mastery of fixed bodies of knowledge, as indicated by grades in and admission to discipline-based courses and by performance on standardized exams (Elliott, 1990; Newell, 1992). However, the intended object of learning in interdisciplinary courses and programs is rarely the mastery of fixed bodies of knowledge. Faculty who teach interdisciplinary courses claim they are trying to teach new ways of thinking and not specific content (Nick and Finn, InterScience faculty members, Interviews, November 2007). To understand what students experience and learn in these courses and programs, researchers must align their definition of learning with that of the interdisciplinary context.

Ways of thinking are aspects of culture, where culture can be defined as "the norms, values, beliefs, expectations, and conventional actions of a group" (Aikenhead, 1996, p. 7). One way of framing student learning in interdisciplinary science contexts, then, is to consider learning as culture acquisition (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Cultural aspects of interdisciplinary learning that have been largely ignored in the research to date, as have the practices students engage in and the relationships/identities students develop as learners. As Davis and Sumara (1997) explain, "the *relations* among knower and known are not considered the most important feature in the development of a [constructivist] theory of cognition" (p. 109, original emphasis). Yet these relationships form a critical basis for an interdisciplinary perspective on learning. Integration as the making of connections and the bridging of disciplines, is one of the most frequent points of emphasis in interdisciplinary education, in part viewed as a way to approach solving complex problems (Armstrong, 1980; Barisonzi & Thorn, 2003; Elliott, 1990; Gabella, 1995; Klein & Newell, 1996; Lattuca, 2001; Meister & Nolan, 2001; Newell & Green, 1998; Newman, Whatley, & Anderson, 2003; Van Kasteren, 1996). In this way, interdisciplinary learning involves the development of processes and the engagement in activities (the *making* of connections and the *bridging* of disciplines,) more than the acquisition of particular information. If we want to understand what students are learning in interdisciplinary contexts, we need to consider what they do as well as what they know and we need to understand the relationships students develop with the disciplines in which they are engaging (Boaler, 2002; Hanks, 1991; Wenger, 1998). As extensions to constructivist theories, situated and socio-cultural theories offer useful frameworks for researching these cultural aspects of interdisciplinary learning.

2.4 Situated and Socio-Cultural Theories of Learning

Socio-cultural theories of learning are based on the assumption that learning is not an individual activity but rather a social phenomenon (Wenger, 1998), and a "way of being in the social world, not as a way of knowing about it" (Hanks, 1991, p. 24). In other words, learning is participation in social practice (Wenger, 1998). Drawing from Wenger, I use the lens of socio-cultural learning theories to explore students' learning experiences, focusing on their experiences of participation, where participation is "both a kind of action and a form of belonging" (Wenger, p. 4). It is characterized "by the possibility for mutual recognition," and thus is a "source of identity" (Wenger, p. 56). Lave and Wenger (1991) understand identity as "long-term, living relations between persons and their place and participation in communities of practice" (p. 53). Identities in this sense are an indication of how we see ourselves, and how others see us, in relation to others and to the communities we inhabit and in which we participate.

Socio-cultural learning goes beyond acquisition of knowledge to the engagement in activities, the building of identities, and the acquisition of cultures. This perspective recognises that knowledge is co-constructed through interactions among people and with the environment, where the environment includes biography, history and culture. All of this happens within a social community (Wenger, 1998), where community can be understood as both a social configuration and a subjective experience of belonging and difference (Herek & Greene, 1995; McMillan & Chavis, 1998). As such, community requires membership, a sense of belonging, engagement in a joint enterprise, and common practices (Wenger, 1998). Wenger explains that practices are, first and foremost, processes of negotiation by which we can experience the world and our everyday engagement in it as meaningful. Practices are the "source of coherence of a community," that is, practices define the communities in which we learn through participation (Wenger, 1998, p. 49).

From a socio-cultural perspective, to understand what students learn we can scrutinize and make sense of what practices they participate in, how they understand what they do, and how they grow and change through these practices. I have therefore found it useful to think about the learning and teaching taking place in interdisciplinary science classes as a set of social and cultural practices embedded within the highly disciplinary structure of the university.

Identity

Socio-cultural theories argue that learning cannot be understood only as the construction of knowledge, but also as the creation of persons (Lave & Wenger, 1991). Learning changes who people are and is therefore not so much a matter of coming to know, but rather coming to do and to be. What students learn and do is mediated by who they sense themselves to be (Holland et al., 1998).

Identity has been theorized in a number of different ways. Essentialist theories have expressed identity as innate, fixed and singular. In contrast, post-modern scholars have interpreted identity as "frail, fractured and fragmented" (Roth & Tobin, 2007a, 2007b). In line with much of the recent work in science education, I draw from an in-between position, defining identity from Gee (2000) as "being recognized as a certain 'kind of person' in a given context" (p. 99).

Roth and Tobin (2007a) cite Ricoeur to identify two aspects of identity: *idem* and *ipse*. *Idem* identity, or core identity (Gee, 2000), is relatively stable across contexts while narratively constructed and reconstructed through time. This is the self we recognize in ourselves or others, over a lifetime. *Ipse* identity, or what others have called *subjectivity,* or simply *identity* (Gee, 2000), is continuously changing as we interact with others as different selves in different contexts: student, researcher, teacher, mother, partner, friend. Roth and Tobin (2007a) explain that "the two terms, idem and ipse, are dialectically related, as at any one point in time, a person is identical with itself in terms of idem but is also a Self (ipse), with very different temporal properties" (p. 2). While being aware of idem identity, I focus in this study on ipse identities, which I understand to be multiple (Tate & Linn, 2005), contextual, variable, and socially constructed (Gee, 2000). In particular, I am interested in students' identity development within the context of undergraduate interdisciplinary science learning.

I am most interested in the agential production of ipse identities – how undergraduates who pursue explicitly interdisciplinary science learning position themselves (Brickhouse & Lottero-Perdue, 2007) as students, and/or interdisciplinary scientists. Since agency operates in a dialogical relationship with/to passivity (Roth & Tobin, 2007a), I also consider how the students are positioned by others, and thus how others influence the students' identity development (Carlone & Johnson, 2007).

Identity in science education

There is a growing body of identity research in science education, grounded within situated and socio-cultural theories of learning (see for example, Boaler, 2002; Boaler & Greeno, 2000; Brickhouse, 2001; Brickhouse, Lowery, & Schultz, 2000; Brown, 2004; Carlone, 2004; Creighton, 2007; Melville & Wallace, 2007; Roth & Tobin, 2007b; Shanahan, 2007; Solomon, 2007). My research draws most closely on the work of Boaler and Greeno (2000), who use Holland, Lachiotte, Skinner and Cain's (1998) identity contexts of figured worlds, positionality, and the space of authoring as frames for their examination of students' identity, agency, and knowing in the worlds of mathematics education and profession.

Holland et al. (1998) define figured worlds as "socially and culturally constructed realm[s] of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others" (p. 52). Holland and her colleagues situate the formation of identity and agency within these figured worlds. The concept of *figured worlds* is a way of thinking about the imaginary, yet collectively realized communities in which we function. Holland et al. cite the examples of Alcoholics Anonymous, academia, the mental health system, and college romance as figured worlds in which people play roles or types, follow rules, and perform meaningful acts. Drawing from Holland et al., Boaler and Greeno (2000) frame their research through situated and socio-cultural theories, representing learning as a process of identity formation within figured worlds. Boaler and Greeno also consider different ways of knowing (Belenky, Clinchy, Goldberg, & Tarule, 1986) to be characteristics of students' adaptations to their learning environments. I turned to Boaler and Greeno's paper during the writing of my research results, noticing particular resonance between the findings that were emerging from my analysis and the way these authors structured the presentation of their research.

Boaler and Greeno analyzed interview data from 48 students in six high school Advanced Placement calculus classes, uncovering students' perceptions of the mathematics learning environments in their classes, the students' understanding of their positioning in these learning environments, and the identities the students constructed as learners and mathematicians. Students from four of the classes described individualistic learning environments and didactic teaching practices, whereas students from the other two classes described collaborative environments and discussion-based teaching. Boaler and Greeno refer to these different figured worlds as "ecologies of didactic teaching" and "ecologies of discussion-based teaching" (p. 176).

Boaler and Greeno found that students who experienced mathematics within the didactic learning environments were positioned as received knowers within "highly ritualized" figured worlds (p. 177). These students experienced mathematics as a set of procedures for solving problems, and their goal within these classes was to memorize the procedures in order to produce "correct" answers (p. 181). Boaler and Greeno also found that for students to be successful within the didactic teaching classes, they needed to "both assume the role of a received knower and develop identities that were compatible with a procedure-driven figured world" (p. 183). Some of the students in these classes who reported disliking mathematics "resented the lack of opportunities they received to develop a deep, relational, and connected understanding of mathematics." Boaler and Greeno argue that these students, a number of whom "were at one time the highest attaining mathematics students in [their] school," became progressively more alienated, and attained progressively less, "as their mathematics teaching became more procedural" (p. 184-5). The alienated students rejected mathematics not because they were incapable of doing mathematics, but because they perceived doing mathematics to be incompatible with the "kinds of people they wanted to be."

In contrast, Boaler and Greeno's study participants who experienced the discussion-based mathematics classes were positioned as active agents whose role "involved contributing to the shared understanding of ideas that developed among the class" (p. 177). These students were reported to be more positive about their experiences, in part because of the "deeper insights into the mathematics" that the class discussions enabled, but also because of the relationships they developed "between the different aspects of mathematics as well as the people in the class" (p. 178). Boaler and Greeno report that these students described mathematics as "a field of inquiry that they could discuss and explore" (p. 182). The students who experienced the discussion-based classes were given agency, and in return, they constructed positive identities with mathematics.

Boaler and Greeno focused their research on high school mathematics education, and they speculate that the "dependency" and passivity of students that mathematicians often complain about are likely to be products of the traditional pedagogical practices that are often proposed as solutions (p. 196). Boaler's further theorizing (2002) on the interactions between knowledge, practices, identity, and learning developed through her research on a single discipline (mathematics) at the elementary and senior high school levels. Still, this research holds promise for understanding learning in post-secondary interdisciplinary courses and programs. Boaler (2002) found that practices shape the forms of knowledge students develop. Students who engaged in open, group-based projects developed more flexible forms of mathematical knowledge "that were useful in a range of different situations" than did students who engaged only in the reproduction of mathematical procedures demonstrated by their teacher and through textbook exercises (p. 3). My research builds upon and extends the work of Boaler and Greeno by looking at the experiences of a group of students who express alienation with the figured world of mainstream post-secondary science education and who author successful science student identities within the world of interdisciplinary science.

Research on student science identity has focused on elementary and secondary school science, but attention is also being turned towards learning in post-secondary science and engineering contexts (Carlone & Johnson, 2007; Case & Jawitz, 2004; Creighton, 2007; Haggis, 2004; Holley, 2006; Sheppard et al., 2004; Tate & Linn, 2005; Tonso, 2006; Walker, 2001). My research is informed by and extends this work.

Identity in post-secondary science education

Tate and Linn (2005) studied the role that identity played in the experiences of five, upper-level, women of colour, engineering students. Tate and Linn describe three identities the women held simultaneously within the context of their engineering education: academic identities, social identities, and intellectual identities. The authors associate academic identities with the students' perceived success in their academic activities, social identities with the students' social roles in society and/or their academic community, and intellectual identities with the students' choice of career and intellectual field (p. 485). Tate and Linn found that while the women in their study expressed strong academic identities, they did not experience their academically-based social identities in the same way. The students experienced their academic environments as socially very different from their home and/or outside-of-school environments, in large part because of their gender, ethnic, and race-based differences from the majority of their engineering peers. The students' social identities within their academic environments were "characterized by feelings of difference and lack sense of belonging [sic]" (p. 488). Tate and Linn's study usefully demonstrates how students can at once experience academic success and lack a sense of belonging academically. Tate and Linn's study participants managed to overcome the conflicts between their academic and social identities, and carry-on to graduate as engineers. Other students resolve similar conflicts by switching out of science (Seymour & Hewitt, 1997).

Tate and Linn's research identifies multiple identities and communities within which students may study. Solomon (2007) extends Tate and Linn's work by examining the "potentially conflicting communities of practice within which undergraduate students find themselves" (p. 79). Solomon interviewed 12 undergraduate mathematics students at an English university and found that it was rare for any of them to perceive themselves as legitimate peripheral participants (Lave & Wenger, 1991) in mathematics despite being highly successful mathematics students. Disturbingly, the participants in Solomon's study appeared unworried about their perception. Legitimate peripheral participation is a concept proposed by Lave and Wenger to describe a particular way that learners engage in practice and become members of a community of practice (Lave & Wenger, 1991; Wenger, 1998). Legitimate participation implies recognition by the community and meaningful contributions by the learner. Legitimate peripherality implies a growing involvement in the community. Solomon noted that since the communities of "the wider world of mathematics" and of undergraduate mathematics do not necessarily share practices, students who develop identities of participation in one community may not necessarily experience belonging in the other (p. 80). In particular, Solomon argued that the practices that are valued within the community of professional mathematicians might in fact conflict with what is recognized as competence within the community of undergraduate mathematics. By extension, students who develop identities of legitimate peripheral participation in the wider world of mathematics may develop identities of exclusion with respect to the community of undergraduate mathematics.

2.5 Summary

This chapter reviewed and identified gaps in the research on post-secondary interdisciplinary science learning. I situated my study within those gaps and introduced the theories I use to frame my research. This chapter also introduced research that shows how learning practices can influence the forms of knowledge that students develop, as well research showing that identity and agency can play significant roles in the science learning experiences of post-secondary students.

In a climate of budget cuts and subsequent resistance to the creation of new programs, it is important to ask what problem undergraduate interdisciplinary science degree programs are addressing. Science integration is frequently presented as a solution for student alienation and lack of motivation, yet there is little compelling evidence to support these claims. While research supports the arguments that students can experience alienation and lack of motivation in post-secondary disciplinary-science contexts, little is understood about whether and how post-secondary interdisciplinary science contexts can help students to engage with their learning. There is a strong need for research examining interdisciplinary science learning in practice (Benbasat & Gass, 2002; Field & Lee, 1992; Franks et al., 2007; Lederman & Niess, 1998; Wallace et al., 2001). This case study will contribute insights into the forms of knowledge that are produced through disciplinary and interdisciplinary learning practices, and the identities that students can author through participation in interdisciplinary learning communities of practice.

Chapter 3 Methodology and Methods

3.1 Chapter Overview

In this chapter I present the research methodology and methods I have used to frame my study of undergraduate students' experiences of participation in the InterScience program. I begin by explaining my ontological and epistemological framework. Next, I review my research questions and describe the context and site for the research. I then present the design of the study, outline my data collection and analysis procedures, and address the validity and limitations of my research methodology. Finally, I discuss my positioning as a researcher and ethical considerations in this setting.

The research process I present in this chapter is artificially linear, touching on moments in what was, in practice, a messy and recursive process of observing, reading, coding, writing, describing, refining, interpreting, and reflecting. In fact, the specific research questions that I explore in this dissertation emerged only during the research process. The question that initiated my doctoral studies was: What do students learn in undergraduate interdisciplinary science degree programs beyond disciplinary content knowledge? Listening to students' stories from a socio-cultural perspective lead me to consider students' experiences of learning as a process of becoming. In order to understand what students are learning – that is, who students are becoming, what they are doing, and what relationships they are developing, my research became an exploration of students' practices, positioning, and identities, framed through the following research questions:

A. What learning practices are valued by undergraduate students who chose an interdisciplinary science degree?
B. How do undergraduate students experience their positioning in disciplinary and interdisciplinary science degree programs?
C. What identities do students develop through their participation in disciplinary and interdisciplinary science degree programs?

3.2 Ontological and Epistemological Framework

When I contemplated starting graduate studies in education I could think of many ways to represent numerical data (numbers, tables, graphs), but I could not imagine anything else being data, certainly not text or images. And yet, for three years before I started my PhD, a graduate student in education used one of the classes I co-taught in the Faculty of Science as the site for his video ethnographic research. While I did not understand what he was doing, I was intrigued, particularly when he showed me some of his video -- edited, cut, and telling a story. This video became his comprehensive exams and for me, the start of a paradigm shift.

In the years since my introduction to education research I have learned that data can be more than just numbers and I have found myself drawn to narrative, thick descriptions, and a focus on experience and meaning. I now understand that there is no escaping subjectivity in any inquiry. Like qualitative research, quantitative research is subjective, from the researcher's decisions about what problem to pursue, through what unit of analysis to use, what to test and measure and how to test and measure it, to what conclusions to draw and what conclusions to write about, all of which are affected by values, attitudes, and beliefs (Johnson & Onwuegbuzie, 2004). I have come to accept that there can be no "perfect or direct window into reality" (Johnson & Onwuegbuzie, 2004, p. 16). Ontologically, I position myself within a worldview that acknowledges the existence of a reality, but recognizes that the experience of that reality is relative and different for every sensing agent. Agents come to know the world through relationships and interactions with other agents and the environment. Within this framework, I see learning as occurring through a dynamic, complex set of relationships where the learning, the teaching, the subject, and the context are co-emergent and intertwined.

3.3 Context and Research Site

Context – The Mainstream undergraduate program science at LRU

The Faculty of Science at LRU is divided into nine departments, roughly by discipline, each of which offers some number of particular specializations.

Mainstream specializations

Departments present the available specializations in the university calendar, and with them, lists of required and elective courses students must complete in order to earn a Bachelor of Science degree with a major in their area of specialization. I have named the set of department-based degree specializations offered through the Faculty of Science at LRU as the *Mainstream*[3] program.

Students are permitted to choose from among the available specializations in the Mainstream program at the end of their second year, and if their grades meet the department's pre-set minimum for that specialization, the students are permitted to register in the required courses. If a student's second-year grade average is below the department's standard, the student is prompted to select a different specialization. The rejection or acceptance of a student into a particular specialization is automatic, based on constraints programmed into the online course registration system.

Mainstream courses

Once admitted to a specialization, students are permitted to register for the courses that are required for their degree, as well as to choose and register for a certain number of elective courses. At most, students in the Mainstream science programs have significant freedom of choice over approximately 25% of their degree credits (Faculty of Science, 2011). These choices may be unconstrained or they may be broadly constrained (for example, all Bachelor of Science students must complete at least 12 credits from the Faculty of Arts.) The remaining 75% of a Mainstream science student's degree credits are allotted to

[3] I use an uppercase *M* in *Mainstream* to differentiate the particular set of department-based degree specializations that are offered through the Faculty of Science at LRU from the general category of *mainstream* science programs offered by any university.

courses that are either required or prescribed by the department. That is, students may be required to take particular courses (for example, students pursuing a cell biology/genetics major must complete introductory courses in both cell biology and biochemistry) or they may be given a list of accepted courses from which they are permitted to choose (e.g. cell biology/genetics majors must also complete two of the following six courses: Vertebrate Structure and Function, Comparative Invertebrate Zoology, Non-vascular Plants, Vascular Plants or Medical Microbiology and Immunology.) Even the most flexible specialization, General Science[4], places rigid controls over what science subjects students must 'learn' in order to gain their degree.

The average number of students in upper-level (3rd and 4th-year) undergraduate classes in the various departments of the Faculty of Science at LRU ranged from a low of 19 to a high of 83 in the years 2005-2009 (PAIR, 2007). Five departments had average upper-level class sizes of 40 students or less and four departments had average upper-level class sizes of greater than 40. Most Mainstream science course sections are individually taught by faculty members or sessional lecturers who are employed by the course's host department.

Research site: The InterScience program at LRU

The site for my research is the InterScience program in the Faculty of Science at LRU. InterScience is an alternative to a disciplinary major or honours program for senior undergraduate students. The InterScience program runs parallel to the Faculty's departments, and the director of InterScience is responsible to the Dean of Science. At the time of my research, students could apply to InterScience anytime between the third and final terms of their degree, with most students entering the program at the start of their third year.

InterScience application process

Students register their intent to apply to InterScience by creating an account on the program website. This account gives students access to the program's application form and

[4] The General Science specialization lists only 8 specific required courses (out of 40 for the degree) and leaves the remainder open for students to choose. However, after meeting the program requirement to select courses from two or three of five subjects areas of science (chemistry, life science, earth science, ……) and for arts, General Science students are limited to 6 courses over which they have more or less complete freedom of choice.

to a list of potential advisors. Students may contact an advisor at any point prior to submitting their application, but they are strongly encouraged to initiate contact early in the process so that they may work with their advisor on the development of their application. An application must be approved by an InterScience advisor before it can be formally submitted by a student. The program application consists of two essays and a proposed program of study[5]. The first essay is intended to outline the student's vision for her/his science education, emphasizing the importance of disciplinary breadth. The second essay asks student to rationalize their choice of courses in light of their vision. A student's proposed list of courses becomes her/his program of study. In contrast to the Mainstream science program, InterScience students have significant freedom of choice over approximately 75% of their degree credits, with only 25% of their credits associated with courses that are either prescribed or required. A student's program of study must include 4th-year courses from at least two disciplines (referred to as "areas of integration") along with any necessary prerequisites. Students must also take a minimum of three InterScience courses (listed in Table 3, Appendix A), including a 1-credit interdisciplinary seminar.

The InterScience application process can involve anything from a few emails between a student and her advisor, to a year-long process of discussion, negotiation, and revision to the student's application essays and program of study. Once both the student and advisor are satisfied with the application, it is "signed-off" by the advisor and then submitted by the student for formal review (and ideally acceptance) by a program administrator. The student's approved program of study becomes a contract between the student and the program, with the program agreeing to grant the student a degree provided he or she successfully completes the listed courses. Students can change their course of study, but must seek the approval of their advisor for any revisions.

InterScience courses

InterScience courses are limited in size to 36 students, and instructors use strategies that emphasize group-based work, project-based learning, and the discussion of concepts that

[5] In the InterScience program, a student's *program of study* is the contract between the student and the program/university. The program of study comprises the list of courses, particularly 3rd and 4th year courses, which the student must successfully complete in order to earn a Bachelor of Science degree from the Faculty of Science at LRU.

transcend the disciplines (e.g. the science of measurement, the analysis of control systems, and the laws of scaling). Most InterScience courses are team-taught by faculty from different disciplines. The InterScience program employs the equivalent of one full-time, 12-month lecturer[6] and buys the time of all other faculty associated with the program either from their home departments or through honoraria to the individuals themselves, as in the case of program advisors.

InterScience students

Fifty percent of InterScience students spend two years in the program, and the rest spend either one year (34% register and graduate from the program in their fourth year) or three to four years in the program (Faculty of Science, 2004). These longer-term students may interrupt their studies to participate in exchanges, co-op work terms, volunteer-related travel and/or independent research. At the time this dissertation was written the program had no systematic way of tracking the activities of its graduates, but informal surveys conducted by the program administration indicate that alumni have gained admission to post-graduate professional programs in medicine, dentistry, optometry, law, physiotherapy, and education, as well as in graduate (MSc and PhD) programs in cell biology, microbiology, and zoology, among others.

3.4 Research Methodology

I present an interpretive, naturalistic case study of students' learning experiences in the InterScience program, conducted using ethnographic and narrative research methods.

Case study

Much of the research on post-secondary interdisciplinary learning presents broad generalizations based on limited evidence (e.g. grades or test scores). Thus, there is a need for research based on multiple sources of data that can provide a detailed and in-depth understanding of students' learning experiences. Case study is an appropriate methodology

[6] I was the 12-month lecturer in the InterScience program from 1999-2005 (half-time in 2004, and quarter-time time in 2005), teaching or co-teaching up to three of the InterScience courses, advising students, and/or providing administrative support for the program director.

for my research because it allows for an in-depth look at a clearly bounded object of study, such as a program or individuals within a particular program (Merriam, 1998; Miles & Huberman, 1994). Further, within their boundaries, case studies are exploratory, contextual and highly descriptive (Merriam, 1998; Stake, 1995; Yin, 2003). Since "research regarding integration in practice is still relatively rare" (Wallace et al., 2001, p. 9), it is appropriate to use a research methodology that will provide a close-up, yet holistic view of the processes involved in a particular integrated-science context. Case studies provide this kind of view, while drawing upon a wide evidentiary net (Merriam, 1998). Finally, since it is not clear whether the positive learning outcomes reported in much of the research on integrated science are a matter of integration or simply of good teaching (Wallace et al., 2001), my research aims to investigate the relationship between my study participants' engagement in their science education and their participation in an explicitly integrative learning context. Case studies are particularly appropriate where the separation between phenomenon and context is difficult to define (Yin, 2003, p. 13), and therefore for examining students' experiences in the InterScience program.

For the most part, the cases of interest in education and social science research are composed of people and programs. The cases of interest in this study are nine students who were registered in the InterScience program in 2004, 2005, and/or 2006. I conducted my research as a multiple case study (Merriam, 1998), or what Stake (1995) calls a collective case study. Merriam (1998) defines a multiple case study as one where data are collected from several cases or sub cases, and the analysis is conducted cross case in order to identify generalizations. I used this approach to collect and analyze data from the case study students. In Chapter 4, I present a brief narrative introduction of each case. In Chapter 5, I focus my analysis across the cases. As Miles and Huberman (1994) note, "by looking at a range of similar and contrasting cases … we can strengthen the precision, the validity, and the stability of our findings" (p. 29).

Narrative research

I adopted narrative research methods for my case study. Narrative research is "the study of how human beings experience the world" (Moen, 2006), and the primary objects of focus in narrative research are stories. Stories are one of the ways that humans structure the experiences in our lives, in order to make sense of them (Moen, 2006). It is in stories that we become "that which" we are (Bahktin, 1929/1984, cited in Frank, 2002), and narrative research thus recognizes that humans lead storied lives (Connelly & Clandinin, 1990). Recognizing stories "as attempts … to render lives and experience legible and dialogical" (Frank, 2002, p. 11), I invited students to share their stories of experience through interviews and journals and I listened to the stories that developed through students' interactions and relations during class. I sought to find, in the stories students shared, the practices in which they engage and through which they claim identity (Frank, 2002, p. 11).

Narrative research is more than an approach to data collection and interpretation. It is also evident in the researcher's presentation of participants' stories. There has been a strong move in ethnographic and other narrative forms of research away from the "objective" researcher who represents stories of the "other" in a detached and omniscient manner (Lincoln & Guba, 2003). Instead, there is increasing recognition that both research and reporting are "saturated with interpretation" (Gergen & Gergen, 2003, p. 579) and that "all stories … are fictions, such fictions providing the substance of lived reality" (Davies, 2000, p. 57). Reflecting this interpretive perspective, I make no claim to present *true* stories in or of my research, however I can ensure that I present *honest* stories; ones that are trustworthy, fair, and straightforward. I therefore stand in front of and within this text, rather than behind it – writing in the first person and making my interpretations visible through the clear presence of my voice in the text. I have also included the students' voices in the text, making extensive use of full and direct quotes. Finally, I reflect upon and discuss what stories I have chosen to present and how I have chosen to present them to my audience (Connelly & Clandinin, 1990).

3.5 Study Design and Research Participants

My objective in this research was to investigate students' experiences of participation in an undergraduate interdisciplinary science degree program by uncovering the learning practices that are valued by undergraduate students who chose an interdisciplinary science degree, by examining the ways that undergraduate students experience their positioning in disciplinary and interdisciplinary science degree programs, and by describing the identities students develop through their participation in disciplinary and interdisciplinary science.

I conducted this study in two phases. Phase One took place from 2004 to 2005, and involved individual semi-structured interviews with eight students. I used Phase One to gain experience with participant interviews as well as to identify issues of concern to students in the program. Phase Two of my study took place from 2006 to 2009 and it involved participant-observation of InterScience courses, interviews with a further six students, and analysis of program- and student-produced documents. All of the participants in this study were students in the InterScience program, recruited according to ethics protocols at LRU.

I recruited study participants through emails and posters. The program administrative assistant sent a recruitment email to all students who were either registered or applying to the program in 2004, and again in 2006 (see Appendix D). In addition, I hung recruitment posters in the InterScience office/student work area as well as near InterScience classrooms. Twelve students responded to my call for interviews in Phase One, and I was able to arrange interviews with eight of them in January and February of 2004. A further 32 students responded to my call for participants in Phase Two. Six of the Phase Two participants agreed to be interviewed, while the remainder consented to my observations of their InterScience courses. In total, I interviewed 14 students and selected 9 as my case study participants.

I selected the case study students to represent a cross section of my participant population. As shown in Table 1, these nine students differ in their areas of science interest, their year in the BSc, their years in the InterScience program, and the number of InterScience classes they had taken prior to our interview. I also aimed to provide a balance between the students who knew me as a former instructor in the program with those who knew me only as a graduate student in education. Finally, while approximately one-third of the initial respondents to my calls for participation were male, only two of the students I interviewed were, and so I decided to include both of those students in my focal group. Table 1 lists my case study participants (N=9), together with their declared areas of integration and the points of contact I had with them throughout this research.

Table 1: Case Study Participants

Participant	Areas of integration	Year in degree	Year in program	Number of InterScience courses taken	Data sources (I = interview) (CO = course observed) (SW = student work)
Amalie[7]	ecology geography economics social science	5th	Year 2	3	(I) Jan 2004 (SW) Control Systems
Diane[7]	biochemistry genetics English minor	4th	Year 2	4	(I) Feb 2004 (SW) Control Systems
Farah	medical genetics immunology	3rd	Year 1	3	(I) Feb 2004
Keith	math statistics physics cognitive-science	4th	Year 1	3	(I) Sept 2006 (CO) & (SW) Instrumentation
Kuri	physiology human kinetics nutrition	4th	Year 1 applying	2	(I) Oct 2006 (CO) & (SW) Instrumentation, Game Theory
Margaret[7]	life sciences physics	4th	Year 1	4	(I) Feb 2004 (SW) Control Systems
Melanie	physiology anatomy biopsychology	3rd	Year 1	1	(I) March 2007 (CO) & (SW) Game Theory
Sarah[7]	immunology genetics	4th	Year 2	3	(I) Jan 2004 (SW) Control Systems
Todd	atmospheric-sciences chemistry geography	5th	Year 2	3	(I) Oct 2006 (CO) & (SW) Instrumentation

[7] I was the instructor for the Control Systems course taken by these students. This course took place prior to the start of my research.

3.6 Data Collection

Interviews

I conducted semi-structured interviews with my participants, asking students about their interest in science and how they came to the InterScience program, about how they understand and practice interdisciplinarity and science integration, and about their experience of community at the university. The interview protocol is included in Appendix B. The interviews lasted from 60 to 90 minutes, took place on the LRU campus, and were audio-recorded and transcribed verbatim. I was also granted permission by the students to interview their program advisors, teachers, and research supervisors (when applicable) in order to trace the patterns of the participants' interactions and relationships with others.

Observations

To provide a different perspective from which to view students' experiences and their participation in the InterScience program, I observed classroom and group interactions. My observations took place in three InterScience courses during the winter 2006 term (September 2006 – April 2007). I joined the courses as an observer-as-participant (Merriam, 1998) and attended almost every class session for each course for a total of approximately 100 hours of observation. I discussed the nature of my participation in the courses with the instructors and with all students at the beginning of each term, and tried to balance my emphasis on participation versus observation based on their wishes. Each week I audio-recorded whole-class or individual student-group discussions and recorded field notes of my observations of the physical setting, the activities and interactions, and my own reflections while in the classroom. I made my field notes and audio recordings available to the study participants should they wish to review them, although none did.

Documents

Merriam (1998) argues that "documentary data are particularly good sources for qualitative case studies because they can ground an investigation in the context and problem being investigated" (p. 126). To ground my research in the context of the InterScience program and its courses, I included several types of documents in the data for this study:

program materials, course materials, and student work. In order to understand the historical context for the program within the Faculty of Science and the university, I reviewed the InterScience website, public materials (such as fliers, university calendar entries, course descriptions) and historical documents (including reports from the committees tasked to create the InterScience program). To understand the context of InterScience courses, I collected course outlines and assignments and reviewed course websites. To augment the students' stories, I collected the participants' application essays and course assignments.

InterScience students are coached through their application process by program mentors – faculty members who work one-on-one with each applicant, facilitating the students' articulation of their educational vision and the development of their list of courses. Students often write several drafts of their application essays, revising them until the finished product satisfies their mentor as being ready for submission. The educational vision statements that students include in their application essays are therefore highly polished representations of what the program wants to see. Nevertheless, I did not find any cases of inconsistency between the clarity of purpose the students articulated in their application essays and the substantially messier answers they shared with me about why they decided to apply to the InterScience program and what they thought they were learning.

3.7 Data Analysis

I have combined insights from case-based research and narrative analysis to describe, analyze, and interpret the ways that students enter, navigate, and construct identities in undergraduate interdisciplinary science spaces. Inspired by Haggis' (2004) application of complexity theory and narrative analysis as a way to research students' individual experiences of learning in particular contexts, I began my analysis by exploring the "different elements [that] might combine to form the decision," for my research participants, to study science through the InterScience program (p. 339). I focused my questions on the students' motivation for pursuing science and for applying to the InterScience program, and analyzed the stories the students told in response (Clandinin & Connelly, 1996, p. 29). I found it appropriate to analyse students' responses as stories since the questions I asked of students (e.g. "how did you come to be in science?", "what brought you to LRU?", "why did you choose to study science through InterScience?", "how did you hear about the program?") elicited what Manning and Cullum-Swan (1994) refer to as classic *Western stories* (i.e. narratives with a beginning, middle and end). Further, the students themselves identified their responses as stories. For example, when I asked Farah what brought her to LRU to study science, she responded, "It's a long story, do you want all of it?"

Coding

To analyse the stories that students told, I read the case study students' interview transcript line-by-line and first identified the *chunks of text* (Ryan & Bernard, 2003) in which students talked about why they studied science (coded: *why science*) or why they chose InterScience (coded: *why InterSci).* Next I re-read all of the chunks of text looking for themes in the elements that contributed to the students' decisions. As suggested by Miles and Huberman (1994), I started by looking for evidence of themes that I had derived from my reading of the literature, and then added more themes as they emerged from the data. Using principles of narrative analysis (Manning & Cullum-Swan, 1994), my initial themes were the different types of stories the InterScience students relayed. I began with the stories identified by Haggis (2004) in her research exploring narratives about learning in higher education: family story and school story.

Family and *school stories* were ones where the student expressed the influence of family or school experiences on their decisions to study science or to switch programs. The following transcript excepts[8] illustrate the family story theme:

> I come from a family that education is the most important thing in the world. So, there's no way that you can get out of it. [laugh] And … [although] I have this artistic side of me … my parents always made sure that I took [arts as] extra lessons, but that it didn't become my [primary focus]. <Farah>

[8] To simplify the presentation of material quoted from my study participants, I use the following conventions in this and subsequent chapters: (1) unless otherwise stated, participant quotes come from interviews; (2) descriptive information about the participant (e.g. year in program) has been provided in Table 1; (3) ellipses (e.g. …) indicate omissions from within a single utterance. Two dashes (e.g. //) indicate a skip to a second utterance, still within a single conversational thread; (4) Dashes indicate pauses in speech (e.g. --). Brief pauses are indicated with one or two dashes (e.g. -), and longer pauses with three or more (e.g. ---); (5) Square brackets around a word (e.g. [word]) indicate an insertion; (6) curly brackets around a word (e.g. {word}) indicate a word that was difficult to hear/transcribe.

> I grew up in a family where I was always told “we’re not scientists,” and “you can’t do science” and “you can’t do math” and then … I always took this as an assumption. <Amalie >

The following excerpts illustrate the school story theme:

> My high school education wasn’t very good … it really wasn’t extensive…. [It was a] very small school, from a small town, [with] not much money -- going into the school. <Todd >

> Ever since my first year at this university I was --- frustrated by the fact that I just didn’t really feel like I was getting the education that I wanted at an institution that claims to be so --- I don’t know, just to --- scroll out really good students in the end and I just was feeling like my education was just too general and I wasn’t studying the things I wanted to and -- I wasn’t studying in the atmosphere that I wanted to. <Sarah>

I labelled experiences that students expressed as having triggered a change in their direction or interests as *trigger experiences*. The following excerpts illustrate this theme:

> When I was in high school I saw a science fair and I thought that was really thrilling so I went into a science fair myself when I was in grade twelve and I just thought “I’m a scientist.” <Amalie>

> [2nd year biochemistry Professor] concentrated on the pathways, more in detail like ‘this enzyme is going to break this, and that’s what’s going to happen,’ and he did the Krebs cycle, and stuff like that. And that’s what really -- it was my first exposure to Biochemistry, and I’m like “Oh this is actually interesting stuff to me now.” <Diane>

In addition to identifying specific story-type (e.g. family, school, trigger experience), I also coded text where the students explained their *motivation* for studying science or for choosing InterScience. For each excerpt, I noted whether the student’s motivation appeared to be intrinsic or extrinsic (Ryan & Deci, 2000). Where I coded a student’s motivation as extrinsic, I also noted if the student expected utility or attainment value from their participation in the task. I borrowed these latter terms from DeBacker and Nelson’s (2000) use of expectancy-value theory. DeBacker and Nelson (2000) identify intrinsic value as “based on one’s personal enjoyment or satisfaction from engaging in tasks in the science domain,” utility value as “the degree to which students value science for its usefulness in a future endeavour,” and attainment value as “the importance [placed] on accomplishments in the science domain” (p. 247). The following excerpts illustrate the motivation theme.

> I kind of fell in love with science. <Amalie> *[intrinsic]*

> I wanted to be a doctor, I wanted to do something for human health, and that's why I was always fascinated by Science. <Kuri> *[extrinsic – utility]*

> I could get a grasp of what I like and what I will be good at, because [my parents] always believed that you have to be good at something. And you have to really like it to become really successful in it. I believe that too. <Farah>
> *[intrinsic & extrinsic – attainment]*

I also coded the interview data along three additional broad categories: expressions of *identity*, experiences of *integration,* and experiences of the *learning environment*. Within each category I generated and applied sub-codes. For example, within the category of identity I coded for expressions of *identity*, claims of *agency*, expressions of *subjectivity* (positioning by self and others), and things the students *rejected* in their decisions to study science or to choose the InterScience program. The three broad categories, along with relevant subcategories, are illustrated in the following excerpts. For a complete list of the codes I used, see Table 4, Appendix C).

Identity:

> I'm a scientist. <Amalie> *[identity]*

> The idea that I could tailor a degree around what I wanted to learn was the most wonderful idea I'd ever heard since coming to school. [laughing] It's like, "finally, I can do it my way." It's always been my approach to everything – I kind of want to do it my way, I'm not super interested in your way or your schedule, I'm more interested in mine, in my life. <Melanie> *[agency]*

> I remember [first year Professor] used to say "you're a mathematician" and I was just really shocked and then I thought, yeah, maybe I should keep going in science. <Amalie> *[positioning – by others]*

Integration:

> I was making parallels a lot, and analogies, and showing how the evolution in the school of robotics can be compared to the evolution in economics. And how there are different schools [of thought] in robotics, and there are different schools in economics, and how, funnily, they seem to have [things in common]. <Amalie>
> *[knowledge integration – linking]*

> Not only are you integrating the sciences themselves, because that's the very nature of the program, like I said I'm studying immunology and medical genetics, but you're integrating different ways of thinking. <Sarah> *[what gets integrated]*

> With the InterScience classes they give you, like you do a lot of journals, you do a lot of discussions, where you're able to integrate your own areas on a higher level, like on a level with other students and profs and get feedback on them, and you're not just out doing it by yourself. <Diane> *[integration – alone or with others]*

Learning Environment

> I feel like -- instructors in InterScience courses are there teaching me because they want to be, whereas instructors in my discipline specific courses -- not that they're not good instructors, but … I just find they're a little bit more set in their ways that way, I mean, they dish out the information that I have to learn for the exam. <Sarah> *[characterization of the learning environment]*

Data transformation

One technique I used to condense my data was to create two matrices (Miles & Huberman, 1994) detailing the different story elements that emerged from each student's answers to my questions about how they came to study science and why they applied to the InterScience program (see excerpt in Table 2). When the data indicated an expression of identity, motivation, a decision point, or an influence on the students' decision, I typed a brief notation and/or quote in the appropriate column in my matrix.

Table 2: Excerpt from Matrix Displaying Elements of Students' Stories about How They Came to Study Science.

Student	Identity (type of person)	School story	Trigger experience	Family/Others story	Motivation (reason for doing science)	Image/Mood	Positioning (by self or others)	Rejecting
Amalie	always been "artsy"			Parents told her "we're not scientists," "you can't do science," "you can't do math."			Parents: an arts person. More interested in arts than science because of parents statements. Self: "took this as an assumption."	
	(But…)	Language barrier – ESL, thought language arts would be too difficult at University level.	Saw a science fair in grade 11.		-easier than arts (instrumental) - "love of science" (intrinsic)	"thrilling" "I just thought it was a wonderful idea" discovering		
	"I'm a scientist"		Participated in science fair. Worked with university Prof on research. EliteScience	"parents still don't believe it" Same Univ. Prof "you're a mathematician"	- "there's a whole world I don't know about" (curiosity, intrinsic)	Self-confidence, excitement	Self as: investigator, asking questions Prof as: capable in maths.	Self as not capable in science. Parents as authority

These matrices allowed me to identify as many different story elements as possible for each student, and to cross-reference the stories across different students.

I then wrote an interpretive narrative or profile of my case study participants, focusing on each student's experiences of why they came to science and why they chose to study in the InterScience program. These narratives, presented in Chapter 4, serve both to introduce readers to the case study participants' experiences and as the next step in my analysis. While writing each narrative I returned to the original interview transcripts and to the students' InterScience application essays to confirm or disconfirm the emerging storyline for each individual. I also read across the narratives, looking for commonalities and differences in the students' expectations for their university science education, their experiences in Mainstream science, and their experiences in InterScience. Three common themes emerged from this analysis: (1) the participants wanted to access insights from several science disciplines and to practice integrating these disciplinary insights, (2) they wanted to pursue their intrinsic interests and to have a sense of ownership, and (3) they wanted to participate in active pedagogies that support deep approaches to learning. In Chapter 5, I discuss these three themes through a socio-cultural lens.

For this final stage of my analysis I returned to the interview data, refining my original codes and cross-referencing the InterScience historical documents, course outlines, interviews from the students I had not included in my case study, and my field notes from classroom observations to check on my evolving interpretations. I also engaged in multiple iterations of writing "analytic texts" (Miles & Huberman, 1994), mapping relationships, testing my interpretations by collecting and comparing evidence across the cases (Yin, 2003), and refining my explanations through conversations with colleagues at conferences.

3.8 Quality Criteria

My research was undertaken within an interpretive paradigm. Such research should (Creswell, 1998; Eisenhart & DeHaan, 2005; Lincoln & Guba, 2003; Merriam, 1998; Wideen, Mayer-Smith, & Moon, 1998; Yin, 2003):

- be linked to relevant theory;
- present clear supporting evidence for interpretations drawing on rich, in-depth data from multiple sources;
- make transparent the researcher's approach to data collection, analysis, and interpretation;
- show evidence that the researcher searched for disconfirming evidence or alternative interpretations; and
- present a critically self-reflective stance on the part of the researcher.

These characteristics reflect what some have called, using a broad, post-positivistic sense of the word, a "scientific" approach to interpretive research (Eisenhart & DeHaan, 2005; Eisenhart & Towne, 2003), and others have preferred to call simply "good empirical research" (Wideen et al., 1998, p. 135). In addition to the above characteristics of all good research, Merriam (1998) describes three quality criteria specific to qualitative research: dependability, triangulation, and transferability (reader resonance). In the following section, I show how Merriam's three criteria apply to my research approach.

Dependability and triangulation

Dependability arises when the results of a study are seen to be consistent with the data collected for that study. This measure of quality in research reflects the interpretive perspective of a non-static reality. Merriam (1998) argues that the dependability of a study can be enhanced through triangulation, attention to the researcher's bias and position, and the provision of an audit trail. Triangulation involves using several research methods or multiple sources of data to confirm findings and construct a holistic understanding of a situation. To meet these criteria I used interviews, observations and the analysis of documents to build my interpretation of students' experiences. I also tried to attend to my bias and position by being explicit about them, and I provided access to my study data through extended quotes and copies of my interview questions.

Transferability

Another measure of quality in research is the extent to which the case findings are relevant to other situations. Conducting an interpretive case study allowed me to focus attention on the experiences of InterScience students as individuals. To help readers determine whether the findings from my study are transferable to their situation (Merriam, 1995), I have tried to provide enough detail in my narratives and analysis that readers may inhabit the cases for themselves (Connelly & Clandinin, 1990). My hope is that the stories are compelling, and the analysis is plausible (Bullough & Pinnegar, 2001; Connelly & Clandinin, 1990).

3.9 Ethical Considerations

Throughout this study I endeavoured to ensure that my research meets high ethical standards[9], taking into account ethical issues unique to qualitative research: gaining access, informed consent, and confidentiality and privacy. I faced a number of ethical challenges during Phase 2 of my data collection, particularly in relation to (a) negotiating my role in the classroom, (b) accommodating non-consenting students, and (c) non-coercive means of gaining consent.

I negotiated my role in the classroom with all of the instructors and students, and the result was different for every course. The InterScience course on instrumentation and measurement was the first one I observed, and it was also one of the most challenging for me. I had previously taught the course with one of the instructors and he let the students know this when he introduced me. As a result, the students frequently turned to me as to an instructor, asking me course-related questions or seeking my approval of their work. As an instructor I would have freely shared my perspectives and invited the students to challenge them. As a researcher, however, I wanted to hear what the students had to say without biasing them with my own perspective. I struggled to find a balance between being a teacher, a colleague, and a researcher in this setting (Field Notes, Sept – Dec 2006).

[9] My research was undertaken with approval of The University of British Columbia's Behavioural Research Ethics Board.

I faced similar challenges in the game theory course where the instructors invited me to participate as a student, completing assignments and contributing to group activities, in order to better understand what the students were learning. Although I have a strong background in applied math, I have never mastered probability functions and there were days when I was by no means confident in my understanding of the course material. My challenge in this course occurred during group activities when the students would look to me for input, valuing my contributions as a PhD student and Engineer, perhaps more than their own opinion or that of their near-peers. Realising that my participation could affect the students' course grades, I re-negotiated my role in this class to that of an observer only. Conveniently, this change in my role allowed me to focus my interactions with students more on my research questions than on their assignment questions.

A second ethical challenge I faced during in-class observations was dealing with non-consenting students. While most of the students in the courses I observed did consent to participation in my overall study, a few did not and I tried to accommodate their wishes by not recording, participating-in, or directly observing any student groups that non-participants were in. Since the groups changed regularly, there were days when I couldn't find any "consenting" group to sit with and so just chatted with the instructors. At other times, I wrestled with what to record during whole-class discussions in which non-consenting students were actively involved.

Negotiating my role as a researcher and accommodating non-consenting students were just two of the issues I faced during my observations. The ethical consideration of primary concern to my university's ethics review board was that of non-coercive consent. When I started this research I was still working part-time as a Lecturer in the InterScience program and faced the possibility of recruiting participants who were my students. To ensure that any potential recruits who were my students did not experience any perception of coercion to participate in my study, I removed myself from the initial recruitment process and made sure to schedule interviews only after the university registrar had accepted the final grades for the course.

3.10 My Positioning

Recognising, as Wolcott (1994, p. 23) has suggested, that “nothing emerges from qualitative inquiry without considerable assistance on the part of the researcher,” in this section I introduce myself and my positioning as an insider/outsider within the InterScience program, as well as some of the challenges I faced being methodologically consistent.

This dissertation and the degree it supports are my first forays into education research. Prior to my first doctoral course, I had never used the words epistemology or ontology in a sentence (let alone both together), and I was just beginning to imagine that culture, identity, and agency might matter in undergraduate science education. My masters and undergraduate degrees are in mechanical engineering, and my masters’ thesis integrated thermodynamics, environmental economics, chemistry and systems science. I have worked in both industry and not-for-profit organizations, and have been involved in the facilitation of science education and outreach for over twenty-years. From the fall of 1999 to the fall of 2005, I was a teacher, advisor, and/or administrator in the InterScience program at LRU.

Insider/outsider status

I came to this research with the belief that undergraduate interdisciplinary science programs are at the very least not hurting students, and are, more likely, providing strong and unique benefits to students compared to disciplinary science programs. I undertook this research, in part, to understand what those benefits to students might be. At the same time, however, I have maintained a healthy scepticism and openness to finding evidence that disconfirms any or all of these beliefs. I am confident of my ability to maintain this openness in part because, while I had insider knowledge and access to the program, my status in the program during the period of this research became that of an “outsider.”

I last taught in the program in the fall of 2003. I have not been involved in the daily administration of the program since the spring of 2004, and the last two students I advised in the program graduated in the spring of 2005. As a result, I did not know the students who were enrolled in the program during my course observations and they did not know me. In addition, two of the InterScience courses in which I conducted my observations (Instrumentation and Game Theory) were introduced since I was last involved as a program

Lecturer. I had met some of the course instructors, but I had not worked with them and had not helped develop or teach their courses. Thus while I entered this research with a certain degree of "insider" knowledge and access to the InterScience program, a position that has influenced my conceptualization of this research and my selection of this program as the site for that research, I was in many ways new to the program as it existed while I conducted most of my study.

In conducting this study my goal was to understand students' experiences with/in post-secondary interdisciplinary science education. I did not set out to present "victory narratives" about the InterScience program. Nevertheless, the students I interviewed were overwhelmingly positive about the program and their experiences in it. They not only said positive things, but they demonstrated enthusiasm through their smiles and gestures, as well as their conviction that more students should know about the program. As Todd explained:

> It's a cool program, for sure. That's why I wanted to do the interview, because I feel I can -- I feel strongly about it. I think that people should know about it.

The narratives I present are the ones that came through from each of the participants in this study and that represent the experiences these students most wanted to share.

Methodological consistency

Despite my intention to engage with my research participants in collaborative interpretive inquiry, my history made enacting this intention a challenge. As mentioned earlier, I struggled to balance my positioning as researcher, teacher, student and colleague within the InterScience context. When faculty members were asking for my feedback on their teaching while students were asking me to clarify course expectations at the same time I was trying to figure out the course content while not forgetting to "do my research," I sometimes retreated to a position of passive, ostensibly "objective" observer. Because I had successfully taught myself to maintain this positivist positioning through two engineering degrees, it was the one I easily trusted and turned to intellectually. It was also a position that seemed, at times, to be the most ethical. Interestingly, when I forgot myself and got swept up in conversations with a group of students or with faculty members, I stopped worrying about my influence and instead engaged with the participants in the co-construction of knowledge.

I can see from my field notes, however, that there were also times when I caught myself doing this and stepped back into a more passive role.

This dissertation represents not only a study of students' experiences with/in an interdisciplinary science program, but for me an experience of crossing several disciplines to engage in research. Inter- and cross-disciplinary work are fraught with tensions, yet we cannot actively engage in research, being alive and venturing into new frontiers (Pinar, Reynolds, Slattery & Taubman, 1995) without facing the tensions they bring. I have tried to be open about these challenges and the ways that I have used them for creative interaction with my research world.

Chapter 4 Narratives of Experience

In this chapter I present narratives of the case study students' experiences in the Mainstream science program and the InterScience program at LRU. The narratives are based on my analysis of interviews and documents collected from nine InterScience students, as well as my observations and interactions with the students through InterScience courses. I use the narratives to introduce the students, and to present the stories they shared with me about their interest in science and how they came to the InterScience program, how they understand interdisciplinarity and science integration, and about their experiences in the Faculty of Science. I constructed the narratives to highlight the students' perceptions of their Mainstream and interdisciplinary undergraduate science education.

4.1 "I'm a Scientist!" – Amalie's Story

Amalie wasn't expected to study science. In fact, her parents expected quite the opposite: "We're not scientists," Amalie was always told, "you can't do science" and "you can't do math." Until grade 11, Amalie thought of herself as an "arts person" and was headed towards the study of language arts in university. In grade 11, however, Amalie saw a science fair for the first time and thought it was thrilling:

> I just thought it was a wonderful idea. All these displays and all these kids getting to do - discovering, experiments and stuff … that was like, Whoa! <Amalie>[10]

The following year, Amalie entered and won her school's science fair, seeking out and finding help from professors at the local university. Amalie's research won her entry to the regional, and later national-level, science fair competitions, and along the way she discovered "a whole world" she didn't know about in scientific research journals. "I'm a scientist" Amalie declared, and she applied for admission to EliteScience[11], a small, competitive-entry first year program at LRU. Amalie particularly liked that EliteScience was "integrative":

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[10] All student quotes in this chapter are drawn from interviews.

[11] *EliteScience* is a pseudonym for the program Amalie took in her first year. EliteScience students join their Mainstream peers in second-year.

> I’ve always hated boxes and … I’ve always felt like the system was very fragmented. So EliteScience was about integrating biology and chemistry and physics and math and all the profs were going to be in the room at the same time and I thought that was really cool. <Amalie>

Amalie enrolled in Mainstream science courses in second-year and found them “more difficult” than she expected. Amalie didn’t struggle with the content so much as the learning environment. The tests were different – “more about textbook material and how quick you are” rather than “thinking outside the textbook,” and Amalie was shocked to find that many of her professors had no time for office hours and that many of her second-year courses encouraged competition among students.

> A lot of classes you come in and the professor says “I’ve been told by the Dean that I’m supposed to give so many A’s, so many B’s, so many C’s,” and so everybody freaks out and [looks at each other] like “Ha, you’re the one who’s going to get the C, not me.” <Amalie>

Amalie believed university study should be motivated by passion and a desire for personal growth, and she was disappointed that many of her classmates seemed to treat higher education like a factory, “just going to campus every day and then coming out,” earning a degree by putting in time.

> I have the feeling that a lot of students at LRU come to university but they don’t really get a chance to think a lot, just because they’re in this frenzy to get into the factory and get out. It’s funny how many people go through university and they don’t think. <Amalie>

Unsure of how she wanted to focus her studies, Amalie took her third year off to do research and write a paper on insect diversity at another university. That year she became very interested in sustainability and “how sustainability was about integrating ecology, economy, and society.” Amalie was interested in ecology because it was “a lot about links and how things are interconnected,” and math/economics because she thought it was “cool that we could create models and explain how the world works.” She decided to come back to LRU to create a “sustainability degree” through the InterScience program. Amalie thought that InterScience “sounded a lot like EliteScience” – integrative, small classes, and access to professors.

4.2 "Waving the Boundaries" – Diane's Story

Diane had always been intrigued by science, particularly biology, and when she retained that interest after taking all of the available science courses in high school, she decided to study biology in university. Diane was curious about physiology and how the body works, and she liked that science provided a process for answering questions and for "looking at how accurate those answers are."

Diane took the standard Mainstream science courses in her first year in the Faculty of Science at LRU (biology, math, physics, chemistry, and English). She found the first-year courses were fairly general, but she enjoyed learning aspects of chemistry that she "didn't get in high school," as well as the little bit of genetics that she got in biology. The following year, Diane mostly took chemistry and biology courses, including cell biology, organic chemistry, and biochemistry. The biochemistry course surprised Diane – she really liked learning about biochemical pathways.

> It was my first exposure to biochemistry, and I thought 'Oh this is actually interesting.' … Seeing some of the organic chemistry stuff we were doing in light of … how it would apply in terms of biochemistry, [I thought] okay maybe there is hope, [laughing] that this stuff is actually useful. <Diane>

Diane's experiences in first and second-year got her thinking about specializing in either biochemistry or cell-biology/genetics, but neither option seemed ideal. The biochemistry major required several organic and physical chemistry courses, and while she "liked [that] material," she "didn't enjoy doing it" and Diane really wanted to study something she would enjoy. Further, Diane didn't want to give up her minor in English, which she would have had to do in order to pursue her interests in physiology and genetics through the few elective courses the biochemistry major allowed. Similarly, the cell-biology/genetics major would have allowed Diane to pursue her interests in genetics and physiology, but she would have had to give up on the biochemistry courses.

Diane felt that "disciplinary degrees have got boundaries set, for different fields" of science, and she wanted to "wave the boundaries." Diane rejected doing a double-major degree when she realized that "if you did two majors, you're looking at two different areas from two different perspectives and you don't get much correlation or much chance to actually link them except … by yourself." She was relieved to learn that the InterScience program could satisfy all of her interests in one degree.

The InterScience program created an environment where Diane could "[get] knowledge" by taking lectures in different areas of science through department-based courses while also learning how to integrate that knowledge through InterScience courses.

> It creates a good environment for InterScience students because you [get to] see the mindset of biochemistry students versus the mindset of genetics students, and then … you're in the middle of both of them and … you're not just to one extreme but you're more centred in the middle of it all. <Diane>

Diane particularly appreciated that the InterScience courses gave her the opportunity to "learn different ways of integrating."

> You do a lot of journals and a lot of discussions where you're able to integrate your own areas, on a higher level, like on a level with other students and profs and get feedback on them. You're not just out doing it by yourself. <Diane>

Overall, the InterScience program allowed Diane to "grow as a person" because it let her "take responsibility for her own choices" as a student.

> [It's easy sometimes to say] "Oh, I have to take this course, so that's why I'm not doing well." But no, you chose this course so … take responsibility for your actions [laughing]. It helps you to grow on a bigger personal level, just to become an adult, in a way. <Diane>

4.3 "Most People Skip Challenging Themselves" – Farah's Story

Farah was expected to study science, just as her mother and father had done. Farah's parents believed that education was "the most important thing in the world," and that the arts, while important, were done "as something extra." Farah didn't mind though, since she loved science. She was the one in her high school biology classes who volunteered to do dissections and lab work, and she leapt at the chance to participate in a science fair in grade 11.

> We got to work on some projects with students and professors from the university … and it was amazing. For someone who is in grade 11, [that was] huge. <Farah>

Farah attended middle-school and high-school through a program for gifted students in her home country. Her high score in the country's university placement exams would have earned her direct admission to "almost any [National] medical school that [she] wanted to" attend. Although Farah's ultimate goal was to go to medical school, she elected to pursue a Bachelor of Science degree in Canada first. Science was a good background for becoming a medical doctor, and LRU was reputed to be the best school in the province for studying science.

Farah has a passion for genetics, so she registered in the Mainstream science program's cell-biology/genetics specialization at the end of her second year. She took the program's required biology and chemistry courses but, while she enjoyed the genetics, she wasn't learning exactly what she wanted.

> [There were two courses] that I hate-, not hated, but I was not exactly enthusiastic about. One was cell physiology. I love physiology and I love cell biology … but cell physiology is not exactly what I want. It's too .. I don't know, too off topic for me. Even though I like genetics, I'm not exactly a cell biologist. <Farah>

An elective course in immunology "changed [her] life." Farah knew that she liked genetics, and that immunology was interesting, but she was surprised to discover how much she liked immunogenetics. Unfortunately, the only ways to study medical genetics at LRU were through a graduate program or by doing a double degree in cell-biology/genetics and microbiology. Neither option worked for Farah – she was still focused on becoming a medical doctor and didn't want spend time getting two degrees before attending medical school.

Farah found it hard to relate to classmates in her first few years at LRU. Large class sizes in the Mainstream science program prevented her from getting to know other students, and the ones she met didn't seem to have much in common with her. Farah didn't want to "take courses that you really don't want to but you have to because it's the [graduation] requirement." She wanted to do independent research and to study in order to "satisfy [her] own curricular curiosity," but her classmates couldn't see the point of doing that before graduate school. "Unfortunately," Farah noticed, "most people skip challenging themselves."

After looking over "practically every course and program offered at LRU," Farah learned that the InterScience program would let her to take some of the graduate medical-genetics courses and combine them with undergraduate courses in immunology, all in one degree. Further, InterScience encouraged students to take directed studies courses in order to conduct independent research. A bonus, from Farah's perspective, was that InterScience classes were small and interactive.

> [The InterScience courses are all different,] but I think most of them have these [things] in common … lots of group work, lots of group discussions, … lots of research – I mean on-line research, so reading lots of papers, … small final [laughing]; and lots of presentations, making power point, hand-outs, [that kind of thing.] … Oh, and no mid-terms [laugh]. That's the best part of it, because your mark is distributed over the entire semester so you're constantly working. <Farah>

Farah was grateful that the InterScience courses "pushed her" to keep on top of her assignments and to "know the material." This was unlike "almost all of the courses we take in [Mainstream] Science," where "if you want to be a passive person, it's really okay."

4.4 "There had to be a Really Good Reason" – Keith's Story

Keith graduated from high school at 15 and started university right away, but he dropped-out twice, the second time for six years before coming back to LRU, because he "didn't know why [he] was going to school." Keith wasn't interested in "just going to university to get a -- degree." He believed "there had to be a really good reason for it."

Keith started his university education studying the arts and then switched to general science in his second year. He was eventually drawn to operations research – a branch of science that uses analytical methods to optimize solutions for complex problems. It seemed a natural fit for Keith's interest in using mathematics and statistics as tools for applying physics and computer science to the solution of "lots of different kinds of problems." Unfortunately, operations research tends to be a master's level program, and Keith couldn't find any undergraduate Mainstream program specialization that would allow him to combine his interests.

> It's sort of like, "Oh you want a degree in math/physics? This is what you take." … You have some choices between some classes, but you're really set in what you get to take. <Keith >

Keith was attracted to InterScience "just for the freedom" it allowed him to take what he wanted. Keith wanted to take courses from across mathematics, statistics, physics, and computer science, preferring to "directly pick exactly what [courses he] wanted" rather than to try and fit them into the "structure" of a math or physics degree. He was quick to point out that having the freedom to pick his courses from across all areas of science did not imply a lack of focus or rationale to his education. "The good thing about InterScience," he explained,

> is that you actually have to write a rationale [for why you're] taking these courses and … a vision of what [you] want [your] education to be. // You're not everywhere on the map, you do have some sort of area that you are focusing in on." <Keith>

In his third and fourth year, Keith took most of his courses from the mathematics, statistics, and physics departments. The InterScience courses acted "like a pivot" to "bring them all together" for him. Keith described integrated science as a process of "building a personal connection between areas of science."

> There's this area [of science,] there's that area, and there's me and I'm trying to bring them together. … You see some gap between two things and you see yourself filling the void. <Keith>

Keith liked that integration encouraged students to "keep an open mind" and to deal with multiple perspectives on problems, rather than "focusing on one small, little topic." Keith knew that, to a certain extent, he was sacrificing depth for breadth, but he was okay with that. "A lot of science isn't black or white," Keith explained, and integration allowed him to "feel okay with being in [between multiple knowledge areas] -- you're self-assured even though you're floating." <Keith>

4.5 "Living My University Life the Way I Really Wanted" – Kuri's Story

Kuri has always been fascinated by science, and she sees it as a skill that can be used to help other people. Kuri traveled from overseas to come to LRU and study science as preparation for becoming a medical doctor, but she was disappointed by the reality she experienced during her first few years at university. Kuri felt her professors were like "walking textbooks" – dry, boring, non-emotional and non-interactive, and Kuri was certain that she would never use most of what she was being asked to memorize.

> I like psychology, but it's pure memorization. … Same with immunology and biology, basically. Bio 2XX was horrible, it was pure memorization. I didn't even know why I had to do it, because I knew I was going to forget it once I wrote the [laughing] final. <Kuri>

Kuri also found that her classmates were "so competitive" – she would try to make friends but other students were "so busy with their own stuff" that Kuri found it hard to get to know people.

Kuri had come to LRU believing that education made people "more open minded," but when she experienced discrimination by a boyfriend's highly educated father, she became discouraged. Kuri started questioning the point of attending university and she thought seriously about leaving. She stayed at LRU out of guilt over the money her parents had already spent on her education, but she had stopped caring about school altogether.

> I was just getting by, I didn't really care, and I just wanted to pass and to graduate as soon as possible. So I did not do well in first and second year. … There wasn't really one sort of program that I was really passionate about. <Kuri>

Kuri worked part-time in the university's student affairs office during her second-year, mostly conducting campus tours for high school students and their families. While helping set up an information session for first-year students, Kuri met a graduate of the InterScience program who "loved it so much" that she wanted to promote the program "to everyone." Despite her new friend's enthusiasm, Kuri was sceptical about the kinds of jobs she would be able to get with an "interdisciplinary" degree, because "it's like you're not specialized in anything and you don't have the skills … to get a job."

> Even though I heard before that an undergrad degree is just so general that … your boss wouldn't care what kind of degree you have ... I didn't think I was going to have any -- skills or a lot of experiences or anything [if I did an interdisciplinary degree.] For example, if you go into immunology, there are immunological companies for that kind of stuff, or [if you do] pharmacology [there are] pharmacological companies, but [with interdisciplinary science] you're just not qualified to be considered an undergrad of something – you're just too general. So I didn't think [companies would] even interview me, just look at my resume and say 'hey, this girl isn't qualified.' <Kuri>

Talking to InterScience faculty advisors helped Kuri realize "that's not the case," so she decided to apply to the program and see what she could do. She ended up really happy with the application process.

> [Writing my curriculum rational and vision statement] was very helpful because -- I guess I have a very low self-esteem and I don't really think I am smart enough do things. … Before I didn't have a goal, I just hated my situation and everything, but now I'm working for a goal and it makes me really, really happy. On my vision statement I had to explain why I want to do certain things and why is it my dream and … I [kind of] convinced myself that I can actually do what I want to do, so I -- really appreciate [that] process. It took a long time, but really helped me to discover who I am. <Kuri>

Kuri was accepted into the InterScience program at the beginning of her fourth year and began taking InterScience courses along with other upper-level courses in human kinetics, nutrition, child psychology, and immunology. Kuri's explanation of the difference between the InterScience courses and the others was simple: she wasn't bored in the InterScience ones.

> [For example, the InterScience measurement course] gave me skills, like time management skills, presentation skills, [and] working with a team. … It can be more intense because … if you don't do your work they're going to know it, but I think I learn a lot more that way, plus I can learn the things that I want to learn. <Kuri>

Kuri "just loved" the InterScience courses "a lot more." She found it was "very, really, really motivating" to be in classes with other students who had clear goals, and with professors who "listen to you … and challenge what you have to say," in order to show that people can think differently. It felt, Kuri explained, "like I'm hanging out with friends." For Kuri, being in the InterScience program meant she was free to be herself.

> I really feel like I wasted my [first] three years in university. // Back then I [didn't] care about school, but now I want to do well and I want to get into grad school … and … I love all the courses I'm taking. I'm really happy that I found InterScience. It pretty much changed my university life and my goals as well. // I'm living my university life the way I really wanted. <Kuri>

4.6 "Mixing Stuff Up" – Margaret's Story

Despite repeated visions of herself as a doctor, Margaret was determined to differentiate herself from her parents, both of whom are surgeons. She went to university to become an English teacher – that was, until she received a less-than-perfect grade in her first year English course. "Maybe I'll do something else," she thought.

> I was really a perfectionist and I had gotten a B+ in English so I was quite disappointed. [laugh]. <Margaret>

A mature student who completed her first undergraduate degree several years before applying to LRU, Margaret remembered her teenage-self disparagingly. Confident that she could do “whatever [she] wanted – arts or science,” the younger Margaret “switched around” a lot, first planning to be a teacher and then a lawyer, until finally abandoning her need to rebel and embracing her interest in medicine around her third year. Margaret remembered wanting to “get stocked up on scientific language and knowledge” in order to “prove that [she] was intelligent.” Unfortunately, she was soon discouraged from pursuing medicine by two professors in science.

> You had to have really good marks [to get into medicine then], really high, high marks and - I thought I was doing well but two professors discouraged me and -- I didn’t have that much – I didn’t pursue it, I thought okay I can’t get in. <Margaret>

Margaret finally settled on a combined degree in science and fine-arts. The science fed her interest in the body, and the fine arts fed her passion for self-expression and creativity.

After ten years working in the arts, Margaret returned to university as an unclassified student, thinking again about becoming a doctor. In her first year at LRU, she took the Mainstream science courses that were prerequisites for medical school as well an InterScience course, “because it was interesting.” Margaret quickly noticed a difference between the InterScience course and the others. In the Mainstream science courses, Margaret found

> It was like – “Here, this is this. Learn it. Thank-you.” [laugh] Don’t research, don’t analyse and construct a mysterious problem and try to solve it. It was just “learn it, this is the way.” <Margaret>

Margaret really liked the smaller class sizes and the discussion in her InterScience course.

> I’ve always thought university should be like that. We shouldn’t just sit there, absorb, and then put it on paper, and be a number. We should actually be discussing and arguing ideas back and forth with other people. <Margaret>

She found that InterScience discussions weren’t “just a question that’s thrown out for an ‘interactive’ course and then answered by the prof.” Instead, “curiosity and questions are encouraged.” Margaret acknowledged that being asked a genuine question and feeling heard might seem like a small thing, but she found it was "enough" to help her become "more interested in finishing a [second] degree, and choosing InterScience," rather than simply taking a series of pre-requisite courses for medicine in the Mainstream science program.

Margaret particularly liked the idea of studying physiological systems through the intersection of physics and biology, but she didn't want to spend another four years in school. She would have had to complete her "first-year, second-year, and third-year physics" courses and go into cellular-level details in biology in order to graduate with a bio-physics degree. Margaret discovered that the InterScience program would allow her to "do a little bit of physics and look at systems," without overly distracting herself from her primary goal of becoming a doctor. She took a Directed Studies course so she could do independent research "on the electricity and conductivity of cells in the electric organ of the electric eel." She was "really excited" to discover that biology didn't have to be "boring" and "descriptive," and that she could analyze a "biological system by applying general laws." In the process of "interweaving two different systems of knowledge," Margaret did "something different than any paper [she'd] read." She was quite proud that as an undergraduate student, she could "do something different -- unique."

Margaret believed that conducting independent research and writing learning journals in the InterScience courses helped "increase [her] confidence level in what [she] has to offer":

> Instead of feeling like a student that needs to do what the teacher says and that doesn't know that much because the teacher knows everything. // I just see myself on the level with – not textbook writers but other book writers. So I value my own opinions and curiosities about the material more. <Margaret>

Margaret viewed university as work (albeit unpaid) and kept her social life and friends outside of the university. Margaret noticed a difference between herself and many of students at LRU. The younger students, she thought, were mostly there "to party" and they "didn't want to get too serious."

> It is different when you're young. You are just kind of like, "wow this is a neat, new experience." When you're older you actually just want to learn. <Margaret>

Nevertheless, she appreciated that with/in the InterScience program, she could connect with other students who shared her interests in "mixing stuff up."

> If someone says they're in InterScience and you're in InterScience there's an automatic -- I don't know what you'd call it -- just ... it's a nice thing to know … someone else is mixing stuff up too. <Margaret>

A few years after graduating from the InterScience program, Margaret gained admission to medical school.

4.7 "Finally, I Can do it My Way" – Melanie's Story

Melanie was a keen student even in high school, completing all of the Advanced Placement university science courses her small school offered. Melanie applied to study science at LRU because she liked science better than art, she didn't want to study business, engineering, or English, and she didn't realize there were any other options.

Melanie's Advanced Placement credits allowed her to skip the standard first-year science courses (math, biology, physics, chemistry), and take some "fun electives" in anthropology and psychology instead. Melanie was keen to learn new things, and she couldn't understand why some students elect to re-do their Advanced Placement credits at university. "What the hell's the point" she wondered.

Melanie's introduction to anthropology and psychology sparked her curiosity about the interactions between "the brain, the body, and the environment." The best available fit for her interests seemed to be a specialization in anatomy and physiology in Mainstream science, so she spent her second year taking pre-requisite courses from the departments of chemistry and biology. Melanie quickly grew bored studying aspects of chemistry and biology that didn't seem relevant to her interests, and she eventually decided that the anatomy and physiology major was too "limited" for her.

> I wasn't really that interested in the physiology and anatomy because of the curriculum. It just was such a scheduled thing, and didn't leave a lot of room for other options, which is not really how I ever viewed an education to be like: a very limited discipline. <Melanie>

Melanie was thrilled when she learned about the InterScience program from her boyfriend and his friends.

> The idea that I could tailor a degree around what I wanted to learn was the most wonderful idea I'd ever heard since coming to school. [laughing] It's like, "finally, I can do it my way." <Melanie>

Melanie titled her InterScience program "Human Form and Function." She wrote in her application essay that she wanted to create "a thorough understanding of the human mind and body," so she designed her program "around taking physiology, anatomy, and biological psychology classes." Melanie took anatomy classes to study the form of the body, physiology classes to learn about how the body works, and biological psychology classes to "pull in how your brain is incorporated into all of that."

> It's a good way to learn a lot about your life and how you can improve it, and what things make you healthy and what things don't. And it's also really interesting to know how things work – to me at least, I find that intuitively interesting. <Melanie>

Melanie was preparing herself for a career in rehabilitation therapy, as an alternative to medicine, because she felt that it was a career that would allow her to engage in problem solving and to help improve the health of children without having to invest the time and money into a medical degree and a specialisation in paediatrics. She was excited that every course she was now taking "incorporates with everything else that I'm taking," and that she no longer had to "take any course where [she was] sitting there feeling: Why am I learning this, why do I need to care about this?"

4.8 "The Kind of Education I Wanted" – Sarah's Story

If you're good at science you go into medicine – that was the presumption among students at Sarah's high school, and it was reinforced by comments from teachers and guidance counsellors. Since Sarah was good at science, she enrolled in the Mainstream program in the Faculty of Science at LRU with the goal of becoming a medical doctor. On a more personal level, Sarah was also driven towards medicine because of her own experiences with a childhood illness. Beyond "studying science," Sarah only knew that she wanted to do "something in biology."

In her first two years, Sarah took "a lot of general biology courses, specifically in immunology and microbiology" and she considered registering in the cell biology/genetics major. However, Sarah grew increasingly frustrated by the fact that she "didn't really feel like [she] was getting the education that [she] wanted."

> Ever since my first year at this university … I was feeling like my education was too general and I wasn't studying the things I wanted to and -- I wasn't studying in the atmosphere that I wanted to. <Sarah>

Sarah was disappointed with the class assignments she was being asked to do – "you've got a midterm worth thirty or forty percent and then your final is worth the remainder." Sarah explained that having only two assessment opportunities provided no incentive to "keep an active interest in what you're studying."

> That encourages people to cram at the very last second and just stuff all this information in your head and I don't know anybody who learns that way. You can learn for a test, but you're not learning for yourself, and, sure enough, I fell right into that pattern. <Sarah>

Sarah also resented being "a number in a class full of five-hundred people" and not being able to talk with her peers and faculty members about what she was studying.

> I hated that. I am a very social person, and the way that I learn involves interactions with other people, not only my peers but my instructor as well. <Sarah>

Finally, Sarah wasn't interested in many of the courses that were required for the cell biology specialization, and she found that many of the elective courses were overly general.

> That's something I really struggled with my first couple of years and I wasn't --- expecting that. I guess I kind of had a glorified view of the education I would get when I came here. … I was just feeling like there wasn't any one subject that I was like, "yes, this is what I want to --- pursue." … Nothing hit me like that. [I was always interested in] a combination of different things, because I like to see how things correspond to each other and relate to each other. <Sarah>

Although most students declare their specialization by the end of their second year, Sarah resisted doing so until she was "really sure" of the direction she wanted to pursue.

Sarah learned about InterScience from friends who were in the program and who had "lots of positive things to say" about it. She discovered that the InterScience program would let her "choose the course material that's the most interesting to" her. Sarah declared herself an InterScience student at the beginning of her fourth year, proposing to integrate the study of genetics and microbiology. Integration provided Sarah with “a label for the feelings” that she had towards the “kind of education” that she wanted.

Within the InterScience program, Sarah found “a group of people much more open to the idea of integrated sciences,” and she got to work with her classmates in meaningful ways:

> [You’ve got classmates from several] different backgrounds, [and by working together] you’re pooling all your general knowledge but you’re also pooling different ways of learning. // Whereas in the labs that I [had in Mainstream science courses,] I think it’s more because of a lack of resources that they’re forcing you to work in pairs --- it’s all running experiments, and making reactions, and that’s something that you can do alone. … There’s no added benefit of having extra people involved in [the single-discipline lab] environment. <Sarah>

Sarah met InterScience instructors who she felt were learning alongside her and not just “dish[ing] out the information that students have to learn for the exam.” InterScience instructors asked Sarah for her perspectives on readings, and she revelled in being asked to show that she had ideas that others would value hearing.

> The great thing about this is that … you’re not some machine just cranking out answers to things, [you’re actually expected to] have a brain, to have a thought about this and have an opinion. It just shows that you’re able to think on a higher level. <Sarah>

Sarah firmly believed that “everybody should have to take an InterScience course.”

4.9 “School Was Kind of an Aside” – Todd’s Story

Todd initially applied to both engineering and music at LRU, figuring he would let the university decide what career path he should follow. When he didn’t get into either program, he took a year off and re-applied the following year to science. He was quickly accepted based on his high-school grades – straight A’s and top of his class. Todd decided to study science because he felt that he “couldn’t do much with an arts degree,” and only engineering, music, and science were interesting options. “But,” Todd noted, “I was younger then. Now I realize -- that it’s not really what you study it’s --- how you go about it. [soft laugh].” Todd went about it quite the wrong way at first; he failed three out of his first four courses.

Todd was a semi-professional athlete who turned professional during his first year and he got distracted. “School was kind of an aside.” Despite the failures, Todd “really liked the classes” and decided to start fresh the following September. He was interested in environmental pollution and started working towards a chemistry degree in the Mainstream program. Todd liked his first and second-year courses “a lot, actually,” but by the end of second year he was competing professionally in a different sport. Once again, his school work started to wither, this time compounded by the fact that the chemistry major didn’t seem to have “any particular focus.”

> Chemistry was so general. … I wanted to study urban air pollution … and I couldn’t [in chemistry] – some courses were applicable, but not really. <Todd>

By the fall of his third year, Todd’s grade point average was just below the cut-off for registration in organic chemistry, one of the required courses for his chosen major. He went to talk with an undergraduate advisor, and was told “there’s no way you can get in.”

> [The advisor] pretty much told me -- that I can’t do a chemistry degree. … At that point I was in third year and I’m like “You can’t get me in?” [I had all] these courses … and this was the [last] one I [absolutely needed] to do a chemistry degree, and he’s like “You can’t do it.” … That was a pretty big blow. <Todd>

Todd’s advisor suggested he “just do a general science degree,” but that didn’t appeal to Todd: “At that time I thought, a general science degree? That’s crap. That’s nothing.”

Todd knew that he could be done in a year if he would just complete the general science degree, but he really wanted to “make the most” of his education. He started researching other options, and realized that the InterScience program would let him actually study pollution in urban environments. “Wow,” Todd thought “I could make my own degree and do what I want to do.” He could finally take the courses in meteorology, geography, and urban development – “the core stuff that -- really comes into play when you’re studying urban pollution and processes” – that he was really interested in, but couldn’t get degree credit for in the chemistry major.

Todd spent a year planning his degree and going through the InterScience application process. He met regularly with his program advisor who “steered [him] in the right direction,” and he started taking courses that he “finally really liked.” “Now that I’m in it,” Todd laughs, “I can’t believe that other people don’t do it. It’s ridiculous!”

4.10 Two "Figured Worlds" of Undergraduate Science

The nine students' stories about how they came to study science and why they decided to apply to the InterScience program all describe similar trajectories of participation (Boaler & Greeno, 2000; Wenger, 1998) in undergraduate science. The students came to the InterScience program after (and in response to) studying in the Mainstream science program. The students' perceptions of the Mainstream and InterScience learning environments are markedly consistent, revealing two distinctly different figured worlds of undergraduate science learning. The students' juxtaposition of these worlds demonstrates their alienation from the Mainstream one and their increasing engagement with the InterScience one.

Holland, Lachiotte, Skinner and Cain (1998) describe figured worlds as narratively constructed, almost imaginary cultural realms, and this resonates with the common "story-lines" that emerged from the students' experiences. The students' InterScience experiences can be analyzed as narratives told against the storyline around which the figured world of Mainstream undergraduate science is organized, and against which "characters, acts and events" are given meaning (Holland et al., 1998, p. 55). In Chapter 5, I will analyze the students' narratives to consider ways that the two figured worlds, Mainstream science and InterScience, are "lived" through practices and activities (Holland et al., 1998, p. 56). I will use examples from the students' stories about how they came to participate in the InterScience program to look at changes in the students' engagement and at how these changes contributed to and were influenced by the development of the students' identities as interdisciplinary science students.

Chapter 5 Results and Discussion

My study examines how undergraduate students experience interdisciplinary science. In Chapter 4, I introduced my case study participants and discussed the two figured worlds of undergraduate science learning that emerged through the students' stories. In this chapter, I present the results of my analysis of the students' interpretations of their experiences and address the three research questions that guided my inquiry:

A. What learning practices are valued by undergraduate students who chose an interdisciplinary science degree?
B. How do undergraduate students experience their positioning in disciplinary and interdisciplinary science degree programs?
C. What identities do students develop through their participation in disciplinary and interdisciplinary science degree programs?

I present my results in three sections: *Practice, Positioning,* and *Identity*. The findings are based on my analysis of interviews and documents collected from nine InterScience students, as well as observations of three InterScience courses over a two-year period.

5.1 Practice

In this section, I address the following question: *What learning practices are valued by undergraduate students who chose an interdisciplinary science degree?*

Practices are, first and foremost, processes of negotiation by which we can experience the world and our everyday engagement in it as meaningful (Wenger, 1998, p. 51-3). Since learning practices define and shape learning outcomes (Boaler & Greeno, 2000; Brown, Collins, & Duguid, 1989; Wenger, 1998), we can come to understand what students learn and what they find meaningful by scrutinizing and making sense of the learning practices they participate in. In presenting my findings I draw on Tinto, Goodsell-Love and Russo's (1993) argument that incompatibility between what students expect from their university education and what they actually experience, is a primary cause of attrition. I present the students' recalled expectations for the practices that their education would enable, and compare these expectations with the students' experiences of what the Mainstream program and the InterScience program were offering. I begin by analysing the students' understanding of the practice of interdisciplinary science.

InterScience students' views of the practice of interdisciplinary science

At first glance, the students in my study seemed to contradict themselves when they explained what they wanted to do in their science education and why they couldn't do it through the Mainstream science program. The students wanted their science education to be *broad* so that they could understand a *specific* problem, and they believed that the Mainstream programs enabled *deep* learning on *general* topics in science.

InterScience students recognized the need to learn from the science disciplines, but believed they couldn't pursue their interests from within any single disciplinary specialization alone. Thus, they wanted to take courses from multiple disciplines. At the same time, the students rejected disciplinary specializations for being too general. Farah's explanation of why she elected not to pursue a combined disciplinary degree in cell biology/genetics and microbiology is representative of the students' perceptions of the disciplinary specializations:

> They were too general. I understand they're undergrad programs, but, well, they were not that specific. <Farah>

There is a maxim that interdisciplinary study produces people who are 'jacks of all trades, and masters of none.' This adage follows from the metaphors that commonly shape assumptions about disciplinarity and interdisciplinarity: the metaphors of depth and breadth. Klein (1996) notes that "disciplinary work is signified by the metaphor of deepening along a vertical axis," while "interdisciplinary work is usually depicted along the horizontal axis of breadth" (p. 212). The culture of university science learning traditionally values depth over breadth, evident by the gradual narrowing of a student's focus from a bachelor's degree through to a PhD. In contrast to these common assumptions, the students in my study viewed disciplinary programs, typically signified by the notion of depth, as too general and interdisciplinary study, typically signified by the notion of breadth, as more specific.

Todd, for example, did not want to gain generalized chemistry knowledge. He wanted to think about urban air pollution, a problem that he recognized involves meteorology, geography, urban development and economics, in addition to certain aspects of chemistry.

> Todd: So many people just do degrees where they do well … but it's so general.
>
> Gillian: What was it about [chemistry] that was general?
>
> Todd: I'd met a lot of people that didn't really know what they wanted to do, but they were doing the degree -- you know? So they have a degree, but --- I wanted to study urban air pollution. That's specific, and I couldn't. There are some courses in chemistry that were applicable, but not really.
>
> Gillian: So if you'd done … the chemistry route … do you think you'd [have been] able to do what you wanted to do?
>
> Todd: No. No. Well yeah, I'd probably be able to do it, but then I wouldn't have the meteorology background at all, or the geography, or the urban development, or the core stuff that -- really comes into play when you're studying urban pollution.

Todd believed that a Mainstream degree would have forced him to study only one discipline and, within that discipline, many aspects that weren't relevant to his specific problem. Todd wanted to draw on several disciplinary perspectives and, more specifically, on particular insights from the disciplines that relate to his problem of interest. Todd and the other participants in my study wanted to learn deeply, but not in the way typically defined by the notion of disciplinary depth. Instead they wanted to develop an "understanding of the overall perspective of several relevant disciplines" (Repko, 2008, p. 126), and then to apply specific insights from each discipline to the particular problem they wanted to understand.

Like Todd, Sarah wanted to study several areas of science in depth and then relate those areas to one another.

> I'm not satisfied knowing about just any one particular thing in depth, I want to know about lots of things and I want to know how they relate to each other. <Sarah>

Sarah viewed introductory or foundational concepts, like the ones taught in first-level courses, as general, whereas she thought of breadth as connecting specific insights from multiple perspectives.

> The breadth for me isn't necessarily in the courses that I'm taking now, because, to be honest in third and fourth year they're getting much more detailed. The breadth for me … is being able to take several different courses that are of that level of detail, and start seeing the integration between all of those. <Sarah>

All of the participants in my study recognized that "the depth/breadth dichotomy … fails to acknowledge a crucial third element"—synthesis (Klein, 1996, p. 212). Klein argues that:

> Interdisciplinary work gets done by moving across the vertical plane of depth and the horizontal plane of breadth. Breadth connotes a comprehensive approach based in multiple variables and perspectives. Depth connotes competence in pertinent disciplinary, professional, and interdisciplinary approaches. Synthesis connotes creation of an interdisciplinary outcome through a series of integrative actions. Synthesis does not come from simply mastering a body of knowledge, applying a formula, or moving in linear fashion from point A to point B. (…). Integrating knowledge … requires active triangulation of depth, breadth, and synthesis." (1996, p. 212)

InterScience students recognized that interdisciplinary work requires the integration of multiple perspectives. Linn and Hsi (2000) define knowledge integration as "the process of comparing ideas, distinguishing cases, identifying the links and connections among notions, seeking evidence to resolve uncertainty, and sorting out valid relationships" (p. xxxi). Similarly, Repko (2008, p. 118-9) argues that integrated understanding is "not merely a reassemblage of the separate disciplinary insights or a juxtaposition of them in a multidisciplinary fashion." This definition is articulated by Farah in the following quote:

> I would say, [integration is taking] things that may appear to not have anything in common [and bringing] them together. For example, they can have something in common, but you don't see it, like what I'm doing. Those two topics, or three or more, they can be really different, but you as a person can make sense out of all of those together, even though they are really different. <Farah>

The InterScience students did not want to receive and repeat disciplinary knowledge, nor did they want to reassemble disciplinary insights or juxtapose them in a multidisciplinary way. They were consciously seeking coherence, connections, and relations among the disciplines in order to generate new knowledge. They wanted to gain what Boix Mansilla (2005) has called *interdisciplinary understanding*.

Boix Mansilla (2005) and her colleagues at Harvard University's Project Zero define interdisciplinary understanding as "the capacity to integrate knowledge and modes of thinking drawn from two or more disciplines to produce a cognitive advancement – for example, explaining a phenomenon, solving a problem, creating a product, or raising a new question – in ways that would have been unlikely through single disciplinary means" (p. 16). By wanting to gain interdisciplinary science understanding, these InterScience students were valuing what Belenky, Clinchy, Goldberger and Tarule (1986) have called procedural knowledge. Belenky and her associates argue that students who value procedural knowledge conceive of knowledge as a process of generating and evaluating multiple perspectives. Belenky et al. further define two distinct forms of procedural knowledge: separate and connected. Separate knowing is associated with critical and objective thinking, typified by the methods of science where the knower seeks to evaluate competing propositions. Connected knowing is relational, oriented towards understanding and connecting different perspectives. My study participants value both forms of procedural knowledge.

InterScience students value an interdisciplinary approach to science education that combines disciplinary grounding, procedural knowledge, and connected knowing. So, when students in my study were talking about seeking a breadth of knowledge in order to understand a specific topic or issue, they weren't contradicting themselves, they were challenging common assumptions about disciplinarity, interdisciplinarity, and the purpose and practices of undergraduate science.

Barriers to valued practices with/in Mainstream undergraduate science

InterScience students found that the Mainstream science program presented them with a number of barriers to participation in the practice of science integration. One barrier the students encountered was the prescription of course requirements for Mainstream specializations. Todd experienced the specification of required courses as the imposition of rules and boundaries around what he could learn, confining him to "one certain box, or one certain faculty, or one certain discipline." He observed that the Mainstream program privileged discipline-based learning, interests, and courses over cross-disciplinary ones, noting that chemistry would have allowed him to study atmospheric science or geography, but only as a "minor or an elective" and not as "part of [his] core curriculum." Todd experienced this marginalization of cross-disciplinarity as a personal affront, a dismissal of own interests and values. This experience of marginalization was reinforced when Todd was denied entry into one required third-year course, a denial that prevented him from completing a chemistry degree. Todd felt as though the university was trying to "push him out of school" when advisors suggested his only option was to "just do a general science degree," an option Todd felt was a "cop-out" since it held no meaning for him. The Mainstream specializations denied him the opportunity to negotiate the meaning of his science education, and thus, to legitimately participate in the practice of science knowing. Todd and the other InterScience students resented being required to take courses they did not want to take and being denied the opportunity to take the courses they did want. They chafed against the implication that their interdisciplinary interests were irrelevant and that they were incapable of participating in a negotiation of what aspects of science were worth studying. As Keith explained,

> The choices that you have [in the Mainstream program] … are limited … [and] that doesn't allow you to really try to put [different areas of science together yourself.] … [It implies that] there's only certain areas of science that really go together … and the relationships [have] already been done by someone else. <Keith>

The InterScience students rejected both being required to take courses within an area of specialization that was not relevant to their topic of interest, and being denied the opportunity to take the courses outside of their specialization that would provide the multiple perspectives the students felt they needed in order to gain a fuller and broader understanding of their topic. InterScience students experienced alienation when the Mainstream science specializations denied them the opportunity to access multiple perspectives. The students' sense of alienation was compounded by their observations of important differences between their expectations of an interdisciplinary science education and the evident expectations of their Mainstream science peers. Most of Sarah's Mainstream classmates didn't share her frustrations about not being able to pursue her diverse interests. Sarah felt that her classmates couldn't relate to her lack of connection with any of the Mainstream programs that were available to her.

> In conversations that I had with friends or other peers in my classes – they were like "No. I'm doing microbiology," or "I'm doing pharmacy" or "I'm doing this or that" – they, they were sure of the program that they were in and wanted to do, and I didn't experiencing that at all …. <Sarah>

Similarly, Amalie noted that her Mainstream science peers did not appear to seek out multiple disciplinary perspectives, or even to be aware of the benefits of gaining multiple perspectives.

> A lot of the people that I know that come from the Mainstream program they think about "Oh, I'm in Biology." Very few think about importing ideas from other disciplines into anything, even a lecture – when you think at the end of the day what you learned {so like} "how does that relate to my other courses?" <Amalie>

The InterScience students also found that the Mainstream science program restricted their access to gaining multiple perspectives from their peers. Sarah noted that each discipline in science teaches its students to "think in a certain way."

> In a lot of the sciences you learn things and you're taught to think of it in a certain, very stepwise manner – you solve problems like this, etcetera, etcetera. So each field kind of has its own approach, because obviously different problems require different ways of thinking about them, and obviously the ones you're going to encounter most often in your field are going to be the ones whose strategies you learn. <Sarah>

Sarah observed and expressed concern that, by learning to think alike, students in each Mainstream specialization narrow their perspectives. Sarah, and Diane, believed that the narrowing of perspectives was reinforced through degree requirements that are so prescriptive that students in any given specialization end of taking most of their courses together, restricting their access to cross-disciplinary conversations among peers. Diane explained that she found the university's practice of "splitting people up" into different disciplines "weird," "even between arts and science."

> I have an English class, and {students seem to} have this idea about science students, and [they ask me] "Are you stupid? Why are you taking English classes if you're in science? You don't have to have [3rd year] English classes." [laughing]. I'm like, "No, but it's interesting." I like going to English because it's different people, different faces, and they think differently and it's just, it's a good way to integrate stuff. <Diane>

As Diane's comment and the following quote from Sarah demonstrate, InterScience students experienced the Mainstream programs' restrictive course requirements as barriers not only to the practice of gaining insights from multiple disciplines, but also to the practice of science integration. InterScience students did not want to integrate on their own. They wanted to learn how to integrate from and through interaction with others.

> If you just did two majors, you're looking at two different areas from two different perspectives and you don't get much correlation, or much chance to actually link them except individually by yourself. <Diane>

Sarah expressed this need for interaction even more clearly:

> This is a common complaint: class sizes and the anonymity of your professors. I hated that. I am a very social person, and the way that I learn involves interactions with other people, not only my peers but my instructor as well. I don't want to be just a number, you know, in a class full of five hundred people and I had a real -- problem with that. <Sarah>

The InterScience students portrayed an image of the Mainstream program as advancing pedagogical strategies that lead to isolation, passivity, and *received* ways of knowing (Belenky et al., 1986). Belenky et al. describe received knowers as ones who learn by listening. Learning, in this sense, is a process of hearing, understanding, and remembering the things that others, and particularly authorities, tell. Received knowers trust what professors say more than students, and they trust others more than themselves, having little confidence in their own ability to generate knowledge. The InterScience students did not want to participate in the practices of received knowing and they became frustrated when no alternative ways of knowing were made available to them.

> I understand that [in] the first couple of years of university … they're trying to give you the foundations of what you're going to learn in your upper two years but --- I was really frustrated by the way I was being educated. I mean, if you asked me to tell you what I learned in those first couple of years I really probably couldn't recount that much information. …. Just because the classes were huge and the layout of courses was always the same. You've got a midterm – this is so classic of science – … worth between thirty and forty percent and then your final is worth the remainder. There are no assignments, if you have a lab you're lucky, because those are a rarity now-a-days too. It's just not conducive to … retaining information. I mean, that encourages people to cram at the, you know, at the very last second and just stuff all this information in your head and I don't know anybody who learns that way. You can learn for a test, but you're not learning for yourself. <Sarah>

InterScience students found that the practices of Mainstream undergraduate science discourage science integration. My study participants experienced program structures that restrict students' access to insights from multiple science disciplines, and pedagogical practices that afford received knowing and thus serve to discourage participation in the practice of science integration.

Access to valued practices with/in InterScience

In contrast to the barriers they encountered with/in the Mainstream science program, my study participants found that the InterScience program had pedagogical structures in place that afforded them opportunities to gain multiple disciplinary perspectives and to integrate the sciences.

The students discovered with/in the InterScience program a space where integrating insights from multiple disciplines was not only valued, it was expected and supported. Several of the students experienced the program application process as a powerful pedagogical tool that enabled them to identify and articulate an integrative purpose for their learning. Keith, for example, was attracted to InterScience "just for the freedom" he was allowed to "take what [he] wanted," but he was quick to point out that having the freedom to pick his courses from across all areas of science did not imply a lack of focus to his education. "The good thing about InterScience," he explained:

> Is that you actually have to write a rationale [in your application] of -- you know, I'm taking these courses and this is my vision of what I want my education to be and then I'm taking these courses for this rationale. // Not only that, you're not just accepted, you have people judging you – what are you doing, do you think that this is right, are these the right courses for you to be taking, stuff like that. So there is a whole process to … being a part of the program, being accepted, … achieving what people consider an integrative theme for your degree. <Keith>

Keith found that the InterScience application process both required and challenged him to articulate a clear vision of what he wanted to learn, and why he wanted to learn it from across the disciplines. Further, he welcomed the engagement of InterScience advisors in the development and approval of his program. The advisors' questions invited Keith to negotiate the meaning of his degree program, and their judgement enabled him to demonstrate (and to be recognized as demonstrating) competence in science integration. In other words, Keith experienced the InterScience application process as a form of legitimate peripheral participation in the practice of science integration.

While Keith noted the empowering value of envisioning and defending his own science program, Melanie explained that building a program around understanding how the body interacts with its environment gave her a reason to care about everything that she was learning:

> I don't have to take any course where I'm sitting there feeling 'what am I learning in this, why do I need to care about this?' Every course I take incorporates with everything else that I'm taking and I end up with a really neat overall understanding. <Melanie>

Melanie's InterScience application allowed her to identify and articulate an integrative purpose for her learning, recognizing the value of and the need to synthesize knowledge in order to understand and address a scientific problem. Although Melanie explained that she had designed her InterScience program "around taking physiology, anatomy, and biological psychology classes," her vision for what she wanted to learn went beyond a simple list of interesting courses. She clearly expressed how the courses she proposed to take would relate to each other and contribute to her creation of "a thorough understanding of the human mind and body." The InterScience application process facilitated Melanie's recognition that linking, connecting, and combining the science she was learning in her anatomy, physiology, and psychology courses was necessary to provide, "a really neat overall understanding."

For Sarah, different elements of InterScience empowered her to think in an integrative fashion:

> The beauty of InterScience is that not only are you integrating the sciences themselves, because that's the very nature of the program, like I said I'm studying immunology and medical genetics, but you're integrating different ways of thinking. <Sarah>

Sarah identified in-class interactions with students who were studying different disciplines, and the exposure this provided to new ways of looking at problems, as powerful features of the InterScience program.

> If I am just not seeing something --- odds are that somebody else in my group is going to have another approach to solving that problem because they come from a different background. [For example,] we had somebody in computer science in the group of three that I had. So I would look at this thing, I'd be like "I don't get it, I don't know why this isn't working" and he'd sit there and he'd be like "well, what if

> we try this" and I would -- so many times -- I would think "I would never have even thought of that." … I think the biggest reason for that is because … I've been kind of trained to think in a certain way and sometimes that would hinder my understanding of something, whereas somebody else [who] doesn't have those same barriers, because they learned in a completely different process from me, would be able to provide some insight into something that I maybe couldn't have answered. <Sarah>

Sarah explained that she would never find herself learning from her peers in a chemistry lab, because most of the students taking senior-level chemistry courses were chemistry majors and they had all been taught to solve the same problems in the same way. It was the structure of InterScience classes, which brought together students who are interested in studying across different disciplines, that gave Sarah access to different ways of thinking. As Sarah's comments illustrate, the participants in my study understood that each discipline "acts like a lens when it filters out certain phenomena so that it can focus on phenomena that interest it" (Repko, 2008, p. 53). The students recognized features of the InterScience program that facilitated their learning across the disciplines and ensured that they could access and use multiple lenses through which to gain a more comprehensive understanding of the phenomena they were interested in.

In addition to accessing multiple disciplines, students in my study wanted explicit opportunities to learn to integrate the different perspectives they were gaining. The InterScience program enabled knowledge integration for the students in various ways, including the requirement that students build and negotiate an explicitly integrative program of courses. InterScience students also identified journaling and discussion as powerful pedagogical strategies that helped them learn how to integrate knowledge. Amalie learned to integrate while writing reflective journal entries for her InterScience courses. Writing in her learning journal gave Amalie the opportunity to "sit down and reflect at the end of the day" about how the things she was learning (in the class, in the lab, in readings, and in other courses) were relating to one another. Amalie's connecting and relating are evident in the journal entries from one her InterScience courses, excerpted below, where she applied control systems theory and readings from neuroscience to expand her thinking about ecosystem planning.

> **October 31, 2003**. In my Planning 5XX class, we just discussed how ecology went through something called "The Physics Envy." In other words, for decades, ecologists have been struggling to describe and predict ecosystem "mechanisms" as if

> they were dealing with simple Newtonian mechanics and simple linear systems. … I wonder if … [InterScience guest speaker, KR's] nematodes were very simple due to the environment they originated in being very simple. … Yeah! Simple environment = simple organisms, would be consistent with KR's point that "baby" nematodes exposed to fewer stimuli and disturbances from the environment develop less well than nematodes exposed to a variety of stimuli, interpersonal (!) interactions and disturbances…. This reminds me of [InterScience guest speaker, AM's]'s talk and his emphasis on one of my favourite concepts: STRUCTURAL COUPLING. The latter represents some kind of "key-and-lock" relationship between two (or more) dynamic systems, so that disturbance from one system (i.e. the input) triggers a reaction, a change in the other (i.e. output), which trigger another reaction or change in the other and so on. … But wait a minute. … I just finished reading the book *The Tree of Knowledge: The Biological Roots of Human Understanding*, by Maturana and Varela … where the authors argue that … structural coupling between a system and its environment is one of the cores of the evolution of intelligence and human understanding. … I really like that idea because it suggests how …. <Amalie, journal entries>

Twice during the term, Amalie shared her journal with a classmate and the course instructor, each of whom added their own questions and reactions to her writing, engaging in a written three-way conversation with her ideas. In response, Amalie created what she called a "nested design" for her journal, following-up on her colleague's comments, "revisiting the journal," and reading her prior writing with "a new mind, new perspectives … and [adding] … new thoughts and new ideas relating to the topic." She wrote in her journal that she found the conversation, and the opportunity the journal provided to "nest new thoughts within the old ones, very, very useful."

Diane too cited InterScience classes for letting her "do a lot of journals and a lot of discussions" where she was able to integrate her own interests "on a level with other students and profs and get feedback on them." Like Amalie, Diane saw the value of discussion and working with others to scaffold and support integration. Diane explained that the opportunities to integrate came about through the ongoing interaction with classmates who were themselves integrating different areas of science.

> You get a chance to look at the details of different things from different perspectives … just from discussing stuff in your groups. … Like somebody will say 'okay from a biochemistry perspective this is what I see,' and then somebody else will say 'okay well this is what I see in physiology.' And that gives you a chance to bring them together in that you now have different views of things, and it's not just your one way, narrow-minded view. … Just from listening and discussing and actually being able to see it from different perspectives … you can say 'Oh I remember learning

> about antigens,' and 'yeah okay, now I see how antigens might link to this idea of genetics, or this concept that we're doing in genetics.' And so, it just opens up other branches for you to think and to not just think a one-way view, it's not just the world is biochemistry, there's actually a bigger picture. <Diane>

Other students began to consciously integrate the sciences once they were accepted into the program. Melanie noted that after becoming an InterScience student she started finding "half the answer" for many of her Mainstream science course problems in the textbook for one course and "half the answer in another," and she discovered it was "helpful to go back and forth."

> The physiology textbook might mention a certain structure but not go into its detail, and if I want I could go look at my anatomy text and -- by understanding the structure in more detail I can understand what they're telling me in biopsychology. <Melanie>

Reading across her textbooks was something Melanie had never consciously done before joining the InterScience program. Similarly, Sarah and Farah became conscious of integrating once they joined the InterScience program. As Sarah explained,

> It's not like I come out of medical genetics and throw aside those two hours and think about physiology next or whatever it is my next class is. When I'm in that physiology class I start thinking about things I heard in the class before it and maybe how it could be used as an example or how they might be related. // [The InterScience program has] given me the skills to see how things relate to each other. … Taking this program has really taught me to appreciate those relationships, and also helped me be able to identify them in the first place. <Sarah>

Sarah acknowledged that seeing how things relate "seems like such a simple concept," but she found it amazing "how many people just don't look at it that way."

> In a lot of ways [education] forces you to really pigeon hole the way that you think and take one line and study it really, really hard so you become an expert in that particular thing. And it doesn't necessarily teach you how to look at all the other things that have an interplay with that particular subject of your interest. <Sarah>

Sarah believed that the InterScience program was helping her to find relationships and to make connections between relevant areas of science.

Finally, the students in my study also identified the generative potential of having explicit, ongoing opportunities to integrate the sciences during InterScience courses. An example comes from Margaret, who talked about an individual research study she conducted in her fourth year that used physics to examine a phenomenon in Biology.

> [I'm doing] an InterScience Directed Studies on the electricity and conductivity of cells in the electric organ of the electric eel. // And in biology they're not interested in that, so they're not describing it, so it takes me so much longer to find it. But then when I find it I can use it, and do something different than any paper I've read. And I'm an undergraduate student and I can do something different -- unique. <Margaret>

Margaret was excited that, by connecting physics and biology in a novel application, she could be generating new knowledge.

To summarize, the participants in my study identified multiple pedagogical structures and strategies in the InterScience courses and program that enabled and empowered their participation in the practice of interdisciplinary science. These strategies included:

1. An application process that asked students to build and rationalize an integrative program of study;
2. Course assignments that emphasized journaling and other forms of conscious/reflective integration;
3. In-class discussions with peers from different disciplinary backgrounds;
4. Course assignments that invited reading across disciplinary texts; and
5. An overall emphasis on making the practice of integration explicit.

Taken together, these pedagogical strategies enabled connected ways of knowing.

Summary and discussion of practice

In this section, I have addressed the first of my research questions: *What learning practices are valued by undergraduate students who chose an interdisciplinary science degree?* I found that the students in my study expected their undergraduate science education to enable the development of their interdisciplinary science understanding through participation in interdisciplinary science practices. InterScience students value the methods of science for the insights that can be generated, so they expected to ground their undergraduate learning in the perspectives of multiple, relevant science disciplines. The students also believe that understanding requires connecting disciplinary insights, and they expected to engage in connected knowing, learning to integrate the knowledge they gained in order to generate new insights. While the students value procedural knowledge, they are not what Belenky and her colleagues (1986) term *procedural knowers*. Belenky et al. describe procedural knowers as ones who are "subservient to disciplines and systems" (p. 140). As I will show in Sections 5.2 and 5.3 below, the InterScience students value their own insights, wanting to add and integrate their own voices and perspectives with the ones of disciplinary experts. Like the *constructivists* Belenky et al. describe, the InterScience students put disciplines and systems "to their own use," making connections and cutting "across the interests and biases that lie within a single disciplinary perspective" (p. 140). The students are becoming what Belenky et al. term *constructivist knowers.*

My analysis of the InterScience students' expectations for disciplinary grounding and integration supports Lave and Wenger's (1991) hypothesis that engaging in practice is a condition for the effectiveness of learning. The participants in my study intuitively understood Boaler's (2000) argument that "the *practices* of learning … define the knowledge that is produced" (p. 172, original emphasis). They expressed a need to engage in the practice of interdisciplinary synthesis in order to effectively gain interdisciplinary understanding. Specific features of both the Mainstream and InterScience programs significantly affected the students' ability to satisfy their learning expectations. Students experienced restrictive course requirements of the Mainstream specializations as barriers to their desire for disciplinary breadth, and they experienced the traditional pedagogical strategies of the Mainstream science courses as barriers to their desire for integration. In contrast, the students experienced the specific structures and pedagogies in the InterScience program as enabling the satisfaction of their learning expectations.

The students had to work to join the InterScience program – they had to apply for acceptance and they found the application process long and intensive – but by being asked to draft an explicitly integrative program of study, and to articulate a rationale for their program, the InterScience students experienced an opportunity to identity and then to pursue their interests by accessing different bodies of knowledge. Finally, the students identified five pedagogical practices that they believed were particularly effective at enabling their participation in the practice of science integration. One key feature of these pedagogical practices is that they are *explicitly interdisciplinary*. Further, they afford deep and connected ways of learning and knowing.

In the next section, I will address the ways in which the approaches to learning underlying the program structures and pedagogical practices in the Mainstream and then in the InterScience program serve to position students as passive or active agents, as well as how these positionings further deny or enable access to interdisciplinary science understanding.

5.2 Positioning

In this section, I address the following research question: *How do undergraduate students experience their positioning in disciplinary and interdisciplinary science degree programs?* Tan and Calabrese Barton (2008) note that "science education often positions students as particular kinds of science learners, with particular participation trajectories" (p. 45). I address my research question by exploring the kinds of science learners my study participants wanted to be and the kinds of science learners they experienced themselves being positioned to be.

The kinds of science learners InterScience students wanted to be

To understand the kinds of science learners the InterScience students wanted to be, I first consider the students' motivations for learning interdisciplinary science and their preferred approaches to learning. These two constructs provide a context for interpreting the students' experiences of their positioning with/in the figured worlds of undergraduate science.

I am conceptualizing motivation in terms of Deci and Ryan's (1985) self-determination theory. Ryan and Deci (2000) conceive of motivation as a multi-dimensional phenomenon that can vary not only in level, but also in type. Self-determination theory distinguishes between the "different types of motivation based on the different reasons or goals that give rise to an action" (Ryan & Deci, 2000, p. 55). Deci and Ryan propose that types of motivation vary along a continuum of relative autonomy. They position intrinsic motivation as the "prototype of [fully autonomous,] self-determined activity" and different forms of extrinsic motivation as extending along the continuum, from most to least autonomous (2000, p. 62). Intrinsic motivation refers to "doing something because it is inherently interesting or enjoyable," while extrinsic motivation refers to doing something for its instrumental value, "because it leads to a separable outcome" (2000, p. 55-60). This continuum model of motivation acknowledges that motivation to learn is a more subtle construct that the intrinsic/extrinsic dichotomy typically suggests.

Ryan and Deci (2000) identified self-determination as the factor that distinguishes what they call "impoverished forms" of motivation from "active, agentic" ones (p. 56). While intrinsic motivation is clearly "active and volitional," Ryan and Deci identify several types of extrinsic motivation, distinguished by the degree of self-determination involved, that can also result in high quality learning because students have "internalized the responsibility and sense of value for [their] extrinsic goals" (p. 56). Students can, for example, be internally regulated even while they pursue learning that they do not find intrinsically interesting.

Since motivation exists "in the relation between individuals and activities," students' motivation for learning can vary by context and subject-area (Ryan & Deci, 2000), and can be influenced by the learning environment students encounter, whether at the program, course, or classroom level (Ames, 1992; Ryan & Deci, 2000; Young, 2005). Since my research is concerned with my participants' experiences studying science within the Mainstream and the InterScience programs at LRU, I make no claims as to the students' overall learning motivations. Following Ryan and Deci (2000), I assess students' motivation through their self-reports of interest and enjoyment of "domain" focused activities, where the domain of my interest in undergraduate science education. Further, I seek to identify the "social and environmental factors that *facilitate* versus *undermine*" (Ryan & Deci, 2000, p. 57, original emphasis) the students' motivation.

Students' motivations for studying science

All of the participants in my study were pursuing a Bachelor of Science degree as a means to an end, and not as an end in itself. Like Keith, my study participants wanted their university education to have a purpose beyond earning the credential of a degree.

> I had to find a really good reason for why I was getting an education. I'm not just going to university to get a -- degree. There's a reason for it. <Keith>

Diane, Farah, Keith, Kuri, Melanie, and Sarah all had instrumental goals in mind for their undergraduate science education, but they nevertheless approached their degree with a learning orientation characterized by "a preference for challenging work and risk taking, an intrinsic interest in learning activities, and positive attitudes toward learning" (Ames, 1992, p. 262). They demonstrated a strong desire for autonomy and self-determination and they identified with the value of learning science. Amalie, Todd and Margaret, the three remaining case study students, differ somewhat from the others in terms of their reasons for pursuing a Bachelor of Science degree. Amalie and Todd came to LRU for primarily intrinsic reasons. Todd wanted to understand urban air pollution, while Amalie sought personal growth – she wanted to expand her own capabilities, to explore, to discover new things and to pursue her passion for science. Margaret, in contrast to all the other students, was not self-determined in her motivation. She came to LRU with a history of seeking external approval, wanting to "prove" that she was intelligent.

As I described in Chapter 4, Margaret attended LRU as a mature student, having experienced and become alienated from Mainstream science education during her first degree. Margaret recalled that at the start of her first degree she had wanted "to get stocked up on scientific language and knowledge" so that she could "be more intelligent." As she began taking classes at LRU, Margaret still wanted the status of an MD designation but her motivation for learning had begun to change. She demonstrated more autonomy and personal identification with her learning by taking an InterScience course for interest, and as she talked about her eventual decision to pursue an InterScience degree, Margaret expressed a growing desire to engage deeply with science. She wanted to explore the creative side of science by discussing and arguing ideas back and forth with people, and she wanted to "develop [her] own body of research."

Regardless of whether they came to LRU for primarily extrinsic reasons or primarily intrinsic ones, all the participants in my study demonstrated a strong desire to pursue their interests and to control their education. Ryan and Deci (2000) note that autonomous motivation is associated with "greater engagement (Connell & Wellborn, 1990), better performance (Miserandino, 1996), less dropping out (Vallerand & Bissonnette, 1992), higher quality learning (Grolnick & Ryan, 1987), and greater psychological well-being (Sheldon & Kasser, 1995), among other outcomes" (p. 63). Ryan and Deci also note that interest, value, and effort can be "systematically catalyzed or undermined by parent and teacher practices" (p. 55), since students can experience externally regulated behaviour as controlled and alienated. An emphasis on grades over learning, for example, can reduce motivation and the use of self-regulated learning strategies (Ames, 1992). This reduction was apparent in Sarah and Diane's comments about "falling into" surface approaches to learning. Motivation influenced the InterScience students' approaches to learning by influencing their persistence, the quality of their engagement, and their self-perceptions as learners (Ryan & Deci, 2000).

Students' preferred approaches to learning

The InterScience students rejected conceptions of learning as primarily reproducing, and instead they conceived of learning as primarily seeking meaning (Marton & Booth, 1997). Drawing from Marton, Dall'alba, and Beaty (1993), Marton and Booth (1997) categorized conceptions of learning as (a) increasing one's knowledge, (b) memorizing and reproducing, and/or (c) applying, to be "learning as primarily reproducing," whereas they defined conceptions of learning as (d) understanding, (e) seeing something in a different way, and/or (f) changing as a person, to be "learning as primarily seeking meaning" (p. 38). The participants in my study certainly wanted to increase and apply their knowledge, but they consistently rejected conceptions of learning as either memorizing or reproducing. Instead they came to LRU seeking understanding and meaning.

Learning that is concerned with seeking meaning and connection must be approached deeply (Marton et al., 1993; Ramsden, 2003). Deep learning implies a relation of meaning between the student and the learning, evidenced by an intention to understand and a holistic approach to learning (Ramsden, 2003). Ramsden (2003) identifies the acts of relating "previous knowledge to new knowledge," relating "knowledge from different courses," relating "theoretical ideas to everyday experience," distinguishing "evidence and arguments" and organizing "content into a coherent whole" as defining features of a deep approach to learning (p. 47). They are also defining features of the learning practices valued by the InterScience students, who clearly preferred to approach their learning in a deep way.

This section has discussed the students' motivations for pursuing an undergraduate degree in science, as well as their preferred approaches to learning. In the following section I discuss how the students experienced their positioning within the figured worlds of Mainstream science and InterScience, and how this positioning either undermined or enabled their desire for autonomy, self-direction, and the search for meaning.

Students' experiences of positioning

Positioning within Mainstream science

As I explained in the Practice section of this chapter (Section 5.1), the InterScience students located themselves outside of what they perceived as the narrow and limited domain of single-discipline science degrees. Instead, they valued multiple meanings, possibilities, and perspectives. The students experienced as a form of marginalization the positioning of their interests as "minor or elective" within the Mainstream science program structures. Further, the InterScience students not only had clear expectations of what they wanted to learn and why, but also of how they wanted to learn. The InterScience students experienced a significant conflict when the Mainstream science courses positioned students as passive recipients of knowledge.

My study participants' descriptions of the Mainstream science courses were remarkably consistent with what Carlone (2004) has called "prototypical science education practices." These practices include:

> Transmission models of instruction; boring, repetitive tasks (e.g., verification laboratory activities, defining vocabulary words from a list in the book); a tacit or explicit privileging of dry, technical rational discourse; a tacit or explicit denigration of students' knowledge and ideas; (…) and the narrow disciplinary view of the science curriculum (…). (Carlone, p. 394)

Carlone noted that prototypical science education practices reproduce what Calabrese Barton and Yang (2000) call the "culture of power" in science education. Calabrese Barton and Yang note that this culture of power is evident when teachers and texts control what knowledge counts, when "classroom activities fail to reflect the 'real work' of scientists," when science appears "fact-oriented, (…) decontextualized, objective, rational, and mechanistic," and "where there is a push toward one right answer" (p. 876). This culture is "restrictive, demanding conformity to a narrow set of norms and expectations" (Barton &

Yang, 2000), expectations that include a disciplinary view of science, received knowing on the part of students, and a view of science as a static knowledge base.

Sarah described a "typical" science course in the following way:

> You've got a midterm worth between thirty and forty percent and then your final is worth the remainder. There are no assignments and if you have a lab you're lucky, because those are a rarity. // [If you do have assignments, they] are like here is your problem, give me a numerical answer. Big deal, you can get that from the textbook. // And this is a common complaint: class sizes and the anonymity of your professors. I hated that. … I don't want to be just a number, you know, in a class full of five hundred people. <Sarah>

Sarah expected to approach learning in a deep way, but she perceived her role in the Mainstream science degree classes to be narrowly defined. She was a number, a nameless individual who was to attend classes, receive information, and memorize it on her own. Sarah became frustrated when she found herself adapting her approach to learning to fit the learning environment she faced.

> [It] encourages people to cram at the very last second and just stuff all this information in your head and I don't know anybody who learns that way. You can learn for a test, but you're not learning for yourself. So, sure enough, I fell right into that pattern. That's exactly what I would end up doing because there's no reason or encouragement between that time from the beginning of school until the midterm, and then that other block between the midterm and the final --- to really keep up and keep an active interest in what you're studying. [And] it's so general, it's really not specialized and you're studying a lot of stuff you really don't want to know about anyway, so there's no encouragement or motivation there. <Sarah>

Similarly, Diane described her frustration during lecture courses.

> I think it's frustrating when you realise that lecture courses don't work really well because you're pretty much just regurgitating, or trying to just look at material, take notes, go home, and -- you do learn procrastination because of midterms. [It's] just the way university works, especially in a big scale university …. Even though you plan on it not being [that way] but because you have so many things you have to do, [you just] cram at the last minute for your exams, and you don't get as good an opportunity out of the experience to actually enjoy the material …. <Diane>

By encouraging surface approaches to learning, the pedagogical structures in the Mainstream science courses positioned students as received knowers. This positioning influenced my study participants' approaches to learning, shifting them from deep to surface. The students resented being positioned that way:

> We shouldn't just sit there, absorb, and then put it on paper, and be a number. We should actually be discussing and arguing ideas back and forth with other people. <Margaret>

The participants in my study didn't want to learn through memorization or by receiving knowledge. They wanted to work hard, to question things, and to be challenged in return. Amalie, for example, described her ideal learning environment as one that encourages students to work together "instead of against each other, [so that] they end up getting better results and probably learning more too." Amalie acknowledged that finding the right balance between competition and cooperation could be difficult, but she felt that anything would be better than the classes where "you come in and the [professor] says I've been told by the Dean that I'm supposed to give so many A's, so many B's, so many C's, and so everybody freaks out and is like, Ha, you're the one who's going to get the C, not me."

Interestingly, the students did not necessarily blame the professors nor claim that they were not good instructors.

> I just find they're a little bit … set in their ways. I mean, they dish out the information that I have to learn for the exam. Some of them are better at doing that than others in terms of what they use, you know, visual aids, etcetera, maybe they just have a knack for explaining things better, but still, the bottom line is that's what they're there for: to just throw out a bunch of information at you like that. <Sarah>

Diane similarly described the role of professors in the Mainstream science program as "walking textbooks." The students' perceptions of the role of their professors, and their experiences of the pedagogy in most of their Mainstream science courses ran counter to the way these students wanted to learn, in the processes creating barriers to the students' satisfaction of what they wanted to learn and why. My study students understood that integration would not just happen, that it required explicit work on their part, and they wanted their chosen courses to help them engage in the process. The students responded to the conflict they experienced between the kind of students they wanted to be, and the kinds of students they were positioned as, by disengaging from their education.

When the Mainstream science specializations positioned the students as passively compliant and extrinsically motivated, the students experienced a sense of alienation. Further, because of the particular kinds of science learners that the InterScience students wanted to be, they experienced a sense of difference from their Mainstream peers. Nancy explained in her interview that "it's kind of hard when you're just solo and you've got this -- view on education, this is how it should be -- and you're the only one [who] thinks that way."

Keith could see other students who seemed to be satisfied fulfilling the role of knowledge receivers, taking courses only because they had to, complying with degree requirements and investing nothing of themselves in the process. In contrast, Keith saw no "point" in attending university unless he could experience a feeling of choice in what he was learning and therefore internalize the value of why he was learning it. Keith left the university a few times prior to applying to the InterScience program because he felt he hadn't found "a good reason" for getting an education. For Keith, a "good reason" was one that he had chosen and could personally invest in.

> It's a process of finding purpose. It's … an emotional thing, … a personal investment in why you're taking this [course or program.] You could be taking a course because you have to, technically, but [when] that's what you've specifically chosen to do [then] you have [found] some sort of purpose in it. Like, I take a lot of math classes and sometimes it gets a little dry, but at least I know I'm there to learn something a little bit more …. Some people, I can see, they're just waiting to get out [of] it. <Keith>

Similarly, Todd described meeting "a lot of [students] that didn't really know what they wanted to do, but they were doing the degree," and unlike those students, Todd wanted his degree to have a focus. He didn't want to "just skate through" his undergraduate education. Further, Amalie noticed that her Mainstream science classmates seemed to want to treat the university "like a factory," where they're in a "frenzy to get in (…) and get out," and they "don't really get a chance to think." She understood that a lot of students come to university "because they need a degree and then they want to get a job and a house and a car and to-do," but she wanted to "get out, and try to do different things, and talk to friends, and explore – not for an ultimate goal, but more for personal growth." Amalie enacted her intrinsic interest in learning when she took a year off to do research in a lab, with no expectation of earning degree credit for the experience.

The participants in my study did not experience a clear sense of purpose and of belonging in the Faculty of Science before entering the InterScience program. Instead, they experienced a sense of difference because of their motivations for studying science and their perspective on science learning. It wasn't until they took their first InterScience class and started talking with other InterScience students that the participants in my study realised they were not alone. When she met other students who shared her perspective, Nancy said it felt like a "pat on the back" that reinforced her belief in her education. The participants in my study experienced a sense of connection with people who, as Margaret explained it, "mix stuff up" – that is, with people who integrate the sciences. InterScience classes provided spaces where this connection was formed.

Positioning within InterScience

My study participants' descriptions of Mainstream science courses were remarkably consistent. So too were their descriptions of InterScience courses. All of the students claimed that if they walked into a random class on campus, they would be able to tell if they had walked into an InterScience course. The room and class size would be small (20 – 40 people), and people would be interacting. Amalie noted that the desks would likely be in a circle, "to bring the group together and talk and share." Most of the seats would be full, because "you have to be there for the group activities, and there would be a lot of questions about [individual] projects with the teacher" <Margaret.>. The instructors would seem "excited about what they're teaching" and it would seem as though they were "learning along with" the students <Sarah>, asking questions that they don't already have the answers to <Keith>. If they weren't talking one-to-one with a student or a small group of students, the instructors would likely be at the side of the room, listening and asking questions while students present. They would know the students by name <Sarah>. The group would be "willing to learn and mix things and to challenge other people's thoughts" <Kuri>, yet no one would seem to "feel stupid, or like they're going to be judged" <Keith>. It wouldn't be immediately clear what the course topic was, since the discussion might range from "the evolution of human beings to the pharmacology of some drugs," and it wouldn't "really add up unless it's InterScience" <Farah>.

In contrast to the students' experiences of being positioned as nameless numbers in the Mainstream science program and courses, their experiences of positioning with/in the InterScience program were ones of recognition. To put it simply, the students felt like people. This feeling of recognition was initiated by the program application process that, by pairing students with an advisor/mentor whose role is to help students figure out what they want to learn, positions students as people whose interests and educational needs matter. The feeling of recognition was reinforced, as Margaret's comment shows below, by the small size of InterScience classes:

> This is very simple – in a small class you feel like a person but in a big class you feel like a number. <Margaret>

In-course discussions with faculty members and peers also helped the students to feel heard. Sarah described an InterScience assignment that asked her to "read two papers, and then … hand in a … question that I had after reading the papers … and some type of comment," that could be anything from what she thought about something that was mentioned in the paper to a thought that she "conjured up because of the paper." The key point, for Sarah, was that she was asked to show that she has an opinion.

> You can show … that you're not some - machine just cranking out answers to things. You actually have a brain, you have - a thought about this, you have an opinion about this - and that just shows that you're able to think on a higher level. <Sarah>

Sarah experienced that InterScience assignment positioning her as an active, thinking agent who had the potential to contribute to the generation of knowledge. As Sarah explained:

> Someone who can question things like that is going to be able to come up with new questions to answer. And while you have to answer those new questions in a scientifically accepted way, you wouldn't have been able to think them up in the first place if you weren't able to think outside the box that way. <Sarah>

Similarly, Margaret explained that because her point of view was taken into consideration through journaling and in-class discussions, she experienced an enhanced sense of self-confidence:

> It starts encouraging you to think as if you are a researcher, as if you are already like a TA or a teacher [who is] developing your own body of research, instead of just learning the information. // It's not that you're right or wrong. Curiosity and questions are encouraged. <Margaret>

The InterScience students experienced the InterScience program positioning them as active agents in their own education, capable of and expected to know what they wanted to learn, to plan their education in order to achieve their aims, and to contribute to the generation of new, integrated knowledge. The participants in my study found the self-determination and choice they craved through the InterScience program. The program allowed the students to be in charge.

> If you're a student in charge of integrating biology and physics, you decide what level you want to look at. You decide what two areas of knowledge you want to combine. <Margaret>

The role of the InterScience program advisors was to support students through the process of determining what they wanted from their education and to enable, through strong advising, the students' self-determination.

Discussion of students' positioning

Ryan and Deci's (2000) self-determination theory asserts that behaviours are motivated by three psychological needs – "namely, the innate needs for competence, autonomy, and relatedness" (p. 57). These three needs emerged repeatedly in my study participants' expectations for their post-secondary science education. The InterScience students expressed a strong need to experience agency and control over what and how they were learning. Further, the students wanted to approach learning in a deep and connected way. The students in my study were seeking meaning through their science education, and they were unable to learn that way within the Mainstream science culture of power. This culture prevented the students from experiencing a clear sense of purpose or of active participation in their own education. Their desire for agency conflicted with the ways in which the Mainstream program positioned the students as passive recipients of an education. The students experienced a conflict between this positioning and the kinds of science learners they wanted to be. In contrast, the InterScience program positioned the students as self-determining agents, thus enabling the satisfaction of these needs. Melanie expressed the thrill the students experienced at being able to tailor a degree around what they wanted to learn:

> It was the most wonderful idea I heard since coming to school. [laughing] It's like, "finally, I can do it my way." <Melanie>

My analysis of the students' desire to follow their interests and to experience a sense of ownership over their education has revealed a key feature of the InterScience program: *giving students choice and control over their learning*. Ryan and Deci (2000) noted that "choice and the opportunity for self-direction (e.g., Zuckerman, Porac, Lathin, Smith, & Deci, 1978) appear to enhance intrinsic motivation, as they afford a greater sense of autonomy" (p. 59). This is evident in my study participants' descriptions of their experiences. For example, Keith disengaged from university science education when he was unable to find purpose or meaning in what he was studying. Keith re-engaged when he found the InterScience program, and in particular, when the InterScience program enabled choice and self-direction in his learning. After joining the InterScience program, Keith remained intrinsically interested in some course topics and extrinsically interested in others, but in all cases he was taking the courses by choice and that made all the difference in how he experienced his education.

It is important to understand the students' motivation for learning because it contributed to their disengagement from the Mainstream science program and their subsequent (re)engagement through the InterScience program. Students' motivations for learning influence, and are influenced by, what they learn and how they learn (Schunk & Zimmerman, 2008). The participants in my study experienced the Mainstream science program as controlling what students should and could learn, whereas the InterScience program transferred that control to the students, enhancing their sense of autonomy and hence their "active and agentic" motivation for learning (Ryan & Deci, 2000, p. 56).

My aim in this section was to address the following research question: *How do undergraduate students experience their positioning in disciplinary and interdisciplinary science degree programs?* The structures of the Mainstream science program placed the locus of control over students' education with faculty members and departments. By being denied the opportunity to pursue their own interests, the students perceived that the university expected them to study for extrinsic, instrumental reasons – that is, to "just get a degree" <Todd>. When the faculty-controlled programs emphasized disciplinary knowledge, the students understood that their interest in integrating the sciences was not valued. When the locus of control was with the faculty, the students perceived an expectation that they were to surrender agency and thought. The students rejected being positioned as externally regulated, single-discipline valuing students with no sense of agency. The InterScience program placed the locus of control with the students, supported by faculty, thus enabling students to pursue their interests and to experience control over their education. The

InterScience program valued, recognized and welcomed the kinds of students (Boaler & Greeno, 2000; Gee, 1999; Shanahan, 2007) my study participants wanted to be, positioning them as active, self-determined learners. As I will argue in the next section, the InterScience program also positioned the students as competent and connected learners.

5.3 Identity

My analysis has, to this point, shown that the InterScience students wanted the opportunity to negotiate the meaning of their education, to pursue their interests and to experience control over what they were learning. In this section I address my third research question: *What identities do students develop through their participation in disciplinary and interdisciplinary science degree programs?*

From a socio-cultural perspective, when learning "transforms who we are and what we can do, it is an experience of identity" (Wenger, 1998, p. 215). Further, Wenger writes that learning, as an experience of identity, is:

> Not just an accumulation of skills and information, but a process of becoming or avoiding becoming a certain kind of person. …We accumulate skills and information, not in the abstract as ends in themselves, but in the service of an identity. It is in that formation of an identity that learning can become a source of meaningfulness and of personal and social energy. (p. 215)

The InterScience students not only wanted to engage in the practice of interdisciplinary synthesis, they wanted interdisciplinary understanding to be a part of who they are. Interdisciplinary and integrative thinking define a clear aspect of the identities constructed by the participants in my study through their participation in the InterScience program.

The InterScience students repeatedly positioned themselves front and centre (literally) in the process of integrating the sciences. Keith, for example, described integrated science as "building a personal connection between areas of science."

> You would be like 'Oh, there's this area, there's this area, and there's me and I'm trying to bring them together.' I guess that would be the general thing of it, --- it's sort of like you see some gap between two things and you personally see yourself filling the void. <Keith>

Sarah identified herself as "one of those people" who "see[s] the positive nature that is associated with being able to look at a few different sciences rather than just one in depth and see how those relate to each other." Her rationale for taking this perspective was that it "enables you to see things on a completely different level than if you just spend your whole life studying one particular thing." Sarah and Keith clearly differentiated themselves, and their fellow InterScience students, from those who Sarah described as "super specialized in things."

Shanahan (2007) noted that

> the social structure and power relations within a community of practice may encourage participation by certain individuals and discourage the participation of others based on how able and willing they are to become the type of person valued in the community. (p. 12)

The participants in my study were unwilling to become the type of students that they perceived the Mainstream science community valued: students who were satisfied with being told what to learn and why, with studying a single discipline alone, with studying for the purpose of acquiring a degree, or with receiving knowledge and taking a surface approach to learning. The students in my study did not "aspire to participate in" the practice of disciplinary science specialization (Shanahan, 2007, p. 12) and they were unwilling to adopt the values and attitudes of the disciplinary-science student community (Johannsen, Linder, & Rump, 2009). The students also believed that the structures and power relations in the figured world of Mainstream science discouraged their participation as the kinds of students they *were* willing to be. The students experienced their lack of connection, and consequent non-participation in the community of disciplinary science students, as a "form of social exclusion" (Johannsen et al., 2009, p.53) that lead some of them to temporarily decide to leave their science studies altogether.

Brickhouse (2001) noted that learning, as seen from a situated cognition perspective, is "a matter of deciding what kind of person you are and want to be and engaging in those activities that make one a part of the relevant communities'' (p. 286). The InterScience program enabled my study participants to (re)engage with their undergraduate science learning by constructing identities of belonging in relation to a community of interdisciplinary science understanding. Kuri, for example, felt like she was among friends in the InterScience program, free to be herself:

> [Interdisciplinary, to me,] means -- just fun and freedom. Being free and - having a lot of choices and happiness and motivation and having a goal. I love going to classes. It feels like I'm hanging out with friends almost. You know? I love seeing [InterScience faculty members], they're both nice and -- I talk to Keith all the time and it just - it's like hanging out with my friends at a coffee shop. <Kuri>

Kuri found that she didn't have to change herself to fit into the InterScience program, and finding that acceptance altered her experience of undergraduate science education. She started "living [her] university life the way she really wanted to" and no longer felt as though she was "wasting her time" at university.

My study participants described learning though the InterScience classes as not only helping them to engage deeply in their learning, but also helping them to re/form and sustain their science learning identities. For example, the difference Margaret experienced between the InterScience courses and the Mainstream ones helped, in part, to change the way she understood herself as a learner. Margaret singled out the use of learning journals in her first InterScience courses as helping to change the way she understood herself as a student:

> Doing the journal in [my first InterScience course,] and then doing it in another course, and now I'm doing it in another course as well, I just see myself on the level with – not textbook writers, but other book writers. So I value my own opinions and curiosities about the material more than if I hadn't written [it] down. --- It's just increased my confidence level in what I have to offer, instead of feeling like a student that needs to do what the teacher says and that doesn't know that much because the teacher knows everything. <Margaret>

The change in Margaret's self-confidence and her way of knowing was mediated in large part by the pedagogical practices of the InterScience courses and the learning environment they offered her. The change, Margaret explained, came about through interaction with science ideas in her learning journal, with her teachers and with her peers in classes, and with the broader science community in research journals. Margaret found these interactions meaningful because they allowed her legitimate peripheral participation (Lave & Wenger, 1991) in the practice of interdisciplinary science understanding. Interaction enhanced Margaret's sense of confidence because her point of view was taken into consideration. "It's not that you're right or wrong" in the InterScience classes, Margaret explained, "curiosity and questions are encouraged. It's not just a question that's thrown out for an 'interactive' course and then answered by the professor [laughing]."

Being asked a genuine question and feeling heard seemed like a small thing to Margaret, but as she told me, it was "enough. The pedagogical structures in the InterScience courses acknowledged and validated Margaret's changing learning orientation and her preferred way of knowing. She began to feel like a person rather than a number, and in the process of generating, writing and connecting ideas, Margaret wrote herself. This sense of being a legitimate peripheral participant – of having the opportunity to gain experience and competence integrating the sciences and of being recognized and validated through InterScience course and program structures – emerged in several of the students' stories.

For Diane, InterScience courses meant that she was able to "see the mindset of biochemistry students versus the mindset of genetics students" and then to see herself "in the middle of both of them." Diane proudly explained that because of her experience integrating biochemistry and genetics, she was "able to understand" and work in a summer immunology research lab even though she had not taken any immunology courses. Diane's experience integrating biochemistry and genetics to understand immunology helped increase her self-confidence in both her degree (in the value of integration) and in herself as a potential scientist. She began imagining herself as a graduate student, expanding her sense of what was possible.

> I think InterScience allows you to grow as a person more than just being guided and led [to do] the disciplinary-based courses and schedules that are already made up for you. Because {it's easy to say sometimes} "Oh I have to take this course, so this is why I'm not doing well," and – well no, you chose this course so this is your responsibility {so/to} take responsibility for your actions. [laughing] It helps you to grow on a bigger personal level, just to become an adult I guess, in a way. <Diane>

Applying Tonso's (2006) model of identity production, it is clear that the students in my study came to the Faculty of Science at LRU with strong science-student identities. Tonso conceived of student engineering identity production as a "complicated process that bound[s] up *thinking about oneself as an engineer*, *performing an engineer self*, and ultimately *being thought of as an engineer"* (p. 273-4, original emphasis). The students in my study graduated from high school considering themselves to be "science people," they had performed well in high school science courses and/or in science fairs, and they had been recognized through awards, grades and admission to LRU's Faculty of Science as strong science students. Further, once my study participants arrived at LRU they performed identities of students who were interested in science and who were motivated to learn because of this interest.

Once at LRU, the students constructed identities of opposition to Mainstream science. From interactions with prescriptive course requirements, didactic teaching practices, distant faculty, and peers who seemed content to study within a single discipline, the participants in my study construed what it meant to be a Mainstream science student: Mainstream students thought of themselves as pharmacy students, or microbiology students, or students who were "super-specialized in things" <Sarah>; they attended university in order to gain a credential, and they put as little effort into the process as possible; they were competent at knowledge reception and repetition, at following instructions, and at memorizing information; they were content to work alone and wanted to gain in-depth knowledge in a single area of science; and they were thought of, by Mainstream faculty, as passive learners, incapable of generating knowledge. The participants in my study refused to accept the process of becoming Mainstream science students. They wanted to "mix stuff up" <Margaret> and the InterScience program gave them the opportunity to do so.

Solomon (2007) noted conflicting communities of practice within which undergraduate students can be positioned, and she argued that the requirements for successful participation in a community of undergraduate learners may be quite different, and in practice conflict with the requirements for successful participation in the broader discipline of mathematics. My research extends and complements Solomon's work by arguing that the requirements for successful participation in a community of discipline-based undergraduate learners may be quite different, and in practice conflict with the requirements for successful participation in an interdisciplinary science community. As a result, the most 'successful' undergraduate students may be those who are least enabled to legitimately participate in interdisciplinary science understanding, while those who are best aligned with interdisciplinary science understanding may be least successful in discipline-based undergraduate programs and courses, and thus least likely to 'make it through' to practicing interdisciplinary science. Faced with the conflict between the requirements for success in the Mainstream science program and her own personal alignment with interdisciplinary science, Kuri considered dropping out and, for a while at least, Todd, Margaret and Keith actually did. They only (re)engaged with their university studies after finding InterScience.

If, as Wenger (1998) argues, learning is the "vehicle for the development and transformation of identity" (p. 13), the students in my study learned that they didn't belong in Mainstream science. The students resolved their non-participation with/in undergraduate science by changing the community in which they situated their science-student learning practices. They found with/in the InterScience program a community of practice to which they could identify and belong, and they became what Belenky and her colleagues (1986) term *passionate knowers* who value *constructed* ways of knowing:

> Exposed to the methodologies of several disciplines, acquiring the analytical skills and methods of each, they experience themselves as investigators and search for truths that cut across the interests and biases that lie within a single disciplinary perspective. Unlike procedural knowers, who remain subservient to disciplines and systems, constructivists … [put] systems to their own service. They make connections that help tie together pockets of knowledge. There is a new excitement about learning and the power of the mind. (Belenky et al., 1986, p. 140)

5.4 Summary

My analysis of the students' expectations and experiences has shown that the InterScience students wanted to relate different areas of science in order to be able to frame, understand, and contribute to solving specific and complex problems. They wanted their education to mean something and to allow them to make a difference by coming to know science as an integrated practice and not just gaining isolated, discipline-specific scientific knowledge. In order for this to happen, the students wanted to choose and control what they would learn, to learn actively and interactively with their peers and their professors, and to be recognized as individual participants in a community that values integration of the sciences. The students experienced the structures of the Mainstream science program and the pedagogies of the Mainstream science courses as barriers to the successful fulfillment of what they wanted from their undergraduate science education.

The structures of the Mainstream science program placed the locus of control over students' education with faculty members, positioning students as passive recipients of knowledge. When the locus of control was held by faculty, the students experienced a loss of agency and recognition, and when the faculty-controlled programs emphasized disciplinary knowledge, the students understood that their interest in integrating the sciences was not valued. By being denied the opportunity to pursue their own interests, the students perceived that the university expected them to study for externalized, instrumental reasons – that is, to "just get a degree." When course pedagogy emphasized individual work, isolation, and rote memorization, the students experienced a further loss of connection and recognition.

The participants in my study believed that science is inherently interdisciplinary, and they undertook undergraduate science learning in order to gain interdisciplinary science understanding. To gain this understanding, the students wanted to participate in learning practices that would allow them to access insights from multiple disciplines and to integrate those insights in the generation of new knowledge. The InterScience program and pedagogies enabled their participation. The InterScience program addressed the students' expectations in four critical ways, by providing:

1. program structures that enable students to draw insights from multiple science disciplines;
2. pedagogical practices that provide explicit opportunities to learn how to integrate the sciences and to participate in the practice of science integration;
3. program structures that position students as active agents by placing the locus of control over students' learning with the students, and
4. pedagogical practices that afford deep learning, the generation of meaning and legitimate peripheral participation in a relevant community of practice.

The InterScience program provided my study participants with opportunities to gain experience and competence in the practice of interdisciplinary understanding. Returning to my study's theoretical framework, the InterScience program provided my study participants with (a) a community of interdisciplinary science practice, (b) opportunities to gain competence in the practices of that community by providing explicit opportunities to learn and practice the skills of knowledge integration, (c) recognition of legitimacy in both the students' forms of participation and in the practice itself, evident through participatory pedagogies and program structures that expect self-determination, and (d) opportunity for competent participation in the practice of interdisciplinary science understanding. Wenger

(1998) writes that “practice is, first and foremost, a process by which we can experience the world and our engagement with it as meaningful” (p. 51). My analysis has shown that for my study participants, a meaningful education is one that leads to the development of interdisciplinary understanding and the formation of an interdisciplinary science student identity.

Chapter 6 Summary, Future Research, and Conclusions

My research explored students' experiences of participation in InterScience, an undergraduate interdisciplinary science degree program at LRU. I analyzed the students' pathways into interdisciplinary science by comparing the students' expectations for their undergraduate science education with their stories of experience in the Mainstream science program and the InterScience program. My analysis of the students' expectations indicated that the InterScience students[12] enrolled in an undergraduate science degree in order to gain interdisciplinary science understanding. These students viewed science as inherently interdisciplinary, and wanted to participate in practices that would allow them to engage in science as an interdisciplinary way of knowing and doing. They found the structures and pedagogical strategies of Mainstream science *limited participation* in the practices of interdisciplinary science understanding, whereas the InterScience program structures and pedagogies *enabled participation*.

In this chapter I summarize my research findings by revisiting the questions that guided my research and framed my analysis.

Research Objective:

What are students' experiences of undergraduate interdisciplinary science?

Research Questions:

A. What learning practices are valued by undergraduate students who chose an interdisciplinary science degree?
B. How do undergraduate students experience their positioning in disciplinary and interdisciplinary science degree programs?
C. What identities do students develop through their participation in disciplinary and interdisciplinary science degree programs?

To answer these questions I looked at two particular programs, the Mainstream science program and the InterScience program at LRU. I present my conclusions by first

[12] By "InterScience student", I mean the participants in my case study research. I do not intend, nor claim, that my conclusions apply to all students who register in the InterScience program.

summarizing the findings for each of my research questions, and then by addressing my overall research objective. I also discuss the implications of my study and make suggestions for further research.

6.1 Summary

Question A: What learning practices are valued by undergraduate students who choose an interdisciplinary science degree?

My study found that students who pursue an undergraduate degree in the InterScience program at LRU value learning practices that lead to insights from multiple science disciplines and that facilitate interdisciplinary understanding. My study participants view interdisciplinary understanding as a way of knowing that can lead to the generation of new insights. The students' expectations for their education correspond almost directly to four "core premises" that underlie the "stringent definition" of interdisciplinary understanding developed by Boix Mansilla and the team at Harvard University's Project Zero. The four core premises are: *disciplinary grounding*, *integration*, *purposefulness*, and *performance* (Boix Mansilla, 2005).

My study showed that students who chose an InterScience degree value the practice of grounding their learning in the disciplines. Boix Mansilla explains that interdisciplinary understanding, rather than being "naïve common sense," is "deeply informed by disciplinary expertise" (p. 17). As my analysis has shown, the InterScience students recognize this premise. They do not reject discipline-based science learning altogether. Rather, they want to access insights that have "survived the scrutiny of [discipline-based] expert communities" (Boix Mansilla, 2005, p. 17), and they value the practices of gaining and integrating the perspectives from multiple disciplines.

The InterScience students understood integration as an active process of combining, relating, or interweaving different knowledge systems for the purpose of solving problems. They were seeking coherence, connections, and relations among the disciplines in order to generate new knowledge. The students' valuing of relational knowing aligns with the second and third premises underlying Boix Mansilla's definition of interdisciplinary understanding, namely integration and purposefulness. Boix Mansilla states that "the integration of the disciplines is not an end in itself but a means to achieve a cognitive advancement" whereby disciplinary perspectives "are not merely juxtaposed," but rather they "actively inform one another, thereby leveraging understanding" (p. 17). My analysis shows that the InterScience students wanted to be active participants in the practice of integrating the science disciplines. The students held what Boix Mansilla called a "performance view of understanding—one that privileges the capacity to use knowledge over that of simply having or accumulating it" (p. 16).

Students who participate in the InterScience program value procedural knowledge but lean towards constructivist ways of knowing and deep approaches to learning. In expecting to generate and evaluate multiple insights, the InterScience students demonstrated that they value what Belenky, Clinchy, Goldberger and Tarule (1986) have called constructed knowledge, or what Wenger (1998) refers to as *knowing,* (as opposed to knowledge). According to Wenger, "knowledge is a matter of competence with respect to valued enterprises – such as singing in tune, discovering scientific facts, fixing machines …," whereas knowing is "a matter of participating in the pursuit of such enterprises, that is, of active engagement in the world" (1998, p. 4). The InterScience students wanted to integrate the disciplines and to actively engage in the world of interdisciplinary science. This was evident through their expressed preference for constructed ways of knowing, and their rejection of pedagogical strategies that asked them to "recall, retain, and recount" information (Sarah, interview).

Elements of the Mainstream science program create barriers to the learning practices that are valued by InterScience students. The Mainstream program's prescriptive course requirements create barriers to accessing knowledge from multiple science disciplines and to participating in the practices of science integration. By requiring specific courses and limiting others to electives, the Mainstream specializations can marginalize students' desire to pursue their interests and to access insights from multiple science disciplines. In addition, the large-groups and didactic pedagogies adopted in most Mainstream science courses can isolate students from one another and from faculty members, presenting further barriers to the generation of cross-disciplinary insights. Finally, learning practices that encourage received knowing present barriers to legitimate peripheral participation in the practices of science integration. The InterScience students experienced these barriers as alienating.

Elements of the InterScience program *enabled* access to learning practices that are valued by InterScience students. The InterScience program's application process and course pedagogies enable access to multiple science disciplines and foster student participation in the practices of science integration. The Program's application process asks students to choose courses from multiple science disciplines and facilitates students' envisioning of an interdisciplinary science education. InterScience courses enable access to multiple science disciplines by bringing together students from a variety of disciplinary backgrounds and involving them in cross-disciplinary discussions. InterScience courses further enable students' participation in the practice of science integration through the assignment of reflective learning journals, in-class discussions, and by regularly asking students to consciously integrate their learning. The InterScience students experienced each of these practices as empowering.

Question B: How do undergraduate students experience their positioning in disciplinary and interdisciplinary science degree programs?

I addressed this research question by exploring the kinds of science learners my study participants wanted to be and the kinds of science learners they experienced themselves being positioned as. To understand the kinds of learners the InterScience students wanted to be, I considered both the students' motivations for learning interdisciplinary science and their preferred approaches to learning.

As learners, the InterScience students wanted to pursue their interests and to control their education. The students were self-determined in their motivation to learn, wanting the freedom to pursue their interdisciplinary interests and the right to decide for themselves (with strong advising) what to learn.

The InterScience students wanted to approach learning science in a deep way. The InterScience students wanted to engage in the process of learning science, to pursue their passions, and to understand disciplinary science content. They also wanted to relate the different aspects of what they were learning and to make their learning meaningful. Each of these desires reflects a preference for deep approaches to learning science rather than shallow ones. Deep approaches have been defined as "including a search for personal meaning, based on intrinsic interest, curiosity and a desire and ability to relate the learning to personal experience" (Haggis, 2003, p. 94; Prosser & Trigwell, 1999).

In the Mainstream program, InterScience students felt controlled and positioned as received knowers. Mainstream science positions an interest in multiple science disciplines as "minor" or "elective." This positioning marginalizes students who wish to gain interdisciplinary understanding. The Mainstream science courses adopted pedagogies that positioned students as received knowers who needed to be told what to study and what to learn. The students experienced these positionings as alienating and disempowering. Further, the students experienced a sense of difference from their Mainstream science peers who appeared to accept their positioning as passive learners.

In the InterScience program, the students were positioned as knowledge-constructors who were in charge of their own learning. The InterScience students were seeking meaning and purpose from their education, and they expressed a strong desire for choice and control over their education. The InterScience program positioned students as agentic learners (Bandura, 1999). The program invited students to envision their education and to construct a program of study that would allow them to fulfil their vision. The program's learning practices supported students as constructors of knowledge by inviting them into open discussion and by asking them to share (and justify) their experiences and opinions. InterScience was congruent with students' orientations towards learning, and this in turn influenced the students' sense of belonging (Ames, 1992).

Question C: What identities do the students develop through their participation in disciplinary and interdisciplinary science degree programs?

During their tenure in Mainstream science, InterScience students developed academic and social identities of exclusion and disengagement. The Mainstream program positioned students as passive learners and received knowers, and these positionings ran counter to the kinds of learners the InterScience students understood themselves to be. Consequently, the students experienced feelings of indifference, alienation, and disengagement.

The InterScience students developed identities of belonging and of legitimate peripheral participation with respect to the InterScience program. Within the InterScience program, students were positioned as self-determining constructors of knowledge. Consequently, the students experienced academic and social identities of autonomy, belonging, and passionate engagement. The InterScience courses' pedagogical practices of interaction and reflection helped the students construct identities as people who integrate the sciences, enabling them to claim competence and agency. The students sought and found meaning through their participation in a community of interdisciplinary science practice (Wenger, 1998).

The InterScience students experienced undergraduate interdisciplinary science in the InterScience Program as a home. The disciplines permeate and in many ways define the identities students and faculty members construct for themselves within universities. These identities ground and are grounded upon beliefs about knowledge, the purpose of teaching and learning, and the roles of teachers and students. The InterScience students viewed integration as a "connected whole that gives coherence to its parts," that is to say, as "context" (Cole, 1996, p. 135). From Cole we learn that the Latin root for context is *contexere*, which means "to weave together." For these students, integration is an act of weaving, providing a context and coherence for that which is learned in the different disciplines. Moreover, for these students, that coherence was missing when learning was strictly discipline-based. Through participation in an explicitly interdisciplinary program, the students came to understand integration not just as a way of *knowing about* the world, but as a way of *being at home in* the world of undergraduate science.

Research objective: What are students' experiences of undergraduate interdisciplinary science?

Students in the InterScience Program experienced undergraduate interdisciplinary science as a place where they could be themselves.

InterScience students wanted to learn science in order to understand complex phenomena and to solve complex problems. They wanted to make a difference through science and to experience their undergraduate education as meaningfully related to their interests. To gain a comprehensive understanding of their problem of interest, the students wanted to approach their problem from multiple perspectives and so they believed that they needed to connect and relate specific knowledge from several different areas of science. At the same time, the students wanted to be autonomous learners – they wanted choice and control over their education.

Overall, my analysis shows that by giving students choice and control over what they would learn, and by inviting them to become legitimate peripheral participants in the community of integrated science practice, the InterScience program enabled a group of bright, keen, but deeply alienated senior undergraduate science students to re-engage with their university and to become passionate advocates for their undergraduate education.

6.2 Discussion

Wallace, Rennie, Malone, and Venville (2001) conducted a review of literature in order to identify "what we know and what we need to know about curriculum integration in science, mathematics, and technology." Wallace et al. found that "instances of successful integration are idiosyncratic" (p. 12), by which they mean that the success of curriculum integration depends more on the people involved than on the nature of the innovation. The authors also found that "integrated teaching works well in connected contexts" (p. 12), that is, teaching across disciplines works well in contexts that are team-based and where knowledge and skills are transferred from one context to another. My research in part supports Wallace et al.'s findings. The students in my study experienced themselves integrating when they were able to gain multiple perspectives by working with peers who had different disciplinary backgrounds, and when they were asked to connect learning from one context to another. My research, however, challenges Wallace et al.'s finding about the idiosyncratic nature of successful integration.

During the period of time when this study was conducted (from 2004 to 2006), the InterScience program underwent two changes of Director, a change in program administrative personnel, and changes in program advisors and instructors. Despite these changes the students' descriptions of their experiences in the program remained remarkably consistent. For the InterScience students, the success of the innovation seems to have transcended the people involved. The basis for this transcendence may well be the development of the InterScience program as what I will term a *liminal* community of practice – a community that people *pass through* on the way to somewhere else. As a community of practice, the InterScience program sustains itself through a balance of participation and reification (Wenger, 1998). The reified aspects of the program – its *application process*, the *values of supporting student choice and agency*, the *explicitly interdisciplinary intention*, the *nature of an InterScience course* – remain constant, while the participants (the people) change, passing through the program between high school and post graduate studies for the students, and between departmental-based teaching assignments for the faculty. The community of InterScience practice ensures its own continuity, while the liminality of participation in the community ensures that none of program's reified aspects depend on any given individual.

Wallace et al. further found that "we still need to know" what problem integration is addressing. My research fills this knowledge gap within the context of undergraduate science education by showing that the InterScience program is addressing the problem of student disengagement from undergraduate science education caused by conflicts between the students' expectations and their experiences with/in Mainstream science specializations and courses. Wenger (1998) defines participation in a community as engaging in the practices of the community and "constructing *identities* in relation to" the community (p. 4, original emphasis). Participation therefore requires both acting and connecting (Wenger, 1998, p. 55). The students in my study were able to act like Mainstream science students – that is, to perform the activities that were defined as worth pursuing by the Mainstream science community – but they didn't connect with what they were doing or with their peers in the Mainstream science program (Ames, 1992; Lee, 2002).

My research conclusions are supported by recent publications reporting on studies conducted in related contexts (Bennett, Hogarth, Lubben, Campbell, & Robinson, 2010; Machina & Gokhale, 2009) Machina and Gokhale (2009) found that traditional natural science pedagogy is associated with a decline in positive attitudes toward Science and Technology among 18-year old US female college students. Bennett, Hogarth, Lubben, Campbell and Robinson's (2010) recent review of the literature on small group discussions in high-school science education found that small "groups function more purposefully, and understanding improves most, when specifically constituted such that differing views are represented" (p. 69).

Approaches to learning

As reported by Trigwell, Prosser and Waterhouse (1999), research studies have shown that deeper approaches to learning are related to higher quality learning outcomes. Further, there is research evidence that undergraduate science students show a decline in the use of deep approaches to learning as they progress through their programs (Biggs, 1987). Other studies suggest that students are likely to adopt different approaches to learning in different contexts (Ramsden, 2003), and that information transmission approaches to teaching are associated with surface approaches to learning (Trigwell et al., 1999). Such studies suggest that as students progress through their degrees and are faced with traditional information transmission approaches to teaching, students may adopt surface approaches to learning and experience lower quality learning outcomes. The InterScience program seems to be reversing this trend.

I found that students came to the InterScience program wanting to learn deeply, and the program provided them with the space and the conditions in, and through which, they could. The InterScience program positioned the students as self-determining agents, enabling the satisfaction of their need for competence, autonomy, and relatedness. The program allowed students to pursue their interdisciplinary interests and to experience their education as meaningful.

Ideas surrounding approaches to learning have been critiqued, most strongly by Haggis (2003, 2004, 2009). Haggis questions the ways that the concept of approaches to learning have been used in the higher education literature. In particular, Haggis notes that in her reviews of research, the concept has gradually come to mean fixed traits or learning styles. I am not claiming that the InterScience program created deep learners, nor am I suggesting that it caused deep learning to happen, but rather that it enabled students to learn deeply.

Interdisciplinary science pedagogy

Borrowing from Hildebrand (1998), I define pedagogy as “all of those interactions between the teacher, the students, the formal and the hidden curriculum, and the resources that work together to produce the lived experience” of post-secondary science (p. 348). Case and Jarwitz (2004) write that, regarding formal education, Lave and Wenger are “of the opinion that problems with schooling (or university education) are not fundamentally pedagogical but far more related to the ways in which the community of adults reproduces itself, and with whether newcomers are able to find places in which to partake in legitimate peripheral participation” (p. 418). My research suggests that pedagogy is one of the ways in which the community of university education reproduces itself and can act to limit or enable newcomers to find places for themselves within the community. Pedagogy cannot be separated from the problems of university education. Further, Wallace et al. (2001) raise the question of whether the interdisciplinary aspect of integrated programs can be separated from their pedagogy. The InterScience students’ strong connection to the InterScience program, not only through what they want to learn but how they want to learn it, suggests that the answer to this question is, no – pedagogy and interdisciplinarity cannot be separated when the curriculum is one of integration. .

Mary Kinnick stated in her 2004 review of Caroline Haynes’ edited book, *Innovations in Interdisciplinary Teaching*, that interdisciplinary pedagogy is about “facilitating student development, and in particular, how students make meaning of their world and develop their own identity in relation to that world” (p. 278). Kinnick’s statement followed from Haynes’ (2002) introductory argument that “interdisciplinary pedagogy … is concerned primarily with fostering in students a sense of self-authorship and a situated, practical, and perspectival notion of knowledge that they can use to respond to complex questions, issues, or problems” (p. xvi). These are compelling opinions about the impacts of undergraduate interdisciplinary teaching, and ones that Myers and Haynes, in their chapter in Haynes book, *Transforming undergraduate science through interdisciplinary inquiry* (2002), support by drawing on learning theory and a review of research. My dissertation provides empirical evidence to support the claims of Myers, Haynes and Kinnick.

6.3 Implications of the Study

The InterScience students’ experiences in Mainstream science echo what Tussman wrote, in 1969, about a typical students’ university experience. According to Tussman (1969):

> The course forces teaching into small, relatively self-contained units. … [Courses] are normally in different subjects, given by different professors, and with rare exceptions, there is no attempt at horizontal integration. The effect is that … the student presents himself [sic] to the teacher in fragments, and not even the advising system can put him together. … Horizontal competitiveness and fragmentation of student attention are limiting conditions of which every sensitive teacher is bitterly aware. But there is nothing he can do about it. He can develop a coherent course, but a collection of coherent courses may be simply an incoherent collection. For the student, to pursue one thread is to drop another. [The student] *seldom experiences the delight of sustained conversations* [italics added]. He lives the life of a distracted intellectual juggler. (pp. 6-7)

The InterScience students expected their university science education to be integrated and they became frustrated and alienated when it wasn't. The InterScience program provided an educational experience that matched the students' expectations and, in response, the students re-engaged with university science learning. This finding is significant because it tells us that (relatively) minor changes to the structures and culture of degree programs can help retain talented students like those who participated in my study, allowing them to experience the *delight of sustained, integrated science, conversations*.

Implications of giving students choice and control

One of the InterScience course instructors I interviewed, who was new to the program, expressed a common concern that undergraduate students, when given a choice, are more likely to choose "fun" courses than "valuable" ones:

> One of the good things about the discipline[-based programs] is that they set up a package of things that they think, taken as a whole, are of value, and you've got to take the good with the bad. And --- very often the bad, from a student's point of view, is -- actually quite important and valuable and foundational. What worries me about something like InterScience is that it runs the risk of being a bit flashier, of giving the students a bit more freedom to select things that they think are going to be fun, of encouraging the teachers to teach in a way that sounds like it's going to be fun, and maybe losing out on some of that core-foundational stuff that isn't as fun but is pretty important to know about. <Nick, Instructor, interviewed Nov. 2007>

Certainly some faculty members, like Nick, worry that undergraduate students have neither the maturity to choose valuable courses over fun ones nor the knowledge to identify a complete set of valuable courses. However, the behaviour of my study participants indicates that for some students at least, those concerns are unwarranted. None of the InterScience students shied away from challenging or foundational courses when they believed those courses would contribute to an interdisciplinary understanding of their topic of interest. For example, Keith and Diane both talked about taking "boring" or necessary courses, and about how their attitudes towards those courses changed when they were taking the courses by choice rather than by decree. These students demonstrated the self-determination to both choose to take "boring" courses and to approach those courses as engaged learners despite the less-than-engaging learning environments the courses presented.

An important implication of this finding is that, in some cases, students' experiences of alienation or engagement in a course may depend as much, if not more on the students' autonomy in determining the value of the course as on the course learning environment and/or pedagogy. The InterScience students graduate having taken at least 40 undergraduate courses, only 3-5 of which come directly from the InterScience program. This means that at most 12.5% of the InterScience students' courses were explicitly interdisciplinary, deliberately small, and explicitly interactive. The remaining 87.5% of the InterScience students' courses were Mainstream ones. Three to five courses out of 40 do not represent a significant proportion of an undergraduate degree, but my research shows that they can have a significant impact on students' experiences of their degree. My analysis has shown that by trusting students with control over their learning, by valuing multiple ways of understanding, by recognizing multiple approaches to learning, and by offering at least some good course pedagogy, Faculties of Science can attract and retain intrinsically motivated students who want to approach integrative science learning in a deep way.

Implications for students' identity development

Boaler and Greeno (2000), writing about high school mathematics learning environments, argue that "many able students who could become world-class mathematicians leave mathematics because they do not want to author their identities as passive receivers of knowledge" (p. 188-9). My research on the experiences of a group of students who became alienated from undergraduate science education because they did not want to author identities as passive, single-discipline minded, receivers of knowledge supports and extends the findings of Boaler and Greeno and illustrates that their ideas are applicable to post-secondary science learning environments.

One of the sacred values in the construction of university faculty members' academic identities is that of academic autonomy (Henkel, 2005). The participants in my study valued nothing more than the same right to autonomy. To paraphrase Henkel, the students in my study wanted to be "individually free to choose and pursue their own [learning] agenda and [to be] trusted to manage the pattern of their own [learning] life and priorities" (p. 115). Learning autonomy was a central value in the students' science learning identities. When the Mainstream science specializations denied my study participants the opportunity to fully realize their value of autonomy, the students experienced a sense of alienation. As a consequence, they disengaged from university science education.

The InterScience program shifts the 'traditional' academic culture by providing students with the freedom to study what they want, when they want, and how they want. Because of this freedom, the program also gives students a strong sense of control over their education. By asking the students to explain their rationale for the courses they want to take – in essence, to craft a story that makes sense of themselves, their situation and their history – the InterScience program empowers students to construct an identity and begin to claim agency (Riessman, 2002). The application essays allow students to "position themselves as agentic beings who assume control over events and actions, individuals who purposefully initiate and cause action" (Riessman, 2002, p. 701-2). The structure of the InterScience program creates conditions within which students, by "consciously controlling and intervening in their learning," can exercise agency (Winne & Hadwin, 2008, p. 297). The students' experience of agency, perhaps even more than pedagogy and practice, was a critical factor in their construction of identities as legitimate peripheral participants in undergraduate science education.

This dissertation adds to the growing body of research that acknowledges students' decisions to leave science degrees are as much "about the experience of the education environment, and much more about personal agency, than previously anticipated or described in the literature" (Johannsen et al., 2009, p. 51). My research illustrates that when structural aspects of the InterScience program and pedagogical practices within the program's courses facilitated both integration and student control over learning, student engagement was enabled.

6.4 Future Directions

This study provides an in-depth, empirical, qualitative examination of students' experiences of participation in an interdisciplinary science setting. It also indicates there are a number of issues that merit further investigation. For example, future research is needed to determine if and how students' experiences with Mainstream science contribute to their understanding of interdisciplinarity or integrated science. The participants in my study included students who were in their first term in the InterScience program as well as those who were nearing graduation, suggesting that students may come to the InterScience program with an already well-developed understanding of, and preference for, interdisciplinary ways of knowing science. Future research could investigate how students develop interdisciplinary understanding from high school through their undergraduate education. Research could also explore the potential impacts of including explicitly interdisciplinary courses in Mainstream programs, and how students who do not hold sophisticated views of interdisciplinary understanding experience interdisciplinary science education.

The above research could also be extended by drawing upon Aikenhead and Jegede's (1997, 2001, 1999, 1999) research on cultural border crossing in science. Aikenhead (1997) writes about the cultural context of student learning, and in particular about the difficulties some students can experience navigating the borders between their personal cultural identities (formed through interactions with their families and peers) and the microcultures of science and school science. This research can be extended to questions about the experiences of undergraduate students who cross cultural borders between disciplines through interdisciplinary studies. Socio-cultural learning theories suggest that learning occurs in the relationships between people (Smith, 2003) and is the result of dialogic negotiations and conversations. These theories suggest researchers might investigate how easily students cross the borders between disciplines and what cultures they are acquiring, as a way to understand what they do.

Other areas that merit exploration include the ways that race, ethnicity and/or gender complicate students' experiences of disciplinary versus interdisciplinary undergraduate science education. Gender was not the focus of my research, and I have no data on the comparative representation of male and female students in disciplinary versus interdisciplinary programs. However, my findings about the InterScience students' preferred ways of knowing, ways that align with Belenky et al.'s writing about women's ways of knowing, suggest that this is an area for future research.

Finally, since theories shape the research questions we ask (Gerhard & Mayer-Smith, 2008), future research could ask different questions of interdisciplinary science learning by drawing upon different theoretical frameworks. For example, complexity theories of learning support the argument that interaction across difference promotes creative thinking and the generation of knowledge. Complexity theories arose out of a desire to understand dynamic systems, whose behaviour cannot be predicted through linear, cause-and-effect models of relationships (Capra, 1996). One of the most enticing features of complex systems is emergence, the arising of some coherence out of the interactions between elements of a system. Emergence is understood as the enactment of possibility, the site for creativity, and the aspect of a system that renders it more than the sum of its parts. It is in emergence that possibilities are opened and new knowledge can be generated. Factors that must be present in a complex system to enable emergence include an openness or willingness to be disturbed. Systems that are open to being disturbed when faced with new information will be moved into uncertainty, doubt, and confusion. The resulting state of instability is also a state of possibility, from which creativity, novelty, and learning can emerge. Drawing from these theories, future research could explore how the dynamics of an explicitly interdisciplinary class might help the instructor and her students make sense of integrated science for one another.

Capra (2004) explained that an "openness to disturbances from the environment is a basic property of all life," and we can surmise that all students are open to new information that may challenge their beliefs, behaviours, and structures. Living systems, however, choose which disturbances to notice and how to respond to them (Capra, 2004). In educational systems (classes and programs), disturbances must be meaningful in order to get students' attention. Interdisciplinarity may provide meaningful disturbances by regularly presenting students with ideas, vocabulary, and ways of thinking that are different from those taken for granted in the base disciplines. Students who are disposed to deep and connected ways of knowing may be more open to these types of disturbances, and therefore also to embracing the discomfort and temporary loss of control that comes from crossing borders into unknown areas of knowledge. If this is the case, and if a program's structures and teachers are effective at providing appropriate impulses that bring new ideas within "bumping" range of their students, it should not be surprising that faculty see interdisciplinary students engaging in deep, creative learning and in the generation of new knowledge.

6.5 Conclusion

I wrote, at the beginning of Chapter 3, that I see learning as occurring through a dynamic, complex set of relationships where the learning, the teaching, the subject, and the context are co-emergent and intertwined. Given this perspective, and coming at this research with an interdisciplinary background of my own, I didn't initially pay attention when the InterScience students explained that they wanted to engage, with others, in the processes of linking and relating different disciplines of science. "How else," I wondered, "would one approach learning or teaching?" I kept re-reading my field notes and the transcripts of our interviews looking for something troubling, or unexpected and new. But as more and more of the participants told me, much like Sarah did, that "it's amazing how many [students] just don't look at [their studies] that way," I started paying attention.

> It seems like such a simple -- concept but it's amazing how many people just don't look at it that way, because - the way that education is in a lot of ways is it forces you to really pigeon hole the way that you think and take one line and study it really, really hard so you become an expert in that particular thing. <Sarah>

The students I met in this study don't represent the average student in the Faculty of Science or even in the InterScience program. The participants in my study challenged the dominant disciplinary structure of undergraduate education, and became marginalized. By definition, they are not mainstream or average and their experience is not generalizable. They are outsiders who in many ways "speak from the margins of the [science education] playing field" (Foor, Walden, & Trytten, 2007, p. 103). And yet, outliers like Diane, Sarah, and Todd may be the very people that science faculties wish to attract and retain. They may be the future connectors (Gladwell, 2002) and brokers (Wenger, 1998) in science. The InterScience students are able to move among many different disciplinary worlds and subcultures. Like Gladwell's connectors, their relationships with the disciplines are more like those of acquaintances than deep friendships, yet there is strength in their "weak ties" (Granovetter, 1995) to multiple disciplines. The InterScience students may be brokers who are "able to make new connections across communities of practice, enable coordination, and – if they are good brokers – open new possibilities for meaning" (Wenger, 1998, p. 109).

"To be sure," Huber and Breen (2007) write, "there's a sense in which all learning is integrative, if only because new ideas must somehow connect to prior ones" (¶3). The InterScience students, however, are not simply connecting new with prior knowledge. They are deliberately seeking opportunities to gain and to integrate different disciplinary perspectives. University science faculties can't afford to alienate these students. As Davis and Sumara (2006) write, "it is in the possibility of diverse interpretations … that new possibilities for sense-making and foundations for more robust understandings are established" (p. 121). We need to engage these integrative thinkers, and we need to hear their voices.

> I was talking to my friend about [InterScience] and at first he was like "So what kind of job can you get?", but once he saw my vision statement and everything he was like "Why can't everyone else do this?" You know? I think it's easier for the faculty to just [laughing] – to just classify students, you know? But, it's, it's better for us, I think [if they don't]. <Kuri>

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Appendix A InterScience Courses

Table 3: InterScience Courses Offered Between 2004 and 2006, plus Course Enrolments for the Year Classes Were Observed

Course Name (short form)	Course Format	Enrolment 2005-06
Complexity in Science (Complexity)	lecture and activity (small group and whole class)	24
Instrumentation in Science (Instrumentation)	discussion/lecture + lab/activity	8
Interdisciplinary Science Field Course	small group activity	15
Interdisciplinary Science Seminar	individual student presentation or small group debate	35
Models in Science	discussion/lecture + small group lab	14
Overview of Game Theory (Game Theory)	lecture and activity (small group and whole class)	12
Evolution and Medicine	lecture and activity (small group and whole class)	not offered
Control Systems in Science (Control Systems)	discussion, group activity + lab	not offered
Scaling in Science	Discussion, lecture, group activity	not offered

Appendix B Interview Protocol

Interview protocol – views and experiences of students in the InterScience program

Background Questions:

1. What year of your degree program are you in?
2. Is this your first degree?
3. I'd like to know a little about how you came to be an x-year student in the Faculty of Science at LRU. Can you tell me a little about your educational background? (Why science? Why university? What did you study in your first x years at LRU?)

Integration-related Questions

4. How long have you been an InterScience student?
5. Why did you choose to be in/apply to the InterScience program?
    a. Why InterScience? Did you consider a major or honours degree? What changed/made up your mind?
6. What does being an InterScience student mean to you?
7. Process Questions: *Trying to understand what integration means, how students define it and what processes and structures they feel enact it.*
    a. Can you give me an example of what you think integration of the sciences might look like?
    b. How would you know that someone is integrating the sciences? How would you know that integration is happening? What would you look for?
    c. Where did your understanding of integration come from? Can you give me an example? What kinds of messages about integration have you taken from the program? Do you think everyone in the program gets the same message?
    d. Have you had any opportunities to integrate the sciences? Can you give me an example? (During your time in InterScience? Before becoming an InterScience student?)

Program-related Questions

8. Questions about InterScience courses
    a. I'd like to know about your experience with/expectations for InterScience courses. If you were to walk into a random course on campus, would you be able to tell if it was an InterScience course?
    b. Are there any distinguishing features of an InterScience course? (Assignments, activities, assessment)
    c. How would you describe an InterScience course to somebody else?
    d. What have you learned through taking InterScience courses?
    e. How did you learn that?
9. If you were going to tell somebody about the program, what would be important for them to know?
    a. Would you encourage others to become InterScience students? Why or why not?

10. How would you describe the academic culture of your program?
11. What do you plan to do with your InterScience degree after graduation?
    a. Do you feel that having pursued interdisciplinary sciences will help you do that? Why or why not? How?
12. Are there any significant differences between disciplinary programs and interdisciplinary ones? Can you describe those differences for me?

Directed Studies Related Questions (where relevant)

13. Why did you decide to complete an interdisciplinary Directed Studies course?
14. What did you study? Tell me about your project?
15. How did you arrive at that project and that supervisor?
16. What did you learn through doing that project?
17. How did you learn that?
18. How is that project interdisciplinary?

Community Related Questions

19. Do you feel part of a group at the LRU?
    a. If yes, please describe that group. (Who, when/where do they meet)
    b. Would you say that this group gives you a sense of community?
20. Are you part of any academic groups on campus?
    a. Is it important to you to be a part of an academic group? What would be your ideal academic "community" – is there one you would you like to be a part of?
    b. Do you feel that there is an academic community of interdisciplinary scientists on campus?
    c. If so, do you feel a part of that community?

Closing Questions:

21. Is there anything else you think I should know? Any questions that you think I should be asking?

Appendix C Codes Used in Data Analysis

The codes listed below were identified in at least five sources.

Table 4: Codes Used in Data Analysis

Main code	**1st level sub-code**	**2nd level sub-code**	**Description**
Learning outcomes			
Learning environment			characterization of the learning environment
	CLEpreITS		CLE pre InterScience
	CLEPos		CLE related to positioning
	CLEPed		CLE related to pedagogy
	CLEaffect		CLE related to affect
	CLEOther		CLE – Other
	CLEITS		CLE – InterScience
	CLEITSc		CLE – InterScience course
Integration			
	System		references to systems perspective
	Relating		
		“reminds me”	
		relating	
		links	
		fragmented	
		connect	
		combine	
		bring together	
	Perspectives		
		interaction	related to perspectives and learning through interaction
		diff int & disc	related to differences between disciplinarity and interdisciplinarity
	Process		
		source	source of student’s ideas about integration
		what it is	what integration of the sciences means
		what gets int	what gets integrated
		ways to int	ways to integrate
		perspective	integration as seeking multiple perspectives
		learning to int	learning to integrate
	Picture		
		variety	
		holistic	holistic vs. boxes
		educ too general	“my education was too general”

Main code	**1st level sub-code**	**2nd level sub-code**	**Description**
		details	
		breadth	
		bigger picture	
	Knowledge Int		knowledge integration
		linking	
		adding	
		connecting	
Identity			
	Subjectivities		
	Discourse		
Courses			
Community			
	Interaction		group interaction
Experience			
	Self-confidence		
	Positive		
	Passion		
	Open vs. bias		open-minded vs. biased
	Motiv		motivation
	Metacog		Metacognition
	frustration		
	freedom		
	Purpose		finding purpose
	Control		
	Belonging		
	Alienation		
Other			free nodes
	Choice		
	Dislikes from Maj		dislikes from major
	NOS		nature of science
	Ped		pedagogy
	Rejecting		
	Sep. school & life		separating school from “real life”
	Only way		“the only way I could …”
	Why IntSci?		why InterScience?
	Why Sci?		why science?

Appendix D Recruitment Email

Department of Curriculum Studies, The University of British Columbia (UBC)

To: [InterScience] Students and Faculty
Re: Study on Views of Integration and Community in the [InterScience program]
From: Gillian Gerhard, Graduate Student, Department of Curriculum Studies at UBC and Dr. Jolie Mayer-Smith, Associate Professor, Department of Curriculum Studies.
Date: November 24, 2004

We are looking for [InterScience] student and faculty volunteers to participate in a 45-60 minute informal interview. We want to know what integration of the sciences means to you, if and how you integrate, and why you decided to participate in the [InterScience program.]

If you would like to share your views with us, please contact Gillian Gerhard at gillian.gerhard@ubc.ca or 822-2302 by January 15 to set up an interview. Interviews will take place [on campus] in December or January, to suit your schedule.

Data from this study will inform further research on integration of the sciences to be conducted as part of a doctoral dissertation by Gillian Gerhard.

Thanks!