

**PROFESSIONAL DEVELOPMENT OF FOUR GRADE 10 BIOLOGY
TEACHERS IN SINGAPORE
– THE LEARNING STUDY APPROACH**

by

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ABSTRACT

Despite the importance of genetics as a school curriculum topic and its increasing application in everyday life, and despite challenges teachers face teaching genetics, a repertoire of pedagogical strategies that draws upon selected theories of learning may not always be readily available for teachers. In the context of Singapore, this is exacerbated by potential unfamiliarity with the newly implemented genetics curriculum, and how there also appears to be a lack of appropriate teacher professional development programs. What is noteworthy is that these challenges are similarly shared by teachers elsewhere.

A study was framed to investigate how teacher collaboration could be utilized to alleviate, if not overcome, these challenges. Through a learning study framework, four collaborating Grade 10 biology teachers employed the *theory of variation* to manage and overcome the challenges of teaching the new genetics curriculum in Singapore. A learning study amalgamates teacher collaboration, teacher reflection, teachers researching into their classrooms and the employment of a theoretical framework.

This study seeks to answer the research question “How does Singaporean teachers’ participation in a theory of variation-framed learning study affect their learning about their own pedagogy?” The thesis reports a phenomenographic analysis of the different ways the teachers experienced learning during collaborative endeavors, revealing the complex nature of teacher learning – complex ways of curriculum interpretation, lesson planning and implementation, and evaluation of teaching practices. The impact of the learning study on teachers’ pedagogies and professional development was also elucidated. Consequently, the experience of increased clarity and coherence in terms of curriculum interpretation, demonstration of ownership and authentic

lesson planning manifested during the enactment of theory-guided lessons. The experience of collaborative inquiry into teachers' own teaching practices also led to the generation of new insights on teaching, as well as shifts in their beliefs about teaching and learning. The results support (1) the use of learning study as a professional development approach to enhance students' learning and to encourage teachers to develop their own curriculum; (2) the use of theory of variation as a framework to organize, implement and analyze teacher learning.

PREFACE

This research study obtained the approval of the UBC Research Ethics Board (Behavioural Research Ethics Board; UBC BREB Number: H08-02187).

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CHAPTER 1

INTRODUCTION

This chapter serves as an introduction to the study. The overarching research question and guiding questions are presented. The context of the study is also described, with a brief description of the methodology and methods employed. This chapter concludes with an overview of the thesis.

1.1 Introduction to the study

Teacher learning and professional development have gained much attention in research literature. There are several ways in which the promotion of teacher learning was advocated. While some foreground the importance of collaboration (Arbaugh, 2003; Lieberman, 2000; Shulman & Sherin, 2004; Wineburg & Grossman, 1998) and inquiry into the teachers' individual classrooms (Nelson & Slavit, 2007; Smylie, 1989; Stigler & Hiebert, 1999), others have looked into specific theories that can be applied into the classroom (e.g., Posner, Strike, Hewson & Gertzog, 1982). With the aim of empowering teachers, concerns about how prescribed curriculum may relegate teachers to being mere implementers of the curriculum were also raised (Bencze & Hodson, 1999; Pedretti & Hodson, 1995).

Amongst the various approaches that encourage teacher professional development, the learning study (Pang & Marton, 2003) stands out as having the potential to promote teacher learning. Pang and Marton first introduced the learning study approach in 2003. Initially, learning studies aimed to promote student learning, for example, in the learning of economics (Lo, Marton, Pang & Pong, 2004; Pang, Linder & Fraser, 2006; Pang & Marton, 2003, 2005);

mathematics (concept of slope) (Choy, 2006); and color of light (Lo, Chik & Pang, 2006). However, there seems to be a lack of detailed studies inquiring into how the approach has the potential for teacher learning and development. Later studies (Chiu, 2005; Davies & Dunnill, 2008; Pang, 2006), shifting the focus to foreground and include teacher learning, illustrate the growing interest in this aspect. For example, both Chiu and Pang reported the use of a learning study to enhance teacher professional learning in Hong Kong, while Davies and Dunnill employed the learning study as a model of collaborative practice (in initial teacher education) in a UK university. Despite the growing interest, literature foregrounding the potential of learning study as an approach for professional development appears to be limited. Thus, the seemingly small number of published studies and gaps in literature warrant further research, making it worthwhile to explore the potential of a learning study as a context for promoting and understanding teacher learning.

In the context of Singapore, professional development of teachers has always been one of the top agendas for policy makers. Despite the commitment of policy makers to develop teachers to be better equipped to teach, and despite the several programs and structures in place to support teacher professional development, several modes of professional development occur outside the school context. In light of several studies that emphasize the importance of teachers' own classroom for professional development, (Nelson & Slavit, 2007; Smylie, 1989; Stigler & Hiebert, 1999), it is compelling to consider the possibility of extending the existing modes of professional development in Singapore to approaches that afford teachers opportunities to learn within their own classroom contexts. Thus, in view of how there appears to be a gap in literature, and also of the possibility of expanding the approaches of teacher professional development in Singapore, this current study was situated within the context of Grade 10

science curriculum where teachers enacted the teaching of the new Singaporean genetics curriculum. The implementation of the new biology curriculum (introduced in 2007) has in fact posed several challenges for the teachers. These challenges include (1) unfamiliarity with the content of the new genetics curriculum, which is exacerbated by how there appears to be a lack of a repertoire of pedagogical strategies that draw upon selected theories of learning, and (2) how there also appears to be a lack of clarity and appropriate teacher professional development programs to help teachers enact teaching the new biology curriculum. (See more discussion of challenges in Section 1.3) What is noteworthy is that these challenges presented in the context of a Singaporean biology classroom may in fact be commonplace for teachers elsewhere. To respond to these challenges, the current study was framed to investigate how learning study could be utilized to alleviate, if not overcome, the challenges.

1.2 Overarching research question and guiding questions

In light of the potential of employing a learning study to promote teacher learning and to address challenges in teaching and in teacher professional development, this study was framed to investigate how four Grade 10 biology teachers' participation in a learning study influenced their own learning. An overarching research question that emerged was **“How does Singaporean teachers' participation in a theory of variation-framed learning study affect their learning about their own pedagogy?”**

To aid in the investigation of the overarching research question, the following guiding questions were formulated:

1. What are teachers' understandings of their own teaching and learning practices before participating in and experiencing a learning study?
2. How does participation in the learning study influence teachers' pedagogy and experiences of learning as a form of professional development?

Attending to the overarching research question and guiding questions may eventually lend support for learning study to be added to the repertoire of professional development modes in Singapore and elsewhere. It offers a classroom-based context whereby teachers can share their best practices (Glazer & Hannafin, 2006; Kristmanson, Dicks, Le Bouthillier & Bourgoin, 2008; Stigler & Hiebert, 1999) and learn from other teachers. Teachers can also be encouraged to be engaged in research, and thus have opportunities to link teaching to research and theory. Given that teachers belong to a weak technical culture that require them to increase their "blind faith" in their own teaching practices (Lieberman & Miller, 1990), the opportunities for them to be engaged in the inquiry of their own teaching practices as teacher-researchers are not only desirable, but arguably a necessity.

1.3 The Singaporean context

In this section, the current professional development opportunities for teachers in Singapore are presented. Narrowing down to the implementation of the new Grade 9-10 biology curriculum, the associated challenges are also discussed. Teachers' potential unfamiliarity with the new curriculum and how there appears to be a lack of a repertoire of pedagogical strategies that draw upon selected theories of learning are highlighted. In addition, how there appears to be

(1) a lack of clarity in teachers' approach to curriculum interpretation, as well as (2) a perceived lack of appropriate teacher professional development programs to help teachers to enact the new biology curriculum are subsequently discussed.

1.3.1 Professional development in Singapore

In Singapore, political leaders and education policy makers constantly have education and the challenge of preparing high-quality teachers at the top of their agenda (Goh & Lee, 2008). It is believed that the success of what Singapore hopes to achieve in education hinges on the quality of its teachers, thus necessitating teachers to be dedicated to their own professional development (Goh & Lee, 2008). The emphasis on teacher professional development has led to policies that encourage and support the growth of teachers. These policies, which translate to the setting up of various administrative organizations, programs and professional development centres, result in a diverse range of teacher development opportunities. For example, under the school staff development scheme, officials (reporting officers) are designated to oversee the professional and personal development of every teacher (Ng, 2008). This gives the teachers a platform on which to discuss their professional development plans with their reporting officers. As part of the "Thinking Schools, Learning Nation" initiative of the Ministry of Education, in-service teachers are also entitled to 100 hours of fully subsidized professional training and growth per year (Goh & Lee, 2008; Gopinathan, 2001). Foregrounding a mentorship model, additional teachers are also deployed to enable schools to offload more experienced teachers so that they can mentor the "younger ones" in schools and oversee their professional development (MOE, 2005; Shanmugaratnam, 2005).

Based on the philosophy that teachers must pursue learning on a lifelong basis in order to stay relevant to their students, professional development opportunities in the mode of obtaining higher professional certification (including undergraduate and postgraduate degrees) in service courses are made available through the “Professional Development Continuum Models” (PDCM) (MOE, 2005, 2008; UNESCO, 2008). The PDCM has been in place since 2005 and aims to link pre-service and in-service teacher education. It also strives to link teaching to research. In addition to PDCM, local and overseas work attachment opportunities are also made available through the “Teacher Work Attachment” program (TWA) that was started in 2003, with participating teachers reported to have returned to their classrooms with fresh perspectives and glimpses of business innovation, global competitiveness and service standards (MOE, 2008; Ng, 2008). In addition, in order to sustain teachers’ ongoing professional development, the Ministry of Education has set up centres such as the “Centre of Excellence for Professional Development”, with the aim of championing the sharing of best practices and learning from fellow teachers (Shanmugaratnam, 2005).

The availability of these different modes of professional development clearly signals the new emphasis the Singapore government places on the provision of quality education for young Singaporeans and the preparation of high-quality teachers (Goh & Lee, 2008). However, as briefly mentioned in the introduction, several of these modes of professional development occur outside the school context, despite studies demonstrating the value teachers place on classroom experience. For example, in Smylie’s (1989) study, teachers ranked direct classroom experience as their most important site for professional learning. Similarly, analysis of five case studies of teachers engaged in collaborative inquiry by Nelson and Slavit (2007) revealed that a key element in teachers’ professional growth involves “dialogic inquiry grounded in classroom-

based data” (p. 37). What is underscored is that the most effective place to improve teaching and learn professionally is in the context of teachers’ own classrooms. In addition, the problem of how to apply research findings in the classroom disappears when the inquiry is classroom-based (Gu & Wang, 2006; Stigler & Hiebert, 1999). Thus, if Singapore has education and the challenge of preparing high-quality teachers at the top of their agenda, it becomes compelling to consider the possibility of extending the existing modes of professional development to those situated within teachers’ own classroom contexts.

1.3.2 The challenges of a new genetics curriculum – unfamiliarity and a perception of a lack of a repertoire of pedagogical strategies that draw upon selected theories of learning

The newly implemented biology curriculum, stipulated by the Ministry of Education, outlines the learning outcomes that students will be assessed on in the national biology examination at the end of Grade 10 - the General Certificate of Education “Ordinary” Level (GCE ‘O’ Level) examination. In Singapore, the grades obtained are vital for admission to junior colleges (Grade 11-12), and to tertiary or other higher institutes of learning. Thus, the prescribed curriculum is commonly relied on to determine what teachers should be teaching in their classes.

In the new genetics curriculum, it has been observed that there is an increasing emphasis on the molecular aspects of genetics - such as transcription and translation. Such an effort may be interpreted as an attempt to propel towards achieving the broad curricular goal of increasing scientific literacy - in view of how genetics is one of the cornerstones of modern biology (Rotbain, Marbach-Ad & Stavy, 2006); of the impact of the human genome project (Jegalian, 2000; McInerney, 1996); and of the increasing contemporary application of genetics in our

everyday lives (Jegalian, 2000; Wood, 1993). An educated public capable of judging the safety of genetically engineered organisms, making a stance about the morality of genetics-related health care and deciding on how to regulate access to genetic information is deemed pertinent (Jegalian, 2000; Tsui & Treagust, 2004; Wood, 1993). In other words, the empowering of citizens to make more informed decisions regarding genetics-related issues is necessary. Coupled with the fact that life sciences have been positioned as the engine for economic growth in Singapore (Lim, 2003; Phon, 2003), this new emphasis in the genetics curriculum is not a surprising one.

The new emphasis, however, poses a challenge to teachers who might *not* have been well exposed to the topic of molecular genetics. Most Grade 9-10 Biology teachers in Singapore have at least a Bachelors degree in the sciences, and were exposed to learning of some advanced biology in the university, although *not* necessarily in the field of genetics. Thus, it is reasonable to assume that *not* all teachers would be comfortable with teaching the new genetics curriculum, and may not be able to draw from their prior experiences as students to teach the topic (Blanton, 2003; Nashon, 2005).

The unfamiliarity of teaching the molecular aspects of genetics is exacerbated by the fact that teachers continually face challenges teaching genetics. Research literature has revealed genetics as a topic that is difficult to learn. (See Gericke and Hagberg (2007) for a review.) Several studies highlight students' conceptions that differed from the canonical sciences of genetics (Chattopadhyay, 2005; Lai, 1996; Lewis, Leach & Wood-Robinson, 2000a, b, c; Marbach-Ad, 2001; Venville & Donovan, 2007; Wood, 1993). Students' difficulties in learning genetics include the challenges faced in understanding the relationships between genetic

biophysical entities (chromosomes, deoxyribonucleic acid (DNA) and genes) and relating them with broader genetics concepts such as gene expression, cell division or an understanding of life (Duncan & Reiser, 2007; Lewis & Kattmann, 2004; Lewis & Wood-Robinson, 2000; Marbach-Ad, 2001; Marbach-Ad & Stavy, 2000; Saka, Cerrah, Akdeniz & Ayas, 2006; Venville, Gribble & Donovan, 2005). Understanding the relationships between genetic biophysical entities is often foundational to the learning of other genetic concepts, including the concept of gene expression – the latter includes the genetic processes of transcription and translation, which were topics introduced into the new Grade 9-10 genetics curriculum.

Educational researchers have also attributed the challenges in teaching and learning genetics to (1) understanding phenomena involving small and often hidden genetic biophysical entities that makes it difficult for students to experience the phenomenon (Gilbert, Osborne & Fensham, 1982; Duncan & Reiser, 2007; Mbajorgu, Ezech, Idoko, 2007); (2) the different levels of organizations that necessitates an understanding of mechanisms and interactions (including genetic processes) at the macro, micro and molecular levels (Bahar, Johnstone & Hansell, 1999; Duncan & Reiser, 2007; Mbajorgu et al., 2007; Marbach-Ad & Stavy, 2000); and (3) the ontological differences between the levels of genetic phenomena (Duncan & Reiser, 2007; Tsui & Treagust, 2004; Venville & Treagust, 1998; Venville et al., 2005). Thus, there is often “little opportunity to bring the disparate pieces together to give a holistic overview or to make the relationship between topics explicit” (Lewis & Wood-Robinson, 2000, p. 190). These challenges are exacerbated by the poor organization of genetic topics within the textbook, as well as the time gaps between teaching these topics. Consequently, the building of a coherent conceptual framework may be hindered (Banet & Ayuso, 2000; Chattopadhyay, 2005; Lewis & Wood-Robinson, 2000; Lewis et al., 2000C). (Some of the research studies mentioned here were

used in the current learning study to examine students' conceptions of genetic concepts, and to further discuss the challenges that were similarly encountered by the participating teachers.)

An awareness of the challenges in the learning and teaching of genetics has evoked much interest in possible interventions. Suggestions range from the use of problem-based/problem-solving strategies (Araz & Sungur, 2007; Gelbart & Yarden, 2006; Stewart & Rudolph, 2001), the use of metaphors (Martins & Ogborn, 1997), to the use of models and other strategies that aid in reduction of information students attend to at one time (Rotbain, Marbach & Stavy, 2005; Rotbain et al., 2006). The use of computer simulations (Law & Lee, 2004) and software that feature multiple representations (Tsui & Treagust, 2004, 2007) were also recommended. Alongside these pedagogical strategies, the inclusion of various subtopics or key concepts, with the intent to address possible gaps in student understandings and to approach genetics in a more holistic way (Lai, 1996; Lewis & Wood-Robinson, 2000; Marbach-Ad, 2001), was also advocated. The subtopics of regulatory genes (gene switches) (Lewis & Kattmann, 2004; Lewis et al., 2000C; Wood, 1993), mutation (Lewis & Kattmann, 2004; Tsui & Treagust, 2004); polygenic and multifactorial traits (McInerney, 1996) were amongst those that were recommended.

Consistent with the constructivist tradition, researchers have also advocated the elucidation of underlying beliefs and presuppositions that give rise to students' everyday conceptions (Mbajiorgu et al., 2007; Santos & Bizzo, 2005). According to Lewis and Katmann (2004), these conceptions are essential starting points, rather than obstructions, from which scientific understandings can be developed. Uncovering students' conceptions is common practice for pedagogical strategies that posit a focus on conceptual change (Chi, Slotta &

deLeeuw, 1994; Posner et al., 1982). Some research studies in this area are directed towards the exploration of students' conceptions by using multiple interpretive frameworks (Tsui & Treagust, 2004, 2007; Venville & Treagust, 1998; Venville et al., 2005), advocating the use of epistemological, ontological and/or social/affective perspectives to explore conceptual change in genetics.

While these interventions are valuable for consideration in the teaching of genetics in a Singaporean classroom, the extent to which they may be applied may be limited in the Singaporean context. For example, the amount of time teachers might be willing to spend on trying out new activities (such as problem-based activities) or to include subtopics that are not emphasized in the stipulated syllabus may be a limiting factor. Grade 9-10 teachers generally devote a lot of time focusing on completing the prescribed curriculum and preparing the students for the national examinations. Thus, there might be little perceived incentive to include topics that are outside of the prescribed curriculum. Moreover, the performance of a Grade 9-10 teacher in the Singaporean system is in part determined by how well the students perform in these national examinations. The grades assigned to the teachers also affect the progress of the teachers' careers. Consequently, a phenomenon that may emerge in a general Singaporean grade 9-10 biology class is the employment of teacher-centered pedagogies, since it is perceived to be more "efficient" in terms of time spent. As such, there might also be little perceived incentive to try out new pedagogical strategies that are seen to take up more curriculum time. However, it is worth mentioning the importance of using students' conceptions to guide classroom instruction is valued in a Singaporean classroom. This thus creates a potential disparity between teachers' beliefs about good (biology) teaching and their current teaching practices. The challenges faced by teachers highlighted here were in fact recognized in literature, underscoring the tensions that

emerge as occasions whereby teachers are constrained from implementing a curriculum that is consistent with their personal beliefs - due to the lack of time, an over-crowded syllabus or the pressure of examinations (Elliott, 1991; Evans, 1996; Hodson, 1993).

The limited impact of literature may also be attributed to how it may not always be readily available to teachers (Bencze & Hodson, 1999; Pedretti & Hodson, 1995; Rosenholz, 1989), since some research journals may require subscription that the teachers do not have access to. This is exacerbated by how for “the most part educational researchers ignore teachers and teachers ignore the researchers right back” (Zeichner, 1995, p. 154), thus widening the gap between classroom teachers and educational researchers (Coulter & Wiens, 2002). As such, suggested interventions and pedagogical strategies may have no or limited influence on teachers’ teaching. The challenges mentioned in this section thus shed light on the perception of a lack of a repertoire of pedagogical strategies that draw upon selected theories of learning to help teachers enact the new genetics curriculum.

1.3.3 Lack of clarity in teachers’ approach to curriculum interpretation and appropriate teacher professional development programs to help teachers enact the new biology curriculum

A potential challenge related to teachers managing the new biology curriculum is that there appears to be a lack of clarity and coherence in teachers’ approach to interpreting the curriculum. Although the curriculum is spelt out in terms of students’ learning outcomes, teachers often face difficulty determining the scope and depth of the material to be taught. The challenge of the lack of clarity is deepened by the newness of the genetics curriculum that leaves teachers little to draw from, both in terms of their experiences teaching it, as well as from their

personal experiences of being learners themselves. Moreover, the emphasis of the new curriculum remains relatively unclear to the teachers since it has not been assessed many times in the GCE 'O' Level examinations.

Of equal concern is how teachers may fall into the trap of becoming mere implementers of curriculum designed by others (Bencze & Hodson, 1999, Pedretti & Hodson, 1995). In the Singaporean context, this constant struggle may be further amplified by how much emphasis the entire society places on grades and assessment, with a cultural system that relies heavily on meritocracy (Kam & Gopinathan, 1999). Perceiving the curriculum to be assessment-driven, teachers may thus be compelled to implement the curriculum as closely as is stipulated. In a context whereby it seems that control remains with central authority and teachers merely attend to the technical aspects of implementing these decisions (Pedretti & Hodson, 1995), the concern raised here is that relegating biology teachers' task to merely implementing the curriculum leaves little room for them to reflect on the curriculum, to take a holistic approach towards biology, or to take greater ownership of their teaching.

Addressing this concern, the current study aligns more with Elliott's (1991) view that curriculum development constitutes a process of teacher development that occurs through the reflective practice of teaching. Rather than getting better at implementing an externally designed curriculum, the improvement of teaching is more a matter of developing one's own curriculum. Seen in this light, appropriate teacher professional development programs in the Singaporean context would include opportunities for teachers to make meaning of the curriculum beyond its mere implementation. It would also encourage teachers to evaluate students' learning experiences and their classroom practices based on these meanings, rather than on what is to be

assessed (in examinations) alone. Currently, however, such programs may not always be readily available to teachers in Singapore. Despite the current lack of such teacher development programs, the learning study, which possesses the potential for this particular type of curricular work, lend the power for the emergences of such teacher development opportunities both in Singapore and elsewhere.

1.4 Brief description of methodology and methods

The design of this research study drew from research and “learning study” proposed by Pang and Marton (2003, 2005), from design experiment (Brown, 1992; Collins, 1992, 1999), lesson study (Stigler & Hiebert, 1999), as well as the collaborative and reiterative nature within action research (Elliott, 1991). Learning study amalgamates opportunities for teachers to pool their experiences and resources to collaboratively plan, implement and evaluate theory-guided student learning experiences. Concurrently, teachers conduct research in their own classrooms as a way to inquire into their own practices.

Aimed at understanding teachers’ experience of engaging in their practice, and their experiences of collaborating and enacting teaching the new genetics curriculum, teacher interviews were conducted before and after the study (one before, and two after the study). An overall reflection was also conducted at the end of the learning study, whereby participating teachers were granted time during the meeting to write down short notes of their thoughts and experiences. The three interviews and reflective entries served to elucidate the participating teachers’ understandings of their own teaching and learning practices before participating in and experiencing the learning study, and how their pedagogies and learning as a form of professional development were influenced by their experiences in the learning study.

Student pre- and post-lesson tests and interviews were also administered to determine the impact of the intervention (research lessons) on students' learning. Audio-video recordings of the meetings, research lessons and post-lesson conferences were also made. Coupled with notes of the meetings (prepared by the facilitator-researcher); a "Genetics Questionnaire" that teachers completed at the beginning of the study (focusing on teachers' beliefs about the teaching of genetics); and the researcher's recorded written field notes and journal, these data sources served triangulation purposes (Mathison, 1988) and analysis of the overall process.

The analysis employed largely a phenomenographic approach (see Marton 1988, 1994a; Marton & Booth, 1997) that focused on "experience" and capturing the different ways teachers experienced learning in the learning study. For each teacher, their interview transcripts and overall reflection were analyzed alongside the rest of the data sources. The analysis captured, firstly, the individual experiences of each participant. Subsequently, the analysis proceeded to uncover emergent themes. These themes illuminate how the learning study influences (1) teachers' pedagogies, (2) their beliefs about teaching and learning, and (3) their learning as a form of professional development. Pointing to the lived experiences of the teachers, these themes were also useful for establishing the relationships between teacher learning and the organization of the learning study.

1.5 An overview of the thesis

In this chapter, I have introduced the context of this study, as well as the overarching research questions and guiding questions. I have also discussed the Singaporean context in which this study was implemented, highlighting the challenges in professional development that are common to both Singapore and elsewhere. The methodology and methods that were

employed have also been briefly mentioned. In Chapter 2, theory of variation is introduced. Providing a literature review, it is illustrated how the application of the theory in this research study is suitable, since (1) the theory offers a way to look at learning; (2) was applied in educational settings to enhance student learning; and (3) is useful as a tool to interpret students' learning experiences. The potential of a theory of variation-framed learning study to promote teacher learning is also mentioned. The chapter concludes with a description of how theory of variation was applied in this research study. In Chapter 3, the use of a phenomenographic perspective to understand learning is discussed. The learning study approach is also discussed in greater detail. The rest of the chapter is devoted to describing the methods employed, the data sources and the data analysis process. How I have situated myself in the study, and issues of trustworthiness, validity and reliability are also discussed. In Chapter 4, the results are presented and discussed. Firstly, three of the participating teachers' individual experiences are described. Subsequently, five themes that served to capture the variation in the participating teachers' experiences in the learning study are discussed. In Chapter 5, conclusions are presented, accompanied by a discussion of the significance, as well as the limitations and delimitations of the study. The implications for theory; teacher professional development; implementing future learning studies, curriculum; research methodology; teaching practice and future research direction are subsequently discussed. The thesis concludes with a description of the social science research experienced in this study.

CHAPTER 2

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

This chapter begins with an introduction to theory of variation. The literature review that follows serve to illustrate how the application of theory of variation in this research study is suitable – as a learning theory that offers a perspective of learning; as a theory that was applied in educational settings to enhance student learning; and as a tool to interpret students’ learning experiences. Subsequently, the potential of a theory of variation-framed learning study to promote teacher learning is also described, followed by a brief description of how theory of variation was applied in this research study.

2.1 Theory of variation as a learning theory – a phenomenographic perspective

Theory of variation was developed from the phenomenographic research approach (Marton, 1981). Phenomenography was developed in the early 1970s at the University of Göteborg in Sweden and was first introduced in publication in 1981 by Ference Marton. The phenomenographic perspectives in this study draw from those developed by Ference Marton and his colleagues at the University of Göteborg, and are discussed in this chapter. In the subsequent chapter (Section 3.1 & 3.5.1), some of the critiques of the works of Marton and his colleagues are also discussed.

Phenomenography sets out to reveal different ways in which people experience the phenomena, and/or characterize a way of experiencing something in terms of the critical aspects of the object of learning (a capability or value to be acquired) as discerned by the learner (Pang, 2003). In phenomenography, learning is characterized as learning to experience something in a

certain way, and the consequent variation theory posits that learning is the development of a capability to experience something in a different (more advanced or complex) way from before (Bowden & Marton, 1998; Marton, 1986; Marton & Booth, 1997).

2.1.1 Qualitatively different ways to experience

The earlier works in phenomenography (as was described in Marton and Booth (1997) and Richardson (1999)) comprised of content-related studies of more general aspects of learning (Marton, 1986). These studies lend support that there are qualitatively different ways to learn, which may account for why some people learn better than others. For example, Marton and Säljö (1976a, b) studied 40 female first-term university students' approach of comprehending text, aiming to reveal how a given text appeared to the students and what they understood it to be about. Their study uncovered four qualitatively distinct ways of comprehending the text. The differences represented different degrees of partial understanding of the whole text, which can be ordered in a hierarchy that demonstrates increasing complexity and logical relationships between ways of comprehending the text. Subsequent studies, such as those by Säljö, (1979a, 1979b, 1982), were directed at uncovering the different conceptions of learning. 90 people between the ages of 15 and 73 years from various educational institutions were interviewed. Säljö presented five different conceptions of learning, which were represented in a developmental hierarchy. The results were similarly ascertained by researchers working outside of Sweden, as exhibited by students both in the Netherlands and the United Kingdom (see Richardson, 1999). Marton, Beaty and Dall'Alba, (1993), similarly uncovering the various "surface" and "deep" approaches to learning, described changes in the conceptions of learning demonstrated by 29 students. The results were likewise similar to that of Säljö's, and a sixth conception of learning was added.

The above studies may be deemed to lend support to “developmental phenomenography”, which posits a purpose of using outcomes from phenomenographic studies to help the subjects of the research to learn (Bowden, 1994a) - as opposed to having a ‘pure’ phenomenographic interest (Marton, 1986). The development of literature in the field of phenomenography is deemed to have headed in this direction. Citing the works of Johansson, Marton and Svensson (1985) and Svensson (1989) that focused on how university entrants understood notions of mechanics as Newtown’s first law of motion; Renström (1988) and Renström, Andersson and Marton (1990) that focused on how students between the age of 12 to 16 understood the nature of matter; Neuman (1989) focusing on students’ experience of numbers; Booth (1992a, b) that revealed students’ approaches to learning to program by writing programs and students’ different understandings of recursion, Marton and Booth (1997) drew support from these studies for their assertion that there are qualitatively critical differences in ways of understanding and experiencing various topics or subjects. A similar assertion could be made from the results of later studies. For example, in Lai’s (1996) study, the different ways ten third-year university students understood and approached the genetic topic of meiosis was explored. The works cited here represent part of a body of phenomenographic research studies conducted primarily in educational contexts.

The development of phenomenography, with the object of research as variation in ways of experiencing different phenomena, can thus be appreciated to have two “faces” of variation (Pang 2003). As Pang puts it, the “first” face of variation refers to variation in ways of experiencing a particular phenomenon, with most studies in this strand of research orientation concerned with various ways in which a particular phenomenon appears to different people, as demonstrated in the studies cited above. Thus, phenomenography in this sense is descriptive and

methodologically oriented. Subsequently, recent developments in phenomenography points to a shift in primary emphasis from questions concerning how different ways of experiencing something can be captured methodologically to theoretical questions about the nature of the differences (Pang, 2003). According to Pang, there is a move from description of the different ways of experiencing various phenomena to answering questions that probed for what a way of experiencing something is and the difference between two ways of experiencing the same thing. According to Pang, the theory of variation (Bowden & Marton, 1998; Marton & Booth, 1997) owes its development to this “new phenomenography”.

2.1.2 Notion of experience and the structure of awareness

In phenomenography, the basic tenet is that every phenomenon has a limited number of critical aspects/features that distinguishes it from other phenomena (Marton & Booth, 1997). The differences in the way these critical aspects are discerned and simultaneously focused on correspond to the different ways of experiencing the phenomenon. The emphasis on learner’s experiences urges one to consider what a way of experiencing something is. Turning to Gurwitsch (1964) (cited by Bowden & Marton, 1998; Marton, 1994a; Marton & Booth, 1997; Marton, Runesson & Tsui, 2004; Runesson, 2005, 2006), who also asserted that there is a structure to awareness, distinctions were made between the object of focal awareness (the “theme”); those related to the object and in which it is embedded (the “thematic field”); and those that coexist with the theme without being related to it (the “margin”). In addition, the structure of awareness is built on the premise that while we are aware of everything all the time, we are *not* aware of everything in the same way. As such, qualitatively different ways of experiencing something can be appreciated in terms of the differences in the structure of awareness. In other words, there are different ways of experiencing the same phenomenon when

different aspects are discerned (the “figure”) while others are relegated to the background (the “ground”). At this point, it is worth noting that according to Marton and Booth (1997), “conceptions”, “ways of understanding”, “ways of comprehending” were used as synonyms for “ways of experiencing” in phenomenographic studies.

2.1.3 Discernment and simultaneity

An approach to learning in a particular situation, as informed by phenomenography, involves a combination of the way in which the learner experiences learning and the way the situation is experienced (Marton & Booth, 1997). As discussed above, phenomenography foregrounds variation in qualitatively different ways of experiencing. It also points to the differences in the structure of awareness to account for these differences. Theory of variation thus develops from the point that learning is premised on the learner’s structure of awareness, and is related to discernment, variation and simultaneity (Marton & Booth, 1997, Pang, 2003, Pang & Marton, 2005; Marton et al., 2004). In other words, the structure and limitations of awareness compels the intentional, systematic and careful planning and enactment of instruction based on a pattern of simultaneous variation and invariance, in order that the learner’s attention is directed to the desired aspects for learning to occur. This was illustrated in recent studies employing the theory of variation (Fraser, Allison, Coombes, Case & Linder, 2006; Linder, Fraser & Pang, 2006; Lo et al., 2004, 2006; Marton et al., 2004; Pang et al., 2006; Pang & Marton, 2003, 2005).

In theory of variation (Bowden & Marton, 1998; Marton & Booth, 1997), learning is appreciated as a change in discernment. A learner must experience variability in order to discern, because discernment assumes experienced variation. When certain aspects of a

phenomenon vary while other aspects remain invariant, those aspects that vary are discerned or come to the fore of awareness, and this awareness may result in learning. In addition, the discernment of critical aspects that corresponds to the dimensions of variation of the phenomenon must also take place simultaneously. In this manner, the qualitatively different ways of experiencing something can thus be understood in terms of the discernment of critical aspects, the simultaneity of discerned critical aspects, and the potential for variation in the discerned critical aspects of the phenomenon (Pang & Marton, 2005).

2.2 Theory of variation as applied in educational settings

Theory of variation seemed to have appeared in literature only recently (Pang, 2003; Pang & Marton, 2003, 2005). Although Marton and Booth (1997) did not seem to clearly demarcate the boundaries between phenomenography and theory of variation, the theory can be deemed as an extension of the perspectives about learning held in the phenomenographic tradition. The use of theory of variation in educational contexts often revolves around its employment as a theoretical framework to guide the planning, implementation and/or evaluation of classroom instruction. These studies take place in the context of a learning study (Pang et al., 2006; Pang & Marton, 2003, 2005; Lo et al., 2006). They lend support to an orientation towards how one might create conditions for learners to discern, and be focally and simultaneously aware of the critical aspects of the phenomenon to be studied. Thus, what can be appreciated is that while phenomenography offers perspectives on qualitatively different ways to experience the phenomenon, theory of variation bring to the fore how discernment can be deliberately brought about to encourage more advanced and complex ways of experiencing the phenomenon. The theory foregrounds the creation and enactment of patterns of variation and invariance, as

well as “the best source of insight into what is critical and what is necessary: the learners themselves” (Marton & Pang, 2006, p. 217).

The subsequent sections, focusing on how the theory was applied in educational settings, serve to illustrate through a review of literature how theory of variation was used as a theory to guide the organization, enactment and evaluation of students’ learning experiences. Extending the literature review to illustrate the potential for teacher learning and professional development in a theory of variation-framed learning study, the lack of studies to further enrich this aspect of inquiry is highlighted. The chapter concludes with a brief description on how theory of variation was employed to help frame and analyze both student and teacher learning opportunities in this research study.

2.2.1 Object of learning as the focal starting point

As observed in studies employing the theory of variation, the object of learning was often taken as the focal starting point for teachers to plan and implement their research lessons. What is learned (a capability or value to be developed) is the “object of learning”. That learning always has an object is of central importance to theory of variation (Marton & Booth, 1997; Pang & Marton, 2003; Runesson, 2005, 2006). With the notion of “intentionality”, Franz Brentano posits that all psychological acts are intentional, that is, they are directed towards something else beyond the acts themselves (Bowden & Marton, 1998; Marton, 1986, 1988; Marton & Booth, 1997; Runesson, 2006). Thus, there “is no learning without something learned, there is no thinking without something thought, there is no experiencing without something experienced” (Bowden & Marton, 1998, p. 40).

Theory of variation can be employed as a theoretical framework that guides teachers to determine both the object of learning, as well as the critical aspects that constitute the object of learning. The determination of the object of learning is pertinent because different objects of learning would imply that different things are learnt (Marton & Booth, 1997). In addition, certain patterns of variation and invariance in the learning context are related to a specific object of learning. Marton et al.'s (2004) study supports this view. In their study, how students solved arithmetic tasks were correlated with the nature of the tasks, the latter representing different objects of learning. The results suggest that what was possible to learn was determined by what was discerned. In the same vein, Runesson (2005) posits that theory of variation sheds light on one feature of classroom learning, that is, what it is possible to learn in terms of what may be discerned. Because learning is contingent on experiencing variation, the dimensions corresponding to the aspects of the object of learning in which variation could be experienced and discerned simultaneously define the space of learning (Marton & Booth, 1997; Marton & Trigwell, 2000). Widening the space of learning demands the creation of certain conditions, such as (1) a simultaneous pattern of variation and invariance, which allows the learner's focal awareness to bear upon the critical aspects; and (2) a "meeting of awareness". (The two conditions are discussed in greater detail in the next two sections (Section 2.2.2 and 2.2.3)).

The object of learning, as used in a theory of variation-framed learning study, can be differentiated into (1) the intended object of learning (typically the chosen object of learning to be focused upon, including also the finalized design of instruction consisting the patterns of variation and invariance to be used), (2) the enacted object of learning (how the object of learning is implemented in the classroom, which thus have a direct impact on the students), as well as (3) the lived object of learning (which represents to what extent the object of learning

was mastered by the students after instruction) (Marton & Booth, 1997; Marton & Pang, 2006; Marton & Tsui, 2004). It can be appreciated that the intended object of learning guides the enactment of the pattern of variation and invariance implemented (enacted object of learning), and students' learning (lived object of learning) can be understood by establishing the relationships between the enacted and lived object of learning.

2.2.2 Creating patterns of variation and invariance

According to phenomenography, discernment is deemed as the core of ways of experiencing the world around us. It means that a feature of the physical, cultural, symbolic or sensuous world appears to the subject. With the basic tenet that discernment or experience is always the discernment of variation or the experience of difference, the feature is seen or sensed by the learner against the background of previous experiences (Marton & Pang, 2006). An employment of variation theory thus urges the creation of certain patterns of simultaneous variation and invariance - to determine which particular aspect is varied while other aspects remain invariant, such that the varying aspects are what will be discerned or come to the fore of awareness. This characterizes and brings about certain ways of experiencing.

...we can only experience simultaneously that which we can discern; we can only discern that we experience to vary; and we can only experience variation if we have experienced different instances previously and are holding them in our awareness simultaneously... (Marton et al., 2004, pg. 20).

The importance of a pattern of simultaneous variation and invariance was demonstrated in Pang and Marton's (2003) study, and was further underscored in a subsequent study they conducted in 2005. In the first paper, the economic concept of the distribution of tax burden between buyers and sellers was focused upon. The paper featured two groups of teachers (five teachers each) teaching students in the age range 16-18 years. In the first group, the Japanese

lesson study approach was employed (Stigler & Hiebert, 1999), whereby the lesson plan was based on teachers collaboratively pooling their teaching experiences. The second group adopted the learning study approach, whereby the lesson plan was likewise constituted through teachers collaboratively pooling their teaching experiences, but extended beyond to include the employment of theory of variation to help organize and implement student learning experiences. Comparing students' understanding after the respective classroom interventions, results revealed that fewer than 30% of the students in the lesson study group developed a good grasp of the concept of incidence of sales tax, whereas over 70% of the students in the learning study demonstrated competency in grasping the difficult concept. The differences in the student learning outcomes were interpreted in light of how the concepts were dealt with differently in the classrooms. That is, although teachers in both the lesson and learning study groups introduced variation in the critical aspects of demand elasticity and supply elasticity, only teachers in the learning study group introduced variation in both aspects *simultaneously*. Thus the difference in learning outcome was interpreted in light of this different pattern of simultaneous variation and invariance.

Pang and Marton (2005) subsequently carried out another study that served to reiterate the saliency of patterns of simultaneous variation and invariance in promoting student learning. (The study was also reported in Marton and Pang (2006).) The object of learning was the development of 16-18 year old students' ability to take into account the relative magnitude of change in demand and supply when determining the change in the market price of a commodity. Two teachers were assigned to the learning study group whereas three teachers were in the lesson study group. Similar to the previous study (Pang & Marton, 2003), both groups were afforded opportunities to plan the lessons based on the pooling of collective expertise and

experiences. This study, however, differed from the previous one in that the planning of the lessons also drew on student pre-lesson test and interviews administered, whereas the previous study relied on results of a pilot study conducted by the researchers. The difference between the lesson and learning study group, again, hinged on whether theory of variation was employed as a theoretical framework or not. This study provided deeper insights into the importance of the patterns of simultaneous variation and invariance enacted. What is interesting is that teachers in both the lesson and learning study groups employed patterns of variation and invariance. Both planned a sequential variation in the change of demand and the change in supply, to be followed by a simultaneous variation in the change in demand and supply, as well as the relative magnitude of the change. However, a higher ratio of students in the learning study group was able to demonstrate the object of learning than in the lesson study group - evident in both the post-lesson test and student interviews. The authors attributed the differences in students' performance to four differences in the enacted object of learning, which was alluded when one applied the theory of variation to aid in the interpretation of student learning experiences. In short, what was demonstrated is that the learning study group introduced variation in supply and demand in a more systematic and thorough way. What is equally noteworthy was that the use of theory of variation as a framework for analysis revealed differences in the learning context, elucidating more clearly the differences in the different patterns of variation and invariance enacted and how they subsequently brought about differences in student learning outcomes.

The application of theory of variation to determine the patterns of variation and invariance to be used in classroom instruction was also carried out in other grade levels. Pang et al. (2006) demonstrated how Grade 4 teachers participating in a learning study also made use of patterns of variation and invariance in their classroom teaching. This granted students

opportunities to reflect on the variation of demand while keeping the supply and the types of good invariant; the variation of the supply while keeping the demand and the types of goods invariant; and the simultaneous variations on the supply of the goods as well as the variation in the purchasing power of people (demand for the goods).

The application of theory of variation in classroom teaching was also reported to improve Grade 3 students' learning about the color of light in Hong Kong (Lo et al., 2006). Within the context of a learning study, teachers were sensitized to the variation in students' ways of understanding the formation of rainbows. The insights drawn, coupled with the teachers' own teaching experiences, enabled the teachers to organize their classroom instruction using patterns of variation. Of interest here was how the patterns of variation and invariance were extended beyond the inclusion of critical aspects of an object of learning to include variation in how these aspects could be represented. In the study, students were given opportunities to understand the concept of the splitting and recombination of white light through the use of different objects (such as prisms, soap bubbles) and analogies, while keeping invariant the key concepts that the analogies refer to. In the same vein, Runesson and Mok (2004) likewise support the use of such patterns of variation. The authors presented a classroom lesson that aimed at helping students engage with the mathematical concept of transformation of shapes - "the postman's route". In the lesson, students were presented with the task of having to join nine dots on a paper to determine the route a postman (taking up one dot on the paper) had to take in order to deliver a letter to each of the eight places (represented by the other 8 dots). The lesson demonstrated how the presentation of different solutions to solve the same mathematical problem creates a dimension of variation whereby students could reflect on various aspects of the solutions presented. Firstly, students could discern possible routes from

impossible ones, and subsequently, possible routes from best routes (that were chosen based on the shortest possible route). Secondly, students had to discern the regularities exhibited by the shapes of the set of “best routes”, drawing students’ attention to the rotations and reflections of the shapes (transformation of the shapes).

It is worth mentioning that Lo et al. (2006) reported that the use of analogies to help students discern the part-whole relationship between white light and the rainbow was not as effective as they envisioned. In the evaluation of the lesson, they hypothesized that students may also need to experience simultaneous variation in the light source and variation in the spectrum formed. The “postman’s route” lesson may shed light and support such a hypothesis. While both studies made use of variations in analogies/representations, in the “postman’s route” lesson, these variations were followed up by opportunities to experience the variations of the critical aspects - students were asked to discern the regularities exhibited by the shapes of the set of “best routes”. This was a missing step in Lo et al.’s study.

In a study conducted by Linder et al. (2006), it was decided upon to focus on the need to conceptually discern “what is” and “what is not” for an appropriate application of Newton’s third law. Selected first-year physics students in a university in Cape Town were interviewed. A force concept inventory (Hestenes, Wells & Swackhamer, 1992) was also used to reveal students’ conceptions. Coupled with the use of physics education literature to reveal critical features in learning Newton’s third law, and responses from colleagues who engaged in a discussion forum about the ideas around the literature, the most critical feature of learning Newton’s third law was decided upon. The authors felt it was important for students, when learning about Newton’s third law, to decide on a system and consistently use that system in

their analysis. A comparison was made between the “ad hoc” class and the “variation” class. The latter was given opportunities through a case study to systematically vary the forces acting on an object (a horse), and subsequently the ones acting on the cart attached to the horse. The differences in learning outcomes between the two groups were attributed to the patterns of variation used, with the authors asserting that variation offered a systematic and effective way of promoting discernment and thus allowing students to better understand Newton’s third law.

In the study of Fraser et al., 2006, the use of variation to enhance learning in engineering was supported. The design of the study draws from the notion of a learning study to identify the key aspects of the learning situation. An object of learning was crafted around university students having to learn about the process of distillation. Subsequently, a computer pre-simulation test was run to ascertain third year engineering students’ knowledge of distillation. The insights gained from the pre-test led to the planning and implementation of the learning experiences, whereby a set of exercises was modified based on the pre-simulation test results. The simulation exercise implemented required students to increase the purity of a distillate by varying the number of trays in the columns as well as the feed tray location. A similar study enhancing university students’ learning of engineering was conducted by Fraser, Pillay, Tjatindi and Case (2007). Drawing from the notion of learning study, the study focused on enhancing students’ learning of fluid mechanics using computer simulations. The simulations were developed based on patterns of variation and invariance, drawing also from the results of a “Fluid Mechanics Concept Inventory” (Martin, Mitchell & Newell, 2003) administered. In the first simulation, fluid velocity was varied, while in the second, the diameter was varied to show the changes in velocity and energy through a pipeline. In the third, students can vary the velocity of each of the plates and observe the changes in the velocity profile between the plates. What

was underscored was that the simulations were highly visual in nature, and were useful to aid students' visualization of abstract concepts.

The studies mentioned above (Fraser et al., 2006, 2007; Linder et al., 2006), alongside others (Fraser & Linder, 2009; Linder & Fraser, 2009), illustrate how the variation approach has great potential for enhancing higher education engineering, science and mathematics students' learning in complex learning environments. What is also noteworthy is that the difference between their studies and that of Pang and Marton's (2003, 2005) is that in the former, the researchers themselves were also directly involved in the interventions, whereas Pang and Marton worked with teachers who enacted the teaching of the research lessons.

In a more recent study, Pang (2009) extended the employment of a theory of variation-framed learning study to enhance a domain-specific capability. His study seemed to be amongst the first learning studies of such nature. The study aimed to help Grade 12 students develop not only the understanding of a specific concept, but also their financial literacy. The latter was deemed as a kind of domain-specific generic capability - students' ability to handle complex, everyday financial situations. Using a similar approach as previous studies (Pang & Marton, 2003, 2005), twelve teachers participated in the study – six working in a learning study group, while the other six, in a lesson study group. Pang's study seems to also be amongst the first learning studies to employ multiple student post-lesson tests to capture the impact of the research lessons over a prolonged period of time. Compared to previous learning studies that typically employed one student pre-lesson and one post-lesson test, Pang's approach differed by having three post-lesson tests – one following the research lessons, and delayed posttests six weeks and six months after instruction. The pre-lesson and first post-lesson tests had identical

questions, while new questions were used in the subsequent delayed post-lesson tests. The study reported on how students belonging to the learning study group outperformed the lesson study group in all three post-lesson tests conducted, with a persistent and even widening performance gap observed over time. The differences in learning outcomes were attributed to how the teachers in the learning study group employed theory of variation in the organization and enactment of the object of learning, with the use of more systematic patterns of variation and invariance.

The recent employment of a theory of variation-framed learning study to enhance a domain-specific capability was also reported in Cheung's (2009) study, which focused on the generic capability of creativity in Chinese writing. In the study, the teachers handled the object of learning in different ways by creating different patterns of variation and invariance. This resulted in different student learning outcomes.

The studies reviewed above, and other studies (e.g., Pang and Marton, 2007), illustrate how theory of variation, when employed within a learning study, can help to enhance student learning. A review of literature also revealed studies in which the notions of theory of variation were supported outside the context of a learning study. These studies likewise foreground the importance of patterns of variation and invariance, and provide compelling evidence that the explicit use of variation can make a difference to student learning outcomes. For example, the books *What Matters? Discovering Critical Conditions of Classroom Learning* (Marton & Morris, 2002) and *Classroom Discourse and the Space of Learning* (Marton & Tsui, 2004) provide examples that foreground enacted objects of learning that arose primarily from practice-based insights. These insights occasionally illustrate principles that were compatible with theory

of variation (Marton and Morris, 2002), thus aiding to define and refine the theory. For instance, Kwan, Ng and Chik (2002) (in Marton & Morris, 2002) described a teacher showing his students a video of a sloth a number of times. Each viewing focused on a different critical aspect of the sloth, such as its appearance, its movements. The pattern of variation created thus allowed for different aspects of the sloth to be brought into focal awareness, and thus something new can be learnt about the sloth with each repetition. (The same example was also cited in Marton and Tsui (2004)). Fraser and Linder (2009) mentioned this example, along with that of Runesson and Marton (2002), to illustrate the need for purposeful repetition as a tool to foster reflective learning (Linder & Marshall, 2003; Marton & Trigwell, 2000).

Before concluding this subsection, it is worth mentioning that if the aim of learning is to develop a certain way of experiencing, patterns of variation and invariance should be thought of in context of the learning experience rather than in terms of teaching methods (Bowden & Marton, 1998). In other words, the starting focal point of a learning study should be on what should be learned – the kind of capabilities to be developed and hence a focus on the way in which the object of learning is dealt with (Bowden & Marton, 1998). Such a focus may be deemed valuable, especially in light of Seidel, Rimmele and Prenzel's (2005) study that illustrates how goal clarity and coherence (equivalent to a clear focus on the object of learning) resulted in positive competence development.

2.2.3 Pedagogy of awareness, building of relevance structure and establishment of common ground

In the context of theory of variation-framed learning studies, the potential for teachers to be aware of students' prior experiences of the object of learning was illustrated. Within a learning study, the shared space of learning can be created and widened through the use of pilot test results (e.g., Pang & Marton, 2003); administration of pre-lesson test and/or interviews (e.g., Pang & Marton, 2005); and/or the use of inventories (e.g., Linder et al., 2006) to reveal the different ways students experience the object of learning. This was illustrated in the studies reviewed in Section 2.2.2. The results were drawn upon during lesson planning and implementation, guiding the constitution of the object of learning as well as the design of patterns of variation to be enacted. For example, in Pang and Marton's (2005) study, student pre-lesson test and interviews were conducted. The phenomenographic analysis revealed a distribution of conceptions that represented five qualitatively different ways of understanding changes in price, ordered in increasing complexity. Only one student displayed the most complex conception, that is, to discern the relative magnitude of changes in demand and supply. Consequently, this novel way of understanding changes in price was deemed by the teachers to be a worthwhile ability for students to acquire, and thus constituted the object of learning for the study - to understand changes in price in terms of the changes in demand and supply, while concurrently taking into account the relative magnitude of changes in both aspects. This influenced how the teachers in the learning study group proceeded to plan and enact patterns of variation and invariance in order to help students discern the critical aspects of the object of learning.

A later study (Pang et al., 2006) that also involved students learning the economic concept of price likewise demonstrated how a “pedagogy of awareness” (Marton & Booth, 1997) could be developed from the implementation of theory of variation in the classroom. What was illustrated in the study, as was likewise demonstrated in other studies (Fraser et al., 2006, 2007; Linder et al., 2006; Lo et al., 2006; Pang & Marton, 2003; 2005), is the ‘mutual awareness’ that was promoted between teachers and learners. The “negotiation” of the space of learning could be deemed collaborative, in view that the critical aspects of an object of learning were determined empirically. In other words, the critical aspects of an object of learning were drawn from students’ “real” experiences, which were uncovered through the pre-lesson tests and/or interviews within the learning study. What is underscored is that the characterization of the variation between qualitatively different ways of experiencing something cannot rest on a priori analysis, but is empirically grounded (Marton & Booth, 1997). Such a characterization is taken into consideration together with teachers’ own experiences and ways of experiencing the object of learning (Booth, 1997; Pang et al., 2006) to determine the critical aspects of the object of learning, as well as the organization and implementation of student learning experiences. In doing so, the “common ground” between the teacher and learners can be widened (Bowden & Marton, 1998; Marton & Booth, 1997; Marton et al., 2004; Tsui, 2004). Thus, “pedagogy of awareness” can be promoted via variation in students’ ways of experiencing the object of learning, variation in teachers’ ways of experiencing the object of learning, and the use of variation (theory) as a pedagogical tool to enhance student learning. What is also emphasized is the notion of “relevance structure” - a “way in which the personal context is making certain aspects of the particular situation appear more important than others, making them come to the fore, while others remain in the background” (Bowden & Marton, 1998, p. 38); that there must

be a match between what is figural and ground for both the teacher and the students (Marton & Booth, 1997; Marton & Tsui, 2004, Tsui, 2004).

Foregrounding the importance of widening the common ground and establishing relevance structure, the deliberate use of case studies or examples that are relevant to students has been emphasized in the research studies. For example, in Pang and Marton's (2005) study, case studies such as the price of chicken that were affected by bird flu; the price of VCDs; and the price of a popular "toy rocket" were used as entry points to probe for students' understandings. Also, the case study of the facemask market was used when SARS (Severe Acute Respiratory Syndrome) hit Hong Kong. This exemplified the way teachers established a context for learning, that is, as a way to bring students an experience of the abstract economic concept of changes in price in a meaningful way. In "the postman's route" lesson (Runesson & Mok, 2004), the real-life context of a postman delivering letters helped the students to learn about the abstract mathematical concept of transformations.

Another noteworthy consideration is how revealing students' experiences point to the qualitatively different ways in which the phenomenon is experienced, as opposed to merely capturing conceptions as right or wrong. As such, an understanding can be appreciated in terms of part-whole relationships - a learner's idea can be appreciated as partial rather than wrong (Marotn & Booth, 1997). The power of such a perspective is that conceptions are less easily brushed aside and relegated as problematic. Rather, they can be used to constitute the object of learning, or as ways to understand the phenomenon from the learner's eyes. The importance of students' prior experience is, however, not an exclusive premise of theory of variation. Students' prior knowledge making a difference to what is learned next, both in facilitating and inhibiting

learning, is a basic tenet of constructivism (Driver & Erickson, 1983; Erickson, 2000). Similarly, the conceptual change theory (Posner et al., 1982), an outgrowth of constructivist epistemology (Hewson & Hewson, 1984; Tyson, Venville, Harrison & Treagust, 1997), explicates the role of prior knowledge in students' learning (Gilbert & Watts, 1983; Pintrich, Marx, & Boyle, 1993). Both conceptual change theory and theory of variation contend that learning is simply the addition of new knowledge (Hewson & Hewson, 1984; Marton & Booth, 1997). And although the employment of theory of variation within a learning study may also lead to conceptual change, the student tests and interviews conducted within the context of a learning study were not used primarily to "measure" the presence or degree of conceptual change. Neither was the identification of "wrong answers" its primary intent.

2.3 Theory of variation as a tool to interpret students' learning experiences

The comparison of student pre- and post-lesson tests and interviews was typically employed to evaluate students' learning within a learning study. Together with classroom evaluations (conducted by teachers and/or researcher/s) and analyses of video-recorded lessons, the tests and interviews aid to uncover the changes in the ways students have experienced the object of learning (e.g., Lo et al., 2006; Pang et al., 2006; Pang & Marton, 2003, 2005). As consistent with a phenomenographic approach, these qualitatively different ways of experiencing were often captured as categories that were presented in a hierarchical fashion. The increase of percentages within a "higher order" category after classroom intervention would suggest that learning has taken place, since learning is appreciated as the ability to experience in more complex and advanced ways. In contrast, in Pang's (2009) recent study, the ordering of the categories was based on the number of dimensions of the variation of critical features considered instead - due to the focus on a domain-specific generic capability and their belief that

there is no single definitive way of understanding ill-defined authentic financial problems. In his study, answers that demonstrated the inclusion of *more* critical aspects of the phenomenon were deemed as being more sophisticated and of a “higher level”.

As observed in the studies reviewed earlier (Section 2.2), phenomenographic perspectives and theory of variation were drawn upon to interpret the impact of classroom intervention on students’ learning. Students’ learning experiences were further explored in terms of how changes in these learning experiences (or lack of them) could be understood with respect to the patterns of variation and invariance enacted, and what were consequently at the fore of awareness of the students. Thus, the conditions that were shaping the possibilities of what could be experienced could be evaluated (Marton & Booth, 1997; Runesson, 2006), even as the lived object of learning (what students learnt) was examined in light of the enacted object of learning (how the object of learning was dealt with). Consequently, suggestions could be made to further enhance students’ learning, as was observed in Lo et al.’s (2006) study, as well as that of Fraser et al.’s (2006, 2007).

Extending beyond a learning study context, there are several studies that also illustrate how the principles behind theory of variation were used to interpret the enacted and lived objects of learning. For example, Runesson and Mok (2004) cited the classroom discourse of “the postman’s route” to reiterate the importance of the creation of *dimensions of variation* to enhance student’s learning. Similarly, Chik and Lo (2004), in citing a case study of Chinese language lessons, emphasized the importance of these patterns that afforded students the *simultaneous* experience of context (relevance), whole and parts. Tsui, Marton, Mok & Ng (2004) highlighted, through the descriptions of the physics lessons implemented (on electricity),

the importance of appropriate classroom discourse - particularly the use of questions and language to help students to focus on various critical aspects, while Tsui (2004) underscored the saliency of establishing common ground. What is interesting is that theory of variation can also be used to re-interpret a classroom discourse. For example, Runessons' (2005) study involved a re-analysis of a mathematics classroom. The study revealed the constraints and possibilities on what it is possible to learn in light of theory of variation.

2.4 Potential for teacher learning

Within this chapter, the review of literature revealed how teachers learnt to handle the object of learning by (1) paying attention to the qualitatively different ways in which the object of learning could be experienced by the learners; (2) using these emerged understandings to determine the object of learning and critical aspects, and subsequently, (3) to guide the enactment of the object of student learning based on designed patterns of simultaneous variation and invariance. What is worth reiterating is that although previous studies focusing on the learning study have thus pointed to the potential of learning study to promote teacher development, there appears to be relatively few published studies explicitly addressing this area of interest. Pang (2006) and Davies and Dunnill's (2008) studies are amongst the published works that illustrate the gaining of interest in this aspect.

Pang's (2006) paper reported an investigation of how a theory of variation-framed learning study influenced ten in-service teachers' ways of experiencing teaching economics (sales tax incidence). The teachers were interviewed individually before the start of the learning study, with the aim of uncovering the teachers' views on teaching economics and how they conceived good economics teaching. A follow-up interview was conducted at the end of the

study to examine whether the teachers had developed different ways of experiencing teaching economics. Using a phenomenographic analysis, five qualitatively different ways of experiencing teaching economics were identified. In view that learning was seen as a qualitative change in one's way of experiencing, such that the learner experiences a phenomenon in a more complex way than before, the author demonstrated that teachers learnt professionally. Pang also made the claim that the teachers seemed to have demonstrated a more complex way of experiencing the teaching of economics in accordance to the hierarchically arranged ways of experiencing teaching. Most of the teachers were reported to have shifted their focus from a teacher-centered to a more student-focused approach; from teaching towards student learning; from knowledge and/or skills towards a way of understanding the phenomenon; and from the school context towards multiple contexts. Although there was no explicit mention of how theory of variation influenced the teachers' learning, one can appreciate that a focus on students' understanding and learning is a basic tenet of theory of variation. In addition, a shift in attention to focus on understanding a phenomenon, or to be mindful of the variations in contexts to be taken into consideration, suggest how the theory might have influenced the teachers. This study thus lend support for more studies to pursue a similar line of inquiry to uncover the learning that teachers experience in the context of a theory of variation-framed learning study.

In Davies and Dunnill's (2008) study, rather than implementing a study with in-service teachers, the authors adopted the learning study framework as part of a "plan-teach-review" model in initial teacher education. The trainee teachers were preparing to teach business and economics, as well as design and technology, in secondary schools in the UK. The learning study approach implemented largely resembled that of Pang and Marton's (2003, 2005), and aimed to help trainee teachers to progress to more sophisticated conceptions of teaching.

Because the authors deemed the demands of uncovering students' ways of experiencing a phenomenon using a phenomenographic approach limiting - in terms of its practicability as a routine part of teachers' practice, the trainees participating in the learning study were encouraged to gather data on students' conceptions through alternative approaches. Another difference between the learning study implemented in Davies and Dunnill's study from that of Pang and Marton's is in the use of a "learning outcome circle". Based on the theory of variation, the circle allowed the trainees to map out the features of any particular conception, rather than the typical mapping of critical aspects of a phenomenon. As such, variation theory was used in a more "general" sense in their study. The results of the study indicated how the learning study was used effectively as a vehicle for the trainee teachers to develop new ways to think about students' experience of learning. Especially with the help of a "learning outcome circle", the trainees' thinking during the planning stage gained greater clarity. The results of the study also supported a proposition made in their earlier paper (Davies & Dunnill, 2006) - by providing a basis for focusing teaching on the transformation from everyday understanding to more sophisticated, academic understandings of particular phenomena, theory of variation addressed the problem of separation between students' everyday and school knowledge. However, in the study, there was no explicit mention of the trainee teachers' account of how the theory could have influenced their own pedagogy beyond a sensitization to the different ways their students can approach the topic of interest.

In Chiu's study (2005) (an unpublished thesis), a Grade 10 Chemistry teacher's participation in the learning study was reported. The results illustrated how the teacher's views on teacher collaboration and teachers-as-researchers have broadened; how her goals of teaching has changed; and how her pedagogy was influenced. For example, the teacher came to a

realization that teachers were not only knowledge transmitters. She also came to a realization that collaboration could be employed in a way whereby teachers can work together as researchers to improve their teaching and to enhance their own professional development. The teacher also developed a stronger desire to learn after participation in the learning study. Alongside the rest of the learning studies, Chiu's study thus lends support for the current research study. In seeking to further elucidate the different ways teachers could experience learning in a learning study, the potential of a learning study as an approach for teacher professional development could be explored.

2.5 Theory of variation as applied in this research study

Consistent with research literature (Lo et al., 2004, 2006; Pang & Marton, 2003, 2005; Pang et al., 2006), theory of variation was employed as a theoretical framework in this current study to guide collaborating teachers in the designing and teaching of genetics lessons, and the subsequent evaluation of students' learning. The strength and beauty of the theory, as exemplified in literature, lies in its potential to be used as a learning theory that offers a way of looking at learning, as a theory of instruction (Lo et al., 2006), as well as an analytical tool to understand student learning. This study also extends the use of the theory to the topic of transcription and translation in genetics, and to the educational context of a Singaporean classroom.

The methodological framework in this study also draws upon theory of variation to design the learning study, aiding in the organization and implementation of teacher learning experiences. Learning could thus be appreciated as teachers developing a capability to experience various aspects of teaching in more advanced or complex ways that they did

previously. In this way, they could have learnt professionally. This perspective helped to frame an understanding of the teachers' own learning in the learning study. What is foreground was how conditions that might encourage certain types of learning were thoughtfully and carefully set up through patterns of variation and invariance. A review of literature seems to indicate that the explicit use of theory of variation as a methodological framework to organize and implement teacher learning experiences within a learning study has not been extensively reported. Nonetheless, the analysis carried out by Pang (2006), which borrows the same view of learning from phenomenography and theory of variation to understand teacher learning, lends support for the way the theory was used in the current study. Moreover, having applied theory of variation in two different ways within the current study - to facilitate and understand both student and teacher learning, it lends support for the employment of theory of variation as the theoretical framework for the entire study.

CHAPTER 3

METHODOLOGY AND METHODS EMPLOYED

In this chapter, the use of a phenomenographic perspective to understand learning is further described. Subsequently, the learning study approach is introduced in greater detail, leading to the description of the learning study implemented in this study. The data sources and data analysis process are also described, followed by a discussion on how I have situated myself in this study. This chapter concludes with a discussion on the trustworthiness, reliability and validity of the study.

3.1 Using a phenomenographic perspective to understand learning

Phenomenography, as a research approach, is appropriate in this study because of its relational nature – that phenomenography aims to describe an aspect of the world as it appears or is experienced by an individual (Marton, 1986). Its second-order perspective (Marton, 1981), which posits a focus on the participant's ways of experiencing something, is particularly useful as it is consistent with the research questions of the current study that aimed at elucidating how teachers learn about their own pedagogy. What teachers say about their own experiences and learning could be analyzed and reported by the researcher.

The qualitatively different ways in which teachers experience various aspects of learning, as promoted by a learning study context, can be mapped by a phenomenographic approach. The interest of phenomenography lies in the capturing of the variation and change in capabilities for experiencing the world, or rather, in capabilities for experiencing particular phenomena (Marton & Booth, 1997). Complimented by the theoretical perspective of learning

offered by theory of variation, what is mapped has the potential of capturing changes that indicate how teachers would have experienced a particular critical aspect of their professional lives in a more advanced way (in the context of the current study). This subsequently points to how they learnt about their own pedagogy.

The primary outcomes of phenomenographic research are categories of descriptions comprising of distinct groups of aspects of the phenomenon and the relationships between them, as opposed to information linked to individuals experiencing the phenomenon (Marton & Booth, 1997). These sets of categories of description, termed also as the “outcome space” (Marton, 1981; Marton & Booth, 1997), can thus capture the complex of different ways that teachers collectively experience learning in the context of a learning study. Marton (1986) posits that to read and classify descriptions of a phenomenon is not merely the sorting of data, but the search for most distinctive characteristics that appear in those data – that it is a search for structurally significant differences that clarify how people define some specific portion of the world.

According to Marton and Booth (1997), these individual categories typically reveal something distinct about a particular way of experiencing the phenomenon. The categories are also constituted in a parsimonious fashion (as few categories were explicated as is feasible and reasonable), as consistent with the assumption that there are a limited number of qualitatively different ways to experience the phenomenon. The qualitatively different ways of experiencing depict differences between and within individuals. Pang (2006), for example, has illustrated the use of these perspectives to capture five qualitatively different ways of experiencing teaching economics. He argued that teachers demonstrated a more complex way of experiencing the teaching of economics after participating in a learning study, which was illustrated by shifts in

the categories formed. Similarly, in my study, descriptions of individual teacher's experiences could be captured. As consistent with phenomenography, the "categories of descriptions" subsequently constructed, revealing teachers' collective experiences, were constructed as emergent themes.

3.1.1 The hierarchical relationship of categories

The sets of categories of description that are constructed through a phenomenographic approach stand in logical relationship with one another and form hierarchical relationships, whereby certain ways of experiencing are deemed more advanced than others (Marton, 1981; Marton & Booth, 1997). In the case of student learning, this hierarchical structure directs teachers to what they should be attending to in order to widen the space of learning. For example, in Lai's (1996) study, phenomenographic perspectives were used to capture three qualitatively different types of undergraduate students' conceptualization of meiosis (a genetic topic) as well as four qualitatively different types of approaches taken when students addressed a problem involving a haploid organism (*Ascobolus* sp.). The different ways of conceptualization and approaches were presented as categories of description that were ordered.

The ordering of categories was also illustrated in Pang and Marton's (2005) study, whereby the conception of one student was deemed a novel and most complex way of experiencing change in price. In view of a learning study's potential in helping teachers enhance students' learning of genetics, the categorization of students' learning in my study (although not reported in detail) were likewise ordered. However, the capturing of teachers' experiences in the current study varied from that of Pang's (2006). The interest of the current study lies in capturing the varied ways in which teachers learn rather than their experiences or conceptions of

teaching a specific subject. In addition, the “categories” in the current study were not ordered, but were presented as emergent themes. This is because it was not the intention of this study to deem one aspect of teacher learning to be more advanced than another. Rather, the intention was that in capturing the variation in teachers’ learning experiences, the variety of learning opportunities afforded by the learning study context could be explored.

3.2 The learning study approach

The concept of a learning study was inspired by a combination of the “lesson study approach” - systematic efforts of Japanese (Stigler & Hiebert, 1999) and Chinese teachers (Ma, 1999) to conduct in-depth studies of particular lessons, and the idea of design experiments (Brown, 1992; Collins, 1992, 1999). Lesson studies in Japan and China highlight collaboration amongst teachers to improve teaching and students’ learning. They also posit a focus on a specific object of learning - a capability or value to be developed during a single lesson or over a longer period of time (Pang & Marton, 2003, 2005). Drawing also from design experiments, which aims to “engineer innovative educational environments and simultaneously conduct experimental studies of those innovations” (Brown, 1992, p. 141), learning study also encourages teachers to inquire about their own practice within the context of the classroom. A lesson study can be deemed as an approach to encourage teachers to become researchers in their own classrooms as well. But because design experiments are often theoretically grounded and can be appreciated as intervention research designed to combine the instrumental and theory-oriented functions of research activities (Collins, 1992, 1999), the inclusion of ideas around design experiments serves to compensate for the lack of a theoretical frame in the design of a lesson study (Pang & Marton, 2003). The drawing of the strengths of the two different

approaches (lesson studies and design experiments) constitutes what Pang and Marton (2003, 2005) would deem as the aims of learning study. Firstly, it aims to build innovative learning environments and to conduct research studies of theoretically grounded innovations. Secondly, it aims to pool teachers' valuable experiences in one or a series of research lessons to improve teaching and student learning. In the rest of this section, the steps of the learning study are presented, and the key features of a learning study are discussed in greater detail. The latter also serves to support the use of learning study in the context of the current study - as an approach to encourage teacher learning and professional development.

3.2.1 Steps in a learning study

The main steps of a learning study (Lo et al., 2006; Pang & Marton, 2003, 2005) are summarized below. Although the learning study typically progressed through these steps, the steps are not always in a fixed sequence. Some steps might occur simultaneously, and some might be revisited during iteration cycles (Lo et al., 2006).

1. Choosing and defining the (intended) object of learning.
2. Ascertaining students' pre-understandings and identifying the critical aspects of the object of learning, through in-depth study of the object of learning and analyses of diagnostic pre-tests and/or student interviews to ascertain their pre-understandings.
3. Planning the research lesson, with the teachers and/or researcher (facilitator) working together to establish a course of action grounded in the theory adopted.
4. Implementing and observing the research lessons. Post-lesson conferences are held after each cycle of the research lesson to review the lesson unit.
5. Evaluating the research lesson. Pre- and post-lesson tests comparisons are typically used to reveal students' development of the intended capability.

6. Reporting and disseminating the results, including documenting and reporting the aims, procedures and results of the attempt; and distributing the resulting document to other teachers or to the public.

3.2.2 Collaborative aspect of learning study

Teachers' sharing of practices and knowledge as part of their professional development has long been acknowledged and valued. There is increasing literature foregrounding the need for teachers to work as members of a community (e.g., Arbaugh, 2003; Lieberman, 2000; Nelson & Slavit, 2007; Shulman & Sherin, 2004; Wineburg & Grossman, 1998). The studies highlight the importance of reflection, collaboration, and inquiry as teachers work to transform their classroom practice - to acquire greater depth in curriculum instruction and assessment; to solve problems; to construct knowledge and build up theories; and to form and re-form frameworks for understanding their teaching practice (Chan & Pang, 2006; Little, 2001). According to Hargreaves (1992), collaborative cultures that share and discuss ideas and resources are absolutely central to teachers' daily work. They are naturally found in the "minutiae of school life" (Hargreaves, 1992, p. 226). Hobson (1996) similarly mentioned how teachers can almost always be found sharing anecdotes about their experiences with children. Drawing support from Schubert (1992) who deems that telling anecdotes enables the teller to bring experience into language, Hobson likewise regard telling anecdotes as a vital part of doing teacher research.

Within a learning study, opportunities for teachers to share their knowledge, "anecdotes" and stories are afforded via "lesson-focused" collaborations. The value of such collaborations for teacher professional development was widely recognized (e.g., Davies & Dunnill, 2008;

Hiebert, Gallimore & Stigler, 2002; Pang, 2006; Stigler & Hiebert, 1999). The Japanese lesson study, as accounted for in detail by Stigler and Hiebert (1999), is an approach that exemplifies such collaboration – thus serving as an inspiration to the design of a learning study. (However, it differs from the learning study approach due to its lack of focus on a theoretical framework.) Stigler and Hiebert argued that the opportunities to work in groups to improve instruction have allowed the Japanese teachers to develop a shared language for describing and analyzing classroom teaching, and to teach each other about teaching.

This process of the development of a “shared language” was likewise evident in the learning study approach (Choy, 2006; Lo et al., 2004, 2006; Pang, 2006; Pang et al., 2006; Pang & Marton, 2003, 2005). Beyond the lesson study, the nature of the collaboration afforded by a learning study not only allows for teachers to use, pool and examine their professional knowledge and classroom practices, but that these can be informed and shaped by the learning theory employed. Arbaugh’s (2003) study similarly foregrounds both the collaborative and theoretical aspects, even as teachers found that their participation in the study group helped deepen connections between theory, beliefs and practice. The author attributed such connections to the conscious effort made to ground many of the discussions in theory. Arbaugh’s study lends support that a learning theory may constitute a new or different language given to experience, opening the collective’s possibilities into new ways of thinking and hence learning (e.g., Davies & Dunnill, 2008).

The collaborative nature of learning study, akin to lesson study, may also allow for a “benchmarking process” that teachers can use to gauge their own skills - when they reflect on

their own practice, and identify things that can be improved upon (Stigler & Hiebert, 1999). As Hiebert et al. (2002) aptly describes -

what is discovered will be communicable because it is discovered in the context of group discussion. Collaboration, then, becomes essential for the development of professional knowledge, not because collaborations provide teachers with social support groups but because collaborations forces their participants to make their knowledge public and understood by colleagues. (Hiebert et al., 2002, p. 7)

In the same vein, Marton (1994b) posits that a teacher's personal experiences do not suffice when it comes to preparing students for a wide range of future situations. He supports making a pool of collective knowledge explicit, since it may allow for one to transcend one's personal experiences and taken-for-granted experiential world. Similarly, Bowden and Marton (1998) assert that teachers should learn from other teachers – to become aware of other people's ways of seeing in order that one's understanding is enriched and therefore becomes more powerful. In this way, awareness that resides in each individual becomes linked as teachers articulate their knowledge, forming a “collective consciousness” (Bowden & Marton, 1998). Such a notion is also supported elsewhere (e.g., Nelson and Slavit, 2007).

In a learning study, what is also underscored is the reflection process. Reflection as a way in which teachers learn has been widely recognized in research literature (e.g., Arbaugh, 2003; Clarke & Hollingsworth, 2002; Cochran-Smith & Lytle, 1999; Fenwick, 2003; Francis, 1995; Goodnough, 2005; Schön, 1983, 1987; Shulman & Shulman, 2004; Tillema & Kremer-Hayon, 2000; Van Eekelen, Boshuszen & Vermunt, 2005). Collaboration within a learning study context has the potential to encourage reflection and articulation. Consequently, an internalization of a theory of what teachers are doing and why they are doing it (Chiu, 2005; Davies & Dunnill, 2008), and a kind of joint reflection about the relationship between processes

and products, can occur. (The latter constitutes a central characteristic of what Elliott (1991) would term as “action research”). Elliott also aligned this characteristic with that of Schön’s *reflective practice* (1983, 1987). Schön’s concerns on how to educate *reflective practitioners* led him to identify two reflective processes, of which the first reflects the ability to mirror a reflective process in the action itself, that is, a way of assessing actions in the process of acting – *reflection-in-action*; while the second consist of working through experiences gained from actions after the experience – *reflection-on-action*.

3.2.3 Employment of a theoretical framework

A review of literature has revealed that theory of variation was commonly employed as the theoretical framework in learning studies (e.g., Lo et al., 2004, 2006; Pang et al., 2006; Pang & Marton, 2003, 2005), although this specific theory need not always be the chosen theoretical framework. What was demonstrated through literature is the importance of employing a theoretical framework to guide the organization, implementation and interpretation of students’ learning experiences – as revealed in the literature review in Chapter 2. The review in Chapter 2 also illustrated how the employment of theory encouraged teachers to learn about the object of student learning and how to handle it (e.g., Lo et al., 2006; Marton and Pang, 2003, 2005; Pang et al, 2006) (see Section 2.2.3). The development of such a capability is valuable, in light of Shulman’s (1986) conception of pedagogical content knowledge as one that “goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching” (p. 9). It is the particular form of content knowledge that embodies the aspects of content most germane to its teachability. In addition, the experience of learning to use a learning theory to guide classroom teaching encourages teachers to appreciate that a theoretical framework is

necessary, and “that it is not enough to reflect on tips and tricks for more popular or more efficient teaching” (Booth & Anderberg, 2005, p. 376).

3.2.4 Teachers as researchers

Opportunities for teachers to inquire into their own teaching practices are valued as a form of professional learning (e.g., Pedretti, 1996; Nelson & Slavit, 2007; Wells, 2001; Zack, 2006). Within the context of teachers’ own classrooms, a learning study aims to create a platform whereby teachers can collectively “build innovative learning environments and to conduct research studies for the theoretically grounded innovations” (Pang & Marton, 2003, p. 179). This was a similar aim for design experiment (Brown, 1992). The learning study, however, differs from design experiment on the premise that in design experiment, as many variables affecting the teaching as possible can be studied, whereas learning study posits a narrower focus and addresses only the question of how a specific object of learning can be taught in a powerful way (Marton & Pang, 2006).

The notion of teachers conducting research in their own classrooms as a way to inquire and improve their teaching practices strongly resonates with lines of inquiry involving action research. Earlier works, like that of Stenhouse (1975) (Stenhouse’s Humanities Project), have long recognized research as a necessary component of the work of every teacher, that is, teachers-as-researchers. Subsequent works focusing on improving learning and teaching have also developed (Cochran-Smith & Lytle, 1999; Zeichner, 2003). It is worth mentioning at this point that the steps and collaborative aspect of a learning study could be deemed to resemble that of collaborative action research studies. It is not surprising then, that learning study could be, on one hand, seen as a form of action research (as was mentioned in Marton & Tsui, 2004).

However, one could also argue that learning study's emphasis on a theoretical framework would distinguish both action research models from learning study.

The idea of collective evaluation of teachers' lessons also compels one to look into the nature of such collaborative efforts. Employing an activity-theoretical framework to facilitate teachers collaborative planning, enactment and evaluation of curriculum unit, Engeström's (1994) asserts that "thinking" is seen as embedded in practical collective activity. Similarly, within a learning study context, the opportunity for teachers to inquire into their own practices cannot be divorced from the collaborative nature of learning study. Engeström's activity theory model also points to research on teachers' learning communities, which are grounded in a "situated perspective". Encompassing a situated and social-constructivist view of learning (Putnam & Borko, 2000), the notion of discourse communities sheds light on teachers sharing their varied understandings of pedagogy or their subject areas, whereby they collectively explore their beliefs and values about teaching and learning. The outcome space of learning within these "communities of practice" can thus be interpreted as the coming to a shared understanding of the impacts of their practices on students and/or the larger educational community (Lave & Wenger, 1991). What these works draw attention to, and urges, is to think about learning as a process of social participation.

In a similar vein, and in view that learning study draws from lesson study in its design, learning study can be argued to likewise illustrate how such a process of "social participation" could result in the emergence of joint ownership (Stigler & Hiebert, 1999). According to Stigler and Hiebert, the joint ownership allows for inquiry and critique of lessons to be critical, while escaping the sense of critiquing the individual teacher. Thus, the risk of offending colleagues

can be avoided. Consequently, the discussion can focus more pointedly and deeply on the merits and deficiencies of enacted lessons, and on revisions and improvements. Thus, the learning study, as similar to lesson study, can be deemed to exemplify “critical collegueship” - that

collegiality will need to support a critical stance toward teaching. This means more than simply sharing ideas or supporting one’s colleagues in the change process. It means confronting traditional practice – the teachers’ own and that of his or her colleagues... (Lord, 1994, p. 192).

In the context of a learning study, Pang (2006) has likewise accounted for how teachers have had the chance to reflect upon one another’s teaching by having the opportunity to observe one another’s lessons. From the evaluation of trial lessons and the identification of areas of improvement, the teachers also learnt how to design instruction and enact any given object of learning in a more effective manner. Thus, Pang’s study lends support for learning study to promote teacher learning through teachers’ collaborative inquiry into their own practices. This propels one to further illuminate the nature of such processes.

3.3 Method

In this section, the participants and the learning study implemented are described.

3.3.1 The participants

The study involved a group of four Grade 10 biology teachers from an independent girls school in Singapore. Two teachers (Kate and Chris) had long teaching experiences and the other two (Pam and Amy) were considered less experienced in the profession (see Table 3.1, names used are pseudonyms). School selection was based on its availability, and also because it had a “Professional Development Group” (PDG) program. In the program, teachers were assigned into teams based on the grade level and subjects they taught. Each group was allocated one-hour

slots for weekly meetings. The program aimed to create spaces for teachers to collaboratively work together to improve their practices. The participating teachers belonged to the same PDG teaching Grade 9 to 10 Biology, and the group was formed in December 2008. The selection of participants was based on their availability. In addition, 80 Grade 10 students, belonging to Pam, Amy and Chris' classes also participated in the study. These students represent students in the highest level of academic attainment both in the school and in Singapore.

Table 3.1: Teaching experiences of the participating teachers.

Participant	No. of years teaching Biology (yrs)	Total no. of years in teaching (yrs)	No. of times chosen topic was taught before
Pam	3	3	0
Amy	3	3	1
Kate	7	15	1
Chris	5.5	14	1

3.3.2 Implementation of the learning study

Prior to the implementation of the study, research approval was obtained from the UBC Research Ethics Board. The design of the study drew from research and “learning study” proposed by Pang and Marton (2003, 2005). A total of 15 meetings were conducted – a pre-learning study meeting in October 2008, and subsequent meetings between January 2009 to May 2009. Subsequent meetings were always planned in lieu of what preceded before that. This was an attempt to introduce flexibility within the learning study, such that meetings were enacted based on teachers' readiness to proceed, and to best meet their needs and the challenges that emerged within the study. The meetings are described below.

Meeting 1: Introduction to the study (pre-learning study meeting) (19 October 2008)

The learning study started off with an introduction to the aims of the research study as well as the learning study. How the participating teachers could be involved in the study, their level of involvement and the type of data collected were also discussed. Initially, teachers expressed concern that their participation in this study would increase their workload, and have expressed their reluctance to spend time outside of the allocated meetings on the study. Thus, the agreement was that as much as was possible, all related activities (including data collection by the researcher) should be carried out within the allocated hour. Coupled with their expression of reluctance to spend time on writing reflective journals, weekly reflective journals were not used as a source of data. Rather, time allocated for reflection would be incorporated into the meetings whenever appropriate. In addition, research literature was introduced during meetings with the important parts of the papers highlighted. The full papers were distributed at the end of the meetings as optional readings.

The role of the researcher was also discussed during the meeting, including a facilitator of discussions; organizer of meetings; and a resource person who would introduce relevant literature, the learning study as well as the theory of variation. The researcher would also conduct the student interviews and analyze the student data collected, as well as record and prepare necessary documents for the meetings.

The potential benefits of participating in the study, such as opportunities for teacher collaboration to enhance students' learning, and to inquire into the teacher's own teaching practice, were also presented to the teachers in the meeting. Concerns regarding workload, their participation in the study, as well as confidentiality issues were also addressed, along with other

concerns the teachers themselves expressed. The proposed timeline was also set, and it was agreed upon that the study should be implemented and completed within the first semester of the academic year (January 2009 – May 2009). Subsequently, consent was given by the teachers indicating their willingness to participate in the study, through the completion of consent forms.

Meeting 2: First set of interviews conducted (5-9 January 2009)

In place of a meeting, the first set of semi-structured interviews was conducted by the researcher. Each interview lasted approximately an hour. The first part of the interview focused on teachers' approaches to teaching and learning biology, and their beliefs about what good biology learning and teaching were. This part of the interview also probed for their current teaching practices, revealing the differences in the ways they were teaching and what they perceived good teaching to be. (This set of data was useful as a probe for changes in their beliefs or practices after participation in the learning study, thus revealing how they learnt about their own pedagogy.) The second part of the interview focused on probing for their views on their own learning and professional development. Some of the questions used in the interviews were inspired and modified from those found in research literature (Boulton-Lewis, Smith, McCrindle, Burnett & Campbell, 2001; Pang, 2006; Prosser, Trigwell & Taylor, 1994; Samuelowicz & Bain, 1992; Trigwell & Prosser, 1996, 2004; Wilson & Berne, 1999).

The data collected here was pivotal in the implementation of the rest of the learning study. The understandings that emerged from their epistemological and pedagogical views guided the implementation of the learning study – as consistent with the view that compatibility of the research study with the professional values of teachers' practice, and with their work conditions, should be strived for (Altrichter, Posch & Somekh, 1993). The insights that emerged

also served as a platform whereby future data (such as subsequent interviews) could be interpreted and understood.

In addition, the interviews also provided the teachers a platform to reflect on their own beliefs and practices. This step is akin to the “reconnaissance” phase in action research (Elliott, 1991), which involves teachers engaging in self-reflection to uncover their tacit practice values. Altrichter, et al. (1993) supports such a practice, asserting that interviews constitute a more or less meaningful and conscious learning process for interviewees, whereby interviewees are made to think about a situation or an issue and interrelate experiences, thus potentially gaining a deeper understanding. Other researchers also shared a similar view (Johansson et al., 1985; Marton, 1986). The interviews were transcribed verbatim, and the transcripts were given back to the interviewees once they were ready. In addition, the key points of the interviews were also verbally summarized when the transcripts were given to the teachers, as a way to check for the degree of accuracy in the interpretations. This also provided an opportunity for further clarification of ambiguous parts of the transcripts.

Meeting 3: Choosing the object of student learning (19 January 2009)

This meeting was allocated for teachers to determine the object of student learning, with the aim of helping teachers focus on students developing a capability in relation to specific content, thus encouraging a focus on students’ learning. Rather than a conventional reliance on the curriculum or textbook (as was revealed through the first set of teacher interviews), teachers were thus encouraged to experience lesson planning differently from before. The session started off with an overview of the learning study (introduction to its key features), and an introduction to the notion of an object of study. Subsequently, teachers’ attention was directed to their own

teaching experiences of teaching genetics and other biology topics. Time was allocated within the session to complete a Genetics Questionnaire (Appendix A) that probed for (1) the aspects of genetics that teachers felt were important to teach; (2) the challenges they faced; (3) students' areas of confusion; (4) how students made sense of genetics; as well as (5) the teachers' aims for teaching genetics. The questions crafted drew in part from teachers' responses in the first set of interviews, and in part from research literature (Boulton-Lewis, Smith, McCrindle, Burnett & Campbell, 2001; Koballa, Gräber, Coleman & Kemp, 2000; Prosser et al., 1994; Samuelowicz & Bain, 1992; Trigwell & Prosser, 1996, 2004; Wilson & Berne, 1999). The Questionnaire, coupled with the opportunities carved out for discussions, constitute the deliberate attempts to encourage teachers to reflect on their teaching experiences, and to clarify the problem and challenges faced in teaching the genetics curriculum. This set of data was useful in elucidating the teachers' understandings of their teaching of genetics before participating a learning study, and was useful as a probe for changes in their beliefs or practices after participation in the learning study.

The Genetics Questionnaire also helped to direct teachers' attention towards student learning. This part of the meeting was organized based on the belief that teachers should develop an awareness of their roles, pedagogy and beliefs about teaching and learning. These could well be tacit and taken-for-granted; simultaneously present and residing in different layers of the teachers' awareness, although they may not always be explicit and clear (Marton, 1994). They are also pertinent as "teachers' acts are affected- if not caused, or controlled – by the thoughts they have arrived at, the decisions they have made, the solutions to the problems they have found" (Marton, 1994b, p. 29). Thus, the first set of interviews and the Genetics Questionnaire aimed to bring some of these tacit aspects to the fore. Teachers subsequently

shared what they have written as a way of pooling their experiences. In addition, because it was also the intention for teachers to base their pedagogical decisions on literature, that is, to incorporate literature as a way to bridge possible perceived gaps between theory and practice (Pang, 2006), research literature was also deliberately introduced at this point. The key challenges that were reported in the teaching and learning of genetics were highlighted. In most cases, only highlighted parts or summaries of research papers were given, in view that during the pre-learning study meeting and the first interviews, teachers expressed a reluctance to spend too much time on reading the articles and were asking for “bite-sized chunks”. The literature served as a springboard to propel the teachers towards a more in-depth exploration of the challenges in teaching, and to link their personal experiences to literature.

In the course of the discussions, teachers encountered problems in coming to a collective decision about the object of learning that they wanted to work on. While this created a certain amount of frustration for the teachers and myself, what emerged was a sense that the topic of genetics, spanning across six chapters in the prescribed textbook, was large and difficult to approach holistically. What subsequently emerged was the suggestion to rearrange the genetic topics.

Meeting 4: Introduction to theory of variation (2 February 2009)

Theory of variation was introduced with the use of a PowerPoint slide presentation. The teachers were given a handout introducing the theory (Appendix B). The meeting of awareness and the architecture of patterns of variation and invariance were underscored, of which both were appreciated as ways to widen the space of learning. Theory of variation-framed learning studies were subsequently introduced. In view that one of the main criteria teachers use in

assessing any given “change” is the question whether students will be interested and learn, and if there is evidence that the “change” works (Fullan, 2001), the potential of using theory of variation to enhance student learning was emphasized.

Meeting 5: Determination of object of learning (9 February 2009)

The meeting started off with an example of how teaching experiences and research literature can be used to determine the object of student learning. The example drew upon a pilot study the researcher has implemented in another school in Singapore (see Diagram 3.1). It exemplified how critical aspects of an object of learning could be determined by taking into consideration the fit between the concepts to be taught and the beliefs of the teachers (what they viewed as important to teach). The latter could be informed by research literature or the teachers’ own teaching experiences. These critical aspects could then be used to refine the initially chosen object of student learning.

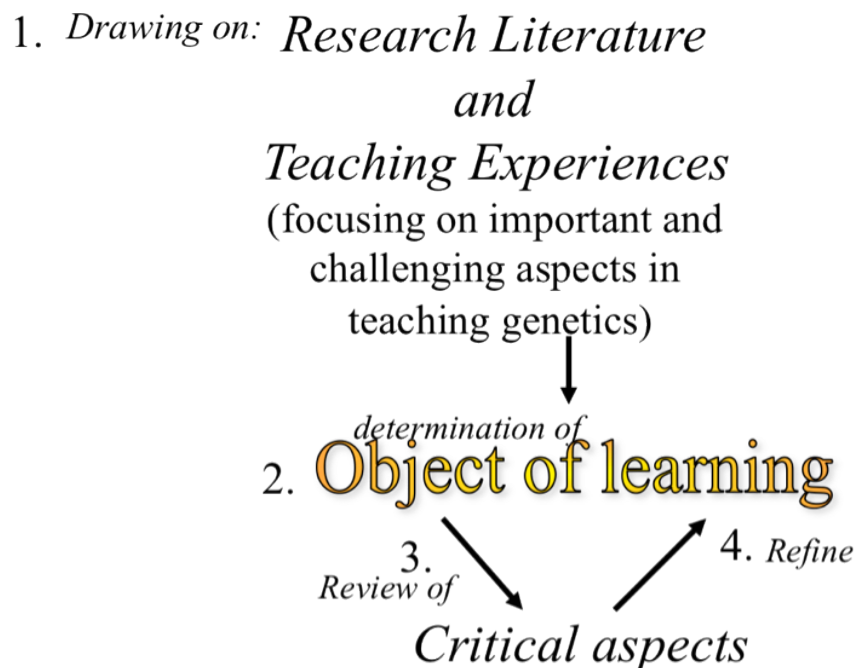


Diagram 3.1: The intended approach to help teachers determine the object of student learning.

The meeting, however, proceeded differently from the plan as illustrated in Diagram 3.1. The participating teachers were struggling to commit to an object of learning and could not proceed to determine the critical aspects (step 3 in Diagram 3.1). They were not sure if they wanted to work on mitosis and meiosis, or on gene expression (transcription and translation). Rather than determining the object of learning, the teachers decided to look into the rearrangement of key topics in genetics first, in order to gain a clearer and bigger picture of the whole genetics curriculum. The flow of the topics was subsequently termed as the “curricular flow”. This “change in plan” is demonstrative of how teachers were granted the autonomy to co-determine the steps of the learning study, as supported by researchers such as Altrichter et al. (1993).

The participating teachers proceeded to map out the key genetic topics onto a large piece of paper. The relationships between the topics were explored. The links that were often not articulated nor stated in the prescribed syllabus were also brought to the fore of their discussion. The space created here not only allowed teachers to pool their valuable experiences, but have also encouraged the articulation of concepts and aspects that were often “taken-for-granted” when teaching genetics. The teachers seemed to have taken a more holistic approach to the genetics curriculum than observed in prior meetings. They subsequently pinpointed the foundational concepts that they wanted students to become capable of understanding and applying in order to enhance the subsequent learning of other genetic content (see Diagram 3.2). The mapping of the curricular flow also served as a platform whereby the participating teachers could discuss the difficulties students face in learning genetics. The team eventually decided to focus on developing students’ capability to understand and use the general concepts in gene expression (including transcription and translation, which are newly introduced into the

prescribed curriculum). They felt that such a capability was important, in view of how fundamental the processes of transcription and translation were to understanding the rest of the genetic topics, such as heredity and expression of traits.

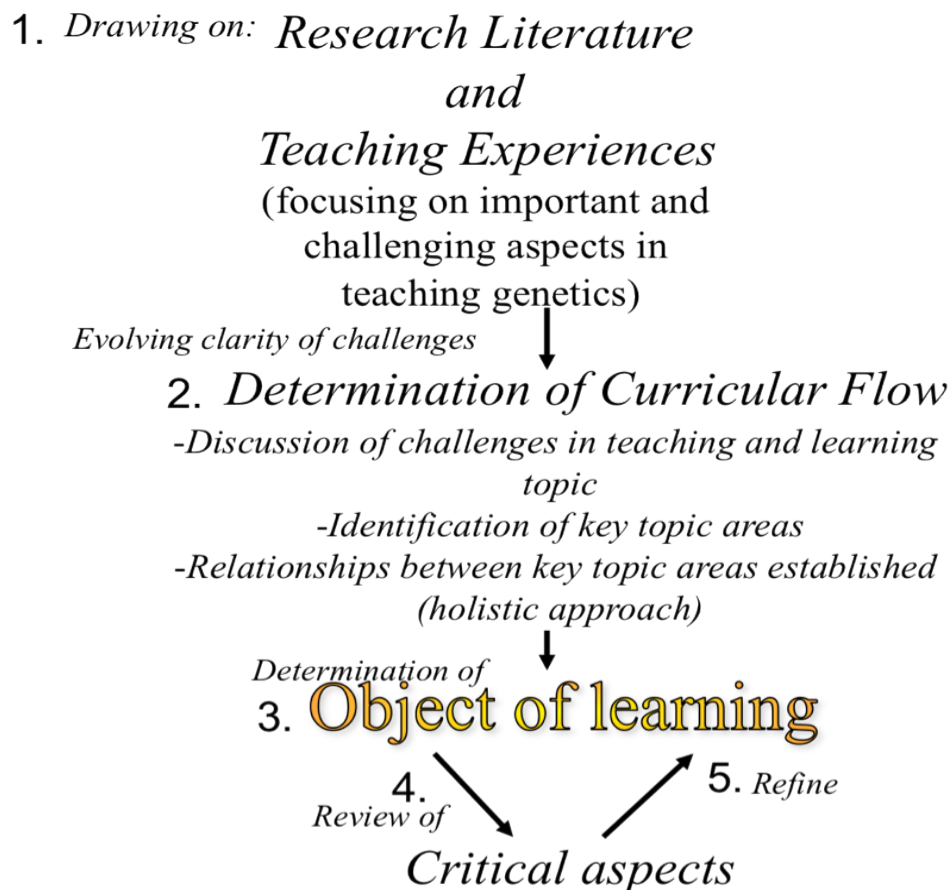


Diagram 3.2: The enacted approach to help teachers determine the object of student learning.

Meeting 6: Confirmation of object of learning, determination of curricular flow (16 February 2009)

The determination of curricular flow extended to this meeting, whereby teachers revisited the map constructed in the previous meeting and finalized the order of the genetic topics (see Diagram 3.3). This step was deemed necessary as the order of the topics differed from what was done previously, and differed from the original scheme of work that was to be followed for that academic year. It also differed from the typical flow in prescribed curricular materials.

The object of student learning was also confirmed. Towards the end of this meeting, teachers were given a handout (Appendix C) highlighting students' understandings of genetics as revealed through research literature (e.g., Allchin, 2000; Lewis et al., 2000a, b, c; Lewis & Kattmann, 2004; Lewis & Wood-Robinson, 2000; Marbach-Ad, 2001; Nelkin & Lindee, 2004; Saka et al., 2006; Tsui & Treagust, 2004; Venville et al., 2005; Venville & Treagust, 1998, Wood, 1993). Samples of pre-lesson tests questions to uncover students' understanding of genetics, as drawn from research literature (Duncan & Reiser, 2007; Lewis & Wood-Robinson, 2000; Marbach-Ad & Stavy, 2000; Venville & Treagust, 1998), were also included in the handout.

Meeting 7: Crafting of student pre-lesson test (2 March 2009)

The crafting of student pre-lesson test drew from a sample pre-test (used for a pilot study by the researcher) given to the teachers, as well as the handout given to the teachers in the previous meeting. The questions used in the pilot study also drew from research literature (Duncan & Reiser, 2007; Lewis & Kattmann, 2004; Lewis & Wood-Robinson, 2000; Marbach-Ad, 2001; Lewis et. al, 2000a, b; Martins & Ogborn, 1997; Nelkin & Lindee, 2004; Saka et al., 2006; Tsui & Treagust, 2004; Venville & Treagust, 1998; Venville et al., 2005; Wood, 1993). The team picked out the questions that they wanted to include in their pre-lesson test. In this meeting, Amy, Pam and Chris chose the classes that they wanted to implement the research lessons. The teachers decided to work with the higher ability girls in the school, expressing their greater confidence of enacting new ways of teaching in these classes. The participating teachers also expressed that, in view of their workload, the researcher should carry out the analysis of the pre-lesson test. The 30-minute pre-lesson test (Appendix D) was administered during the week, of which 80 students participated in the test.

Meeting 8: Review of pre-lesson test (9 March 2009)

In this meeting, teachers were granted the entire hour to look through students' scripts and the analysis of students' pre-test results (n=80) prepared by the researcher. Teachers casually commented on the findings that struck them, and the conversations extended to their recommendations of how the topic could be taught to address students' gaps in understanding. This step was deliberately included to create the space for teachers to draw on empirical data to ascertain the problem and challenges in teaching genetics, thus encouraging teachers to reflect and establish relationships between the data, their prior teaching experiences and their current

teaching practices. This step, as similar to the “reconnaissance” phase in action research (Elliott, 1991), also allowed data to be used to justify the existence of the “problem” to be addressed.

At the end of the meeting, Amy, Pam and Chris recommended five students from their classes (total of 15) to be interviewed. The number of students to be interviewed was determined by the teachers, on the basis of wanting to maximize the diversity in answers and to minimize the disruptions imposed onto the students. The selection was based on the availability and perceived willingness of the students to participate, and also because of the aim to cover a range of answers (in the pre-lesson test) that the teachers themselves wanted to further explore. In order to minimize disruptions, the student interviews were conducted during the recesses (break) allocated within school hours or immediately after school. The interviews were used for clarification or elaboration of answers written in the pre-lesson test, and students were further probed for their understanding of the structural and functional aspects of genes (including the processes of transcription and translation), and the relationships between them. The researcher conducted most of the interviews alone. Kate sat in for the initial few interviews after she expressed interest to observe how the interviews were conducted. Each interview lasted between 15-30 minutes.

Meeting 9: Planning of research lessons (18 March 2009, March school holidays)

This meeting was a two-hour meeting held during the term break (one week) in March. The meeting started off with a review of what preceded in the previous meetings. Subsequently, theory of variation was reviewed, with attention drawn to the importance of establishing common ground, and the architecture of patterns of variation and invariance to be enacted. In the next part of the meeting, the participating teachers read the transcripts of the 15 student

interviews conducted. They discussed their insights gained from the transcripts, as well as the depth and scope of the genetics content that should be covered in relation to these insights. Subsequently, the researcher reiterated the key points that have emerged from the students' interviews and pre-lesson test, and teachers were given a handout summarizing these points (Appendix E). Drawing from the results of the student pre-lesson tests and interviews, and using theory of variation as a theoretical framework, the team collectively determined the critical aspects of the object of learning. The critical aspects included the structural and the functional aspects of gene. The latter can be subdivided, focusing on (1) genes as code for proteins, (2) transcription and translation process, and (3) the function of proteins in gene expression. These critical aspects were decided based on (1) the challenges in teaching genetics emerging from the student data and research literature, (2) their saliency in helping students develop a deeper understanding of genetics, (3) the object of student learning, as well as (4) from what teachers intended to vary and keep invariant. Thus, this part of the discussion included an amalgamation of drawing from teachers' prior teaching experiences; supported literature; empirical data; and the application of theory of variation. The determination of critical aspects also took place concurrently with the discussion of theory of variation-framed pedagogical strategies to be employed. In addition, the extensiveness of the genetic topic also resulted in the teachers constantly relating the object of student learning and the critical aspects to other key topics in genetics. As such, opportunities were also given for teachers to explore the part-whole relationships (Marton & Booth, 1997) between the chosen object of student learning with the rest of the genetic topics. The discussion that took place in this meeting was summarized (by the researcher) into a handout for the teachers (see Diagram 3.4).

Some considerations:

1. To focus not only on the structural aspects, but to concurrently link them with functional aspects, so that students can develop an appreciation that genetic information contains nucleotides that codes for polypeptides which form proteins which can trigger off a cascade of reactions that eventually leads to the traits being observed.
2. From pre-lesson test and interview, some students demonstrated the understanding of "junk DNA" - consideration of non-coding regions of DNA to be introduced as well?

Several students relate genes, DNA and Chromosomes to

1. Determination of traits;
2. Passing down of traits/information;
3. Genetic diseases like Down's syndrome

Revisiting Gene Expression in the topics of:

Genetic Engineering;
Heredity (** whereby the concept of diploidy can be integrated into discussion of gene expression (rather the pathway of gene expression from DNA to phenotype along a single line)

"Relevance" - establishing 'common ground'; possible entry points

Gene Expression

For students to develop the capability to understand and use the general concepts in the genetic phenomenon of gene expression

Prior to teaching gene expression:

Students should be introduced to the **STRUCTURE OF GENES, DNA AND CHROMOSOMES**

i.e., the **NATURE OF GENETIC INFORMATION**

Therefore needs to know

1.

Genes as code for making proteins

Architecture of variation - "Varying the Code"

*Varying the sequences of the nucleotides (gene mutation):
SICKLE CELL ANAEMIA;
DIABETES*

*Varying the 'amount' of the code - 'amount' of gene copies (chromosomal mutation):
DOWN'S SYNDROME*

2.

Transcription

1. Copy of gene - Why is it necessary?
2. 1 gene 1 polypeptide
3. That gene is NOT a protein

Variation in the transcription process - variation in the polypeptide produced, or its number

3.

Translation

Protein formation

Variation in the translation process - variation in protein formed, or its number

4.

Function of proteins in Gene Expression

1. The protein can be an enzyme
2. The protein can trigger cascades of reactions...

Variation in the translation process - Change in chemical processes that occurs

Diagram 3.4: Map of key points discussed in collaborative lesson planning meeting (given as handout).

Preparation and implementation of research lessons (23 March – 17 April 2009)

Amy, Pam and Chris proceeded to plan their lessons based on the patterns of variation and invariance collectively decided upon, while having the freedom to determine the resources and pedagogical strategies they would employ in order to better suit their own classes and teaching styles. This practice was observed in other learning studies as well (Lo et al., 2006; Pang & Marton, 2005). It was decided that the structural aspect of genes should also be emphasized. The different levels in which genetic entities can be understood should be systematically varied - either moving from a more macro view to sub-molecular view (e.g., from cells to nucleus to chromosomes to DNA to genes and then to nucleotides), or vice versa. The relationships between these biophysical entities were also brought to the fore for discernment. Formerly, according to the teachers, this aspect was quickly brushed over and was a “taken-for-granted” aspect. In view that gaps in understandings emerged through the pre-lesson tests, coupled with literature highlighting the difficulties students faced in understanding the relationships between the biophysical entities (chromosomes, deoxyribonucleic acid (DNA) and genes) (Duncan & Reiser, 2007; Lewis & Kattmann, 2004; Lewis & Wood-Robinson, 2000; Marbach-Ad, 2001; Marbach-Ad & Stavy, 2000; Saka et al., 2006; Venville et al., 2005), the team decided that the structural aspects warranted more attention.

Subsequently, the pattern of variation designed was to vary the genetic code (structural aspect), which may result in changes in the mRNA formed during transcription, followed by changes in the protein formed in the translation process, which may subsequently alter the cascade of reactions that the protein trigger. Thus, the reactions might result in changes in characteristics. This sequential variation highlights how the variation of one critical aspect is responsible for the variations observed in the others. It was deemed valuable in helping students

focus on the coding regions of hereditary material (as opposed to “junk” DNA), and it also served to link the structural and functional aspects of genes. This relationship was also deemed important by the team, whose aim was to help students develop a deeper understanding of the genetic processes (functional aspects), which extended beyond the common association of genes with traits, hereditary diseases or as hereditary materials that are passed on. These associations, without a deeper understanding of genetic processes, were in fact reported to be problematic in literature (Duncan & Reiser, 2007; Lewis & Kattmann, 2004; Lewis & Wood-Robinson, 2000; Marbach-Ad, 2001; Tsui & Treagust, 2004; Venville & Treagust, 1998; Venville et al., 2005). These associations may hinder students from having an enriched understanding of genes as productive sequences of instruction that would, through the process of transcription and translation, produce a protein that might result in changes in the expression of traits. Thus, the plan was to introduce mutation as a way to enhance students’ learning of transcription and translation. The new arrangement might also help students better understand the concept of alleles and the concept of diploidy (Allchin, 2000), which were concepts to be covered in another chapter in the prescribed textbook - “Heredity”.

What is also noteworthy is that the pattern of variation and invariance employed actually allowed the process of mutation, which was supposed to be covered in another key topic in genetics (Heredity), to nicely fit into this part of the lesson unit. In addition, teachers were also considering varying the types of mutations to further help students to discern the critical aspects and to establish the relationships between the structural and functional aspects of genes – using different types of mutations such as those caused by nucleotide substitution, nucleotide deletion, nucleotide addition, and chromosomal mutation. In doing so, students’ learning of the processes of transcription and translation may be enhanced.

Within the span of four weeks, the research lessons were implemented. Chris took three lessons to complete the lesson unit planned, while Amy took two lessons, and Pam took three. (Details of the research lessons are provided in the subsequent chapter – Section 4.2.2, 4.3.2 & 4.4.2.) The team observed one another's classes and provided feedback during the post-lesson conferences to improve the design of the genetics unit. Initially, the plan was to provide immediate feedback after the research lessons were taught, but this proved a challenge due to the constraints of time-tabling (teachers' teaching schedule) as well as the teachers' commitments after school. Thus, the weekly-allocated meetings were used as post-conference sessions to evaluate the lessons. It was also arranged such that Chris, who was deemed as the more experienced teacher in the team, implemented the research lessons a week earlier than Pam and Amy. In this way, the two teachers could potentially benefit from both the observation and evaluation of Chris' classes.

Meeting 10, 11, 12, 13: Post-lesson conferences (30 March, 6, 13 and 20 April 2009)

The post-lesson conferences served as a space carved out for teachers to evaluate the lessons based on the patterns of variation and invariance collectively determined. In addition, good teaching practices were also highlighted during the discussions. Within the session, teachers teaching the research lessons were also given opportunities to explain their pedagogical choices and to highlight the challenges faced. The rest of the team suggested improvements and collectively explored options as to how the teacher could proceed. For every lesson, one collaborating teacher was appointed as the "principal observer" who would act as the key person helping to facilitate the post-lesson conference.

The opportunities to observe one another's classes were deemed by the teachers themselves as being "novel". It was not common practice for younger teachers to observe the classes of the more experienced teachers. What is equally noteworthy was that the nature of the observation was also different. Firstly, classroom observations in Singapore are often laden with the notion of assessments (as was also mentioned by the teachers). Teachers are observed and assessed, and a grade is eventually assigned for the teachers' overall performance for the year. In this study, observations were made with the intention of improving classroom practices rather than assessing teachers. Secondly, the observations and evaluation in this study differed from others since theory of variation was used to relate the intended, enacted and lived object of learning, and attention was also paid to the establishment of common ground and the architecture of patterns of variation and invariance enacted.

As a researcher-facilitator, my role in this part of the learning study ranged from pointing out areas that needed clarification, highlighting good pedagogical practices, to the provision of suggestions. In addition, I served as a resource person who would demonstrate how the theory could be enacted in the classroom context. I also pointed out other examples of variation that the teachers have used in their classes that were not collectively planned. In order to provide support for the teachers' pedagogical strategies, research literature was also provided to illustrate the similarities between their practices and those reported in research studies. Because the use of a theory to guide the evaluation of the lessons was deemed a new way to conduct evaluation of lessons, through the use of Chris' lessons, how the theory could be used to determine the impact of his pedagogy on students' learning was also illustrated by the researcher. The teachers were also given handouts noting the key points of the discussions (Appendix F).

Administration of student post-lesson tests and interviews, Meeting 13: Review of post-lesson test and interview results (20 April 2009)

Subsequent to the research lessons taught, student post-lesson test was administered (n=80). Semi-structured student interviews, each lasting between 15-30 min., were also conducted by the researcher to determine the impact of the classroom interventions on students' understanding of genetics. The post-lesson test had identical questions to the pre-lesson test, with the inclusion of an additional question that probed for students' understanding of the relationship between the structural and functional aspects of genes (Appendix G). The same students were interviewed. The interviews aimed for clarification and elaboration of students' post-lesson test answers. Students were also asked to share about the parts of the lessons that encouraged and enriched their learning. The researcher analyzed the post-lesson test and transcribed the interviews.

Comparisons of the pre- and post-lesson tests and student interviews enabled the team to determine possible shifts in students' conceptions of genes and the genetic processes; to determine the extent of mastery of the object of student learning; and to establish the relationships between the enacted and lived object of learning. The data was also drawn upon to support the discussions that took place in the post-lesson conferences. For example, during the third post-lesson conference, the researcher drew on the data to exemplify how the enacted and lived object of learning could be examined in Chris's class. In addition, during the last post-lesson conference (Meeting 13), teachers were granted opportunities to review the analysis of the post-lesson tests and the student interview transcripts. Teachers were also granted time in the meeting to reflect on their own practices, and to document what they would deem as good practices in helping students master the object of learning. A handout (Appendix H) that

teachers could fill in was given to aid and stimulate the reflective process. The design of this part of the learning study thus allowed utilization of empirical data as a basis for teacher reflection. In view of how teachers' experiences of professional learning are closely tied to students' learning experiences (Fullan, 2003), uncovering the impact of the research lessons on students' learning was deemed as important.

Meeting 14: Reflection and documentation of good practices (27 April 2009)

Teachers were given opportunities in this meeting to reflect on and to share the practices they deemed effective in aiding students' development of the capability to understand and use the concepts in gene expression. Some of the key points raised were the (1) establishment of common ground, (2) the patterns of variation and invariance employed ("intentional" and "unintentional") and their effectiveness, as well as (3) the larger picture of the effectiveness of the implementation of the new curricular flow and the inclusion of mutation. Building on the articulated good practices, the researcher explicitly related what teachers deemed effective to the student data collected, as part of the "research aspect" of the learning study that allowed teachers to inquire into their own practices. However, due to the constraints of time, the team only managed to relate students' enriched understandings to the enacted object of learning. There was insufficient time to deliberate in great detail as to why some of the students did not adequately demonstrate the mastery of the object of learning.

What is noteworthy is that although weekly journal writing was not implemented in the current study, this space of discussion and sharing provided an avenue for reflection. It provided a space for the teachers to converse with themselves, thus becoming a powerful means for

(re-)exploring beliefs, attitudes and perceptions of events experienced (Pedretti, 1996; Richert, 1992).

Meeting 15: Reflection on teachers' own experiences in participating in the learning study, evaluation of the learning study (4 May 2009)

In this meeting, teachers were granted opportunities to reflect on their own experiences in participating in the learning study. The reflection served to directly probe for how the teachers experienced their own learning as a form of professional development, and how their pedagogies were affected. A handout (Appendix I) was distributed to facilitate the reflective process. The researcher went through each aspect mentioned on the handout, while granting teachers time to write down short notes of their thoughts and experiences. The reflection was separated into sections according to the different aspects and steps in the learning study, such as the determination of object of learning and curricular flow; focus on students' conceptions and learning, reflective process; collaboration; employment of a theoretical framework; as well as inquiring into own practices through research in the classroom. Notes describing what transpired for each step were provided and served to stimulate recall. In addition, questions were provided on the handout to guide teachers' reflections. The entire reflection was completed within the one-hour meeting.

Final sets of interviews conducted (5-26 May 2009)

Two sets of teacher interviews were conducted prior to the conclusion of the learning study, with each interview lasting approximately 45 to 75 minutes. Apart from Chris who requested to have the first of the two semi-structured interviews conducted immediately after he finished the research lessons, Amy, Pam and Kate had both interviews conducted between the

last meeting of the learning study and the last day of the semester. Within this period, the teachers were also busy with the student mid-year examinations, thus the interviews were conducted whenever the teachers could afford the time to meet. The teachers were given a list of questions that may be discussed in the interviews beforehand. This was done to give teachers more time to think about the questions.

During the interviews, teachers were asked to comment about their experiences in the learning study. Drawing from their responses written in the overall reflection (Meeting 15), teachers were also asked to clarify or to elaborate on various points. Similarly, the third set of interviews was used to clarify some of the teachers' comments made during the second set of interviews. In addition, teachers were asked to share if any of their views about teaching and learning would have changed after participation in the learning study. To aid this, teachers were also asked to comment on any changes they would like to make in their responses to the Genetics Questionnaire. Towards the end of the last set of interviews, teachers were also asked to comment about the organization of the learning study, with the aim to uncover the aspects that might have encouraged or hindered their learning. The interviews thus provided a platform for the participating teachers to further reflect on their learning experiences in participating in the learning study. Some of the interview questions crafted also mirrored the ones asked in the first interview, while others drew from research literature (e.g., Arbaugh, 2003). The interview transcripts were given back to the interviewees.

Reporting of the learning study implemented (28 May 2009, 3 June 2010)

The researcher presented the preliminary analysis of the learning study to the school leaders as a way to share and disseminate the findings. In addition, the researcher also presented

the preliminary results at a conference held in Singapore on 3 June 2009. Teachers participating in the study were invited to co-present the findings with the researcher. However, due to the other commitments that participating teachers had, they were not able to attend the conference. Nonetheless, within the PDG program that the school runs, the participating teachers will have opportunities in the future to share their findings.

3.4 Data sources

Data were collected from a variety of sources to ensure a rich data set. Data sources included questionnaire (Genetics Questionnaire), teacher reflections (conducted during the last meeting), and interview transcripts (3 sets of interviews). Data were also collected in the form of audio-video recordings of all meetings as well as the research lessons. Meeting (including post-lesson conferences) notes, documents and handouts prepared by the researcher recorded the schedule and logistics of the study, and served as a record for what were anticipated as well as what actually transpired during the meetings. The researcher's written field notes and journal entries recorded a variety of information about "self" and "method" (Lincoln & Guba, 1985). That is, they provided information about perceptions of what was happening in terms of the researcher's own insights, values and interests. They also acted like a "methodological log" that reflected the methodological decisions and rationales that were deliberated upon when implementing the learning study. The range of data sources presented here, coupled with student data collected in the form of pre- and post-lesson tests and interviews, were helpful for stimulating recall and analysis of the overall process. Concurrently, they served triangulation purposes in order to ensure trustworthiness (Lincoln & Guba, 1985; Mathison, 1988; Maxwell, 1996). The range of data sources was also particularly useful in shedding light on the preliminary ongoing analysis that took place during the implementation of the learning study.

Enriching the context in which the participants described their own experiences, these multiple sources of data were constantly referred to, and read alongside the interview transcripts and overall reflection. As such, the difficulties in integrating data of different forms could be addressed, through the taking of a holistic approach, that is, the consideration of data in relation to one another (Dall'Alba, 1994).

3.4.1 The use of interviews – drawing from a phenomenographic perspective

In view that interview data formed a large part of the data collected in this study, it is worthwhile to further discuss the use of interviews in this research study. A review of literature indicates that interviews constitute a common method of data collection in phenomenographic studies that sought to explore teachers' understandings and experiences of teaching and/or (student) learning. Examples of such studies involve teachers from different grade levels and institutions - university academics (e.g., Åkerlind, 2004, 2008; Booth & Anderberg, 2005; Martin & Lueckenhausen, 2005; Prosser et al., 1994; Trigwell, Prosser & Taylor, 1994); secondary or high school teachers (e.g., Boulton-Lewis et al., 2001; Cope & Ward, 2002; Govender & Grayson, 2008; Koballa, Glynn, Upson & Coleman, 2005; Pang, 2006; Rogers, Abell, Lannin, Wang, Musikul, Barker & Dingman, 2007); and trainee or prospective teachers (e.g., Koballa et al., 2000; Govender & Grayson, 2008; Wood, 2000). In these studies, teachers' experiences (conceptions) of teaching and/or learning were uncovered, both as more general aspects of teaching and learning (e.g., Boulton-Lewis et al., 2001; Martin & Lueckenhausen, 2005; Van Eekelen et al., 2005; Wood, 2000) as well as those situated within specific content domains (e.g., Cope & Ward, 2002 (learning technology); Govender & Grayson, 2008 (programming); Koballa et al., 2000, 2005 (chemistry); Pang, 2006 (economics); Prosser et al., 1994 (science); Trigwell et al., 1994 (science)). These studies lend support for the use of

interviews in this research study to uncover teachers' conceptions of teaching biology, as well as their experiences participating in the learning study. Interviews were likewise employed in learning studies (e.g., Pang, 2006).

Variation in how interviews were conducted (for example, length of time taken; extensiveness of dialogue; and what constituted the research data) is observed. Despite the differences, the employment of phenomenographic perspectives results in the “explorative character” (p. 169) being an interview’s most central characteristic (Svensson, 1997). Hence, interviews were usually semi-structured and open-ended, which was also the case in this research study. This allowed the interviewees to respond to aspects of the questions that appeared most relevant to them, and to reveal the different ways of experiencing the phenomenon within that context (Åkerlind, 2002, 2004, 2005; Boulton-Lewis et al., 2001; Bowden, 1994a; Dall’Alba, 1994; Koballa et al., 2005; Marton, 1986, 1988; Rogers et al., 2007; Wood, 2000). As Marton (1986) clearly describes:

... interviewing has been the primary method of phenomenographic data collection. What questions are asked and how we ask questions, of course, are highly important aspects of the method... we used questions that are as open-ended as possible in order to let the subjects choose an important source of data because they reveal an aspect of the individual’s relevance structure. Furthermore, though we have a set of questions at the start of the interview, different interviews may follow somewhat different courses. (p. 84)

In the same vein, the interview approach adopted in this research study was also similar to what Booth (1997) would advocate – interviews that are “deep and open”. “Deep” meaning that particular lines of discussion are followed until they are exhausted and the two parties have come to a state of mutual understanding. And “open” to mean that although a structure might be

planned in advance, the interviewer is prepared to follow unexpected lines of reasoning that can lead to fruitful new reflections.

It is also noteworthy that colloquial Singaporean English was also occasionally used by the interviewer and interviewees, in order to further facilitate the “dialogue” that transpired. This allowed the interviewee’s account of his/her experiences to be described in a way that he/she was most comfortable with. Similarly, in Pang and Marton’s (2005) study, the teachers were told to use whatever language they liked, including slang, spoken Cantonese or even pictures, to answer the questions in the interviews. The use of colloquial Singaporean English in the current study also allowed for meanings to be shared quickly, thus enabling the interviewer to listen and to look from the point of view of the participants with greater ease (Dall’Alba, 1994). Dall’Alba (1994) deemed the adoption of such an “experiential perspective” as pertinent, in light that the descriptions from phenomenographic research focuses on the relations between the experienced and the experiencer (the relational nature of phenomenography) (Marton, 1986; Marton & Booth, 1997), and how researchers seek to describe the interviewee’s views. What is also advocated here is for researchers to listen carefully to their participants, as was practiced in this learning study. Thus during the course of the interviews, participants were allowed to express their views as fully as they wanted before another question was asked.

In this research study, each set of interviews was guided by a list of key questions to be used. Questions framed to pursue certain lines of inquiry raised by the interviewees were used, only if they added clarity or enriched the original key questions planned. Key words that emerged in the process of the interviews were also jotted. Rather than paraphrasing the utterances of the interviewees, which might result in premature interpretations of the

participant's comments, the words of the interviewees themselves were used to frame subsequent questions asked. These practices were implemented as a response to the caution and suggestions made by several researchers - as steps taken to collect unbiased data. For example, Francis (1993) raised concern about the use of leading prompts that might lead to "self-fulfilling prophecies" through the mechanism of behavior confirmation. Similarly, Bowden (1994b) expressed concern that the more extensive dialogue engaged by some phenomenographers may go beyond what the interviewees had introduced in the conversation. Mindful of this, Bowden (1994a) used a limited set of planned questions, and all other questions were focused solely on encouraging the interviewees to explain their ideas as fully as possible – as was practiced in this current study. Similarly, Cope (2002a, b) advocated the interviewer to construct follow-up questions in terms of a "structure of awareness" (focusing on the theme, thematic field and margin) rather than on the interviewer's own prior knowledge of the phenomenon of interest.

Prior to concluding this section, the use of interviews to provide teachers with a platform for reflection (Altrichter et al., 1993; Elliott, 1991; Johansson et al., 1985; Marton, 1986) is worthy of discussion. Such a practice may be seen as an address to Säljö's (1997) concern about the "mutual constitution of human experience and discursive practices" (p. 188). That is, the participant's accounting mutually constitutes the experiences described. The position taken in this study is in agreement with Säljö - that there may be many ways in which accounting practices can be used to describe human experience, and that the accounting itself may mutually constitute the experience. Nonetheless, this is not seen as an "attack" on phenomenography, nor does it contradict the intentions of this study. On the contrary, with the aim that teachers' desire to be professionally developed may be deepened, such a mutual constitution is in fact "welcomed" in this research study. The teachers' description of their experiences, as part of

their discursive practices, may encourage them to develop an awareness of their own learning. Consequently, this may propel them towards a disposition of wanting to be further developed professionally, while simultaneously resulting in a constitution of the very experience described. Such a perspective draws support from Chiu's (2005) study, whereby the participating teacher developed a stronger desire to learn after participation in the learning study.

3.5 Data analysis

In this section, the analyses of the participating teachers' experiences and the impact of the research lessons on student learning are described in detail.

3.5.1 Analysis of participating teachers' experiences

The analytical process was framed by largely employing a phenomenographic approach (Marton, 1988, 1994; Marton & Booth, 1997). In this study, teacher interviews were audio-recorded and transcribed verbatim. The transcription process has in fact allowed a phenomenographic analysis to proceed, allowing for "a sense of the meaning of the text as a whole" to emerge, and that "this circling of part to whole and back again results in progressive understanding" (Rennie, 2000, p. 484). During the initial analyses, the conversations were listened to several times by playing the recording in order to include anything that would affect the interpretation of meanings. Ashworth and Lucas (2000) supported such a practice.

The careful reading of the teacher interview transcripts and overall reflective entries marked another step in the data analysis. This part of the analysis involved a selection procedure based on criteria of relevance (Marton, 1988, 1994a). Utterances found to be of interest were selected and marked, with the interpretation of the utterance (in general) made in relation to the

context from which the utterance was taken. The interpretations were also guided by and triangulated with other data sources.

Having an initial idea of the possible ways in which the individual teachers experienced various aspects of the learning study, each of the individual teacher's experiences was described. This step of the analysis provided an opportunity to persist a focus on the individuals' experience and utterances. Terms or aspects that the participants frequently used or paid attention to were also noted. The particularities and coherence of each individual's experiences were thus established. This step supported the view that in describing how a phenomenon or aspect of the world appears to an individual, it is pertinent for the phenomenographer to adopt the individual's perspective; to describe the phenomenon from the point of view of that individual (Dall'Alba, 1994).

The practice here could also be seen as an address to Säljö's (1997) concern - that the utterances of people are transformed into categories of description that may not mean in that context in the same way as they do in their original communicative setting. That is, interviewees' statements are read uncritically as indicators of ways of experiencing, and alternative interpretations of the functional mechanisms of why people talk the way they do are rarely considered. Along a similar vein, Clarke (2002) likewise draws attention to the individual participant by asserting that individuals participate in social practice as a member of a social group, and this membership is a matter of interpretive affiliation by the participating individual. While it is not the intent of the discussion here to discuss in detail the challenge of Säljö's - on the truth claims made in phenomenography that different ways of experiencing can be adequately accounted for and described, whereby conceptions of truth are imposed such that

“method risks becoming ontology” (Säljö , 1997, p. 188), the cautionary tale serves as a salient reminder. For instance, in appreciating that this current research is vulnerable to the criticism that it privileges the participants’ description of their experiences, and in heeding Säljö’s call to draw greater attention to the “complex of motives, skills and preferences that occasion people to talk the way they do” (p. 188), rather than to take them *uncritically* as people’s experiences. This may be accomplished through a meticulous and careful reading of the individual participant’s utterances when the participants’ individual experiences were described, and their utterances could be interpreted in a context that might have shaped their comments. Similarly, such a step may also aid to elucidate the meanings that the individual participants attribute to their own teaching practices (Clarke, 2002) and experiences.

The focus on individual participant’s experiences was also an attempt made to increase the degree of accuracy of the interpretation of the utterances of the participants, so that the “pooling” of meanings (Marton, 1988, 1994) that took place subsequent to this step would ensure that statements grouped together actually embed within them similar meanings. This next step of the analysis acted as a way of looking for patterns through the identification of similarities within and between transcripts. At this point, the attention was shifted from the individual subjects to the meanings embedded in the quotes. The interpretation was thus an iterative process that goes back and forth between the context of the interviews as well as the context of the “pool of meanings”. Because the individual experiences of the participants were described and studied carefully, this iterative process of reading within and between transcripts, of shifting between individuals to the collective, took place with greater ease.

A step-by-step differentiation was then made within the “pool of meanings” (Marton, 1988, 1994). That is, the utterances were brought together into groups on the basis of similarity and the groups were delimited in terms of differences – thus forming categories defined in terms of core meanings of the groups of quotes. At this point, employing theory of variation was particularly useful. Firstly, an appreciation of learning as the ability to experience various aspects of teachers’ professional lives in more advanced or different ways helped to frame the type of learning experiences looked for. Secondly, learning could be appreciated in terms of teachers’ discernment of different critical aspects that were focally and simultaneously present in their awareness. The themes constructed (typically known as categories of description in phenomenographic studies) were tested for their accuracy in interpretation against the interview transcripts and reflective entries, and against the other sources of data. They were then adjusted, retested and adjusted again, with “a decreasing rate of change and eventually the whole system of meaning is stabilized” (Marton, 1986, p. 42). In addition, the descriptions of the individual participants’ experiences were also further refined even as the reiterative process added clarity to both the individual’s as well as the collective’s experiences. The themes, as illustrated, were thus not made up in advance (Marton, 1988). What is also noteworthy was that this reiterative process of focusing on the experiences of individual participants and that of the collective’s allowed for “outliers” to be eliminated, thus constituting a way to establish credibility (Lincoln & Guba, 1985).

3.5.1.1 Variation in the analytical process

Within phenomenographic studies, variation in the analytical process was observed and highlighted (Åkerlind, 2002, 2005; Bowden & Walsh, 1994). Åkerlind (2002, 2005) has noted differences in terms of the amount of each transcript considered. While smaller quotes or

excerpts were considered in this current study - similar to that of Marton's (1986, 1988), others have had whole transcripts considered instead (e.g., Bowden, 1994b; Bowden, Dall'Alba, Laurillard, Martin, Marton, Masters, Ramsden, Stephanou & Walsh, 1992; Prosser, 1994). The latter practice was deemed as a way to address the concern of "de-contextualization" of the quotes, which may reduce appropriate consideration of the context within which the selected quotes were made (Bowden, 1994b). In this research study, in addressing a similar concern, individual participants' experiences were described. In addition, the context was carefully studied by reading the utterances alongside other data sources.

Some researchers start the analysis using preliminary sample transcripts before bringing in the full set of transcripts (Prosser, 1994; Prosser et al., 1994; Trigwell et al., 1994). Similarly, Rogers et al. (2007) used an inductive approach (Patton, 2002) to code a subset of the data into thematic clusters or categories, and subsequently used a qualitative analysis software to code the remaining data into the list of categories. This allowed them to develop a frequency chart that included the number of comments by interviewees for each coding category. In my study, neither practices were carried out when analyzing the participating teachers' experiences, due to the small sample size (four teachers).

It is noteworthy to mention that despite the variation in methods present within phenomenographic studies, crucial commonalities in practice were also observed (Åkerlind, 2002, 2005). These include the efforts to maintain a high degree of openness when reading through the transcripts (in order to derive possible meanings), and the openness to new interpretations. In addition, the whole process is iterative and comparative, with the search for

key qualitative similarities within, and differences between, the categories as a primary feature of the constitution of categories of description (or themes in this current study).

3.5.2 Analysis of student learning

Students' pre- and post-lesson tests were analyzed employing phenomenographic perspectives as well. Initially, varied conceptions for each question were scored whenever that particular conception was present in the students' response. Subsequently, using the phenomenographic analysis described in the previous subsection (Section 3.5.1), students' understandings of the conception of genes, pointing to how they experienced and approached the topic of genetics, were captured in terms of categories. Because it was the agenda of the teachers to help students gain an understanding of genetics that is consistent with canonical science, these categories were ordered in a hierarchical way. Learning could thus be appreciated as the shift of conceptions from a lower-ordered category to a higher one (Johansson et al., 1985; Marton, 1986). Hence, unlike that of capturing the different ways teachers experienced learning within the learning study, the ordering of the categories was deemed relevant and useful within this context. Students were scored for the most advanced conception that they demonstrated throughout the transcript. The student interviews conducted subsequent to the analysis of students' test were used to further test the stability of the categories constructed. In view that student interviews also served as an extension of the pre- and post-lesson tests administered, other insights that emerged from the student interviews were directly jotted down. The results of the student pre- and post-lesson tests and interviews were not reported in detail because this thesis focused primarily on teachers' experiences.

3.6 Situating myself in the study

The notion of insider-outsider in research has commanded much attention, especially in view of how “outsiders” can potentially influence “insiders” (Coghlan & Shani, 2005; Greenwood & Levin, 1998; Pedretti, 1996). Thus borrowing the notion of insider-outsider, I have situated myself within this research study, looking not only at the kinds of “outsider” knowledge I bring into the learning study as a potential resource for the participants (Greenwood & Levin, 1998; Pang, 2006), but also the kinds of “insider” knowledge that I possess that might aid in my role as a researcher-facilitator in the study. The articulation of my own experiences, interests, agendas and biases in this section draws its support from the notion of “cultural authorship” (Clarke, 2002; Clarke & Suri, 2003). The authors’ mention of research studies inevitably reflecting the curricular interests and priorities, as well as the cultural values of the authoring culture, thus underscores the need to make them known.

3.6.1 My experience with the genetics curriculum

Being a former teacher teaching Grade 7-10 biology in Singapore, and having to determine the curricular flow of biology topics to be taught in my former school, the challenges teachers face in teaching genetics were not foreign to me. Coupled with my involvement with the Ministry of Education in Singapore to review the curricular materials for the newly implemented biology syllabus, I have had the opportunity to encounter the new genetics curriculum and to see the potential gaps in the curriculum. I could also anticipate the frustrations teachers might face - as a result of the newness and ambiguity (in terms of its depth and scope) within the new biology curriculum. These experiences have enabled me to empathize with the Grade 10 biology teachers participating in my study, shaping my “insider” knowledge.

My personal experiences as a student learning genetics have also led me to believe that genetics is a difficult topic to learn. The gaps in students' understandings of genetics and challenges teaching it, as highlighted in research literature, have often resonated with my own learning as a student. This encouraged me to find new approaches that might help alleviate, if not overcome, these challenges.

3.6.2 The sense of professional isolation

Being part of a committee that was in charge of professional development of the teaching staff in my former school, Shulman's (1986) underscore for teachers to gain competency in pedagogy, content knowledge and pedagogical content knowledge resonated well with my personal orientation towards teacher professional development. Such an orientation was shaped by my personal observation and experience of teaching as an isolating activity – as is a concern that was commonly raised by researchers (Ahlstrand, 1994; Hargreaves, 1992; Lieberman & Miller, 1990). That, indeed, while the isolation does offer many teachers some degree of valued privacy and protection from outside interference, it has also shut out possible sources of support, praise, and collegial feedback on their competence, value and worth (Hargreaves, 1992).

My concern deepened with the challenges faced to help teachers in my former school to gain competency in their teaching, and develop professionally in their specific areas of expertise. For one, there seems to be very little in-service courses available that would specifically address problematic areas within a specific discipline. In addition, I often felt the “inaccessibility” of research works, resonating with how Pedretti and Hodson (1995) described curriculum theory and educational research as not being seen by classroom teachers to provide

any insights into the design and implementation of students' learning experiences. That consequently, teachers' own personal experiences of the classroom are often used as the basis for curriculum decision instead. In other words, while I knew that there were research studies that will benefit teachers, I often felt that teachers were living "professionally orphaned lives" (Rosenholz, 1989). In part, I attributed this to the research articles being unavailable in the schools, and also to the style of writing and jargons used that made it hard for teachers to understand. Coupled with teachers' already heavy workload (further discussed in Section 3.6.3), I was not surprised by the teachers' reluctance to spend time reading research journals.

It is largely due to these experiences that I was particularly drawn to the potential of the learning study to bridge theory and practice (Pang, 2006); and to enhance teachers' teaching of specific curricular content. My understanding of learning study, personal experiences encountering it during my course of study in graduate school, and opportunity to conduct a pilot study based on the learning study approach (during my pursuit of a Doctoral degree in Education) have allowed me to contribute this piece of "outsider" knowledge to my research study.

3.6.3 Glimpses of the school culture

Being a facilitator on the "inside", I am aware of the challenges around professional development, such as the constraints of time; heavy workload; pressures of completing the curriculum; and pressures of the examinations. Rather than seeing these as hindrances to professional development approaches, they motivated me to consider and design approaches that would allow teachers to work within the realities of teachers' constraints, while concurrently supporting their "moral purposes" (Fullan, 2003) of helping students perform in the national

examinations. My “insider” knowledge has also allowed me to understand and empathize with teachers’ frequent employment of teacher-centered pedagogy, despite their desires to use more student-centered ones. This disparity has also shed light on the inadequacies of current professional development opportunities to help teachers execute more student-centered styles of teaching within the constraints of a Singaporean classroom – the latter being desired by the teachers themselves.

Pointing to a deeper call - that if effective actions spring from effective ways of seeing (Marton & Booth, 1997), then teachers’ perceptions and beliefs about what constitutes good biology teaching and learning cannot be ignored. Rather, conditions that would encourage shifts in their beliefs and practices may be necessitated. Constituting my “outsider” knowledge is my conviction of the idea of “backing into change” – that because most people do not discover new understandings until they have delved into the issue, changes in behavior precedes, rather than follows, changes in beliefs (Fullan, 2001; Werner, 2002). Clarke and Hollingsworth (2002) similarly assert that changes in teachers’ beliefs and attitudes could be driven by new practices of classroom teaching. Their model of teacher professional growth extends to include a variety of possible “change sequences” and multiple teacher “growth networks”, thus pointing to the complexity and interconnectedness between (1) teacher knowledge, beliefs and attitudes; (2) professional experimentation; (3) salient outcomes (including but not limited to student learning outcomes); and (4) external sources of information or stimulus. These research studies have helped shape my beliefs - that participation in the learning study may create experiences that provide the ground for teachers to rethink their own beliefs and practices, and consequently, to influence their teaching practices.

3.6.4 A call to “travel”

I have also situated myself in this research study by borrowing from the critiques of Edmund Husserl’s phenomenology. Knies’ (2006) description of Edmund Husserl’s phenomenology foregrounds his appeal for one to “travel”; and the concept of nation – the home of specific mythical powers, gods, demons, and traditions, wherein they need not account for themselves, and are accepted without judgment, and are ultimately beyond question. According to Knies, Edmund Husserl asserts that real philosophy cannot emerge except via an encounter with the “facticity of foreign nations”, which can motivate an insight into the contingent and arbitrary nature of one’s own national mythos. Such an encounter can be described as a “discipline of travel”. What is essential to the travel is that an encounter with the “facticity of foreign nations” opens an understanding to a visitation, whereby one’s own zone of familiarity stands out in its character of being unthinkingly accepted. Reflecting on these ideas, the question posed is - What could possibly be my “own zone of familiarity that stands out in its character of being unthinkingly accepted”? Layering the notion of “insider” and “outsider” knowledge, what comes to mind were my experiences that have resulted in the way I have perceived professional development and its associated challenges; and perceptions of the potential of learning study as a professional development approach in Singapore (described in Section 3.6.1, 3.6.2 & 3.6.3).

Knies’ (2006) critique of Edmund Husserl’s phenomenology (as was presented in Husserl’s Vienna lecture) was that attitudes were assigned to humanity such that Europe, as a nation, is the spiritual shape governed by the theoretical norm-style (aims at the attainment of universally valid truth for its own sake), whereas non-Europe is the spiritual shape limited by “mythico-practical orientation” (aims at a systematic knowledge of the world, but takes the world as a domain of unquestionable powers bound up with the fate of humanity, and so seeks

its knowledge with the aim of helping us order our lives in the happiest way possible). Knies' contention is that Husserl's phenomenology may still have the "ritual enactment of European Man's self-identification as standard of humanity" (Knies, 2006, p.9). Knies thus supports the movement of post-European Science to render problematic the constituted forms of knowing and call into question methodological imperatives. In the case of phenomenological inquiry, he urges making the notions of "nation" and "travel" methodological problems.

The problematization of "nation" serves to remind me of my own views and the ways I was conceptualizing teacher professional development. The questions posed, then, were whether I thought of myself as the one who knew what was best for the teachers in terms of their professional development; if I have ever thought that they "do not know better" of what could potentially benefit their professional lives; and if I have treated them as "clean slates" that needed to experience the learning study in order to learn, and subsequently to develop a greater desire to be developed professionally. Do these, then, constitute my own "European man's self-identification as standard of humanity"? So fine is the line of desiring teachers to experience learning and professional development in order to empower them to take more control over their professional lives, from that of treating them as "not knowing better", that I fearfully and cautiously tread as a researcher in every stage of this research project.

Knies' (2006) assertion to make the notion of "travel" a methodological problem also led me to consider what needs to be "dethroned" - the dethroning of my own perceptions and privileging of certain aspects of the learning study that might enhance teacher learning. It also compels me to position myself to recognize the interdependency between the forms of knowledge that my participants and I bring into the research project. That firstly, while my own

understandings and experiences as a teacher, professional development organizer, curriculum writer and a doctoral student in Education allowed me to contribute certain forms of “insider” and “outsider” knowledge, the teachers’ experiences are absolutely necessary for me to gain a deeper understanding of the ways they learn. Secondly, I need to recognize that we all learn differently (Marton & Booth, 1997). Thirdly, that we all experience lives as teaching professionals differently. Thus, I should not be imposing my own learning styles and preferences on the teachers. In addition, teachers’ personal and collective experiences can merge with mine, such that in the midst of a reconstitution of personal knowledge, a collective understanding and knowledge might also emerge. In this way, the notion of “travel” breaks down because there is no knowledge that is more “foreign” or “native” than another’s. Moreover, all participants contribute different forms of knowledge (Atweh, Christensen & Dornan, 1998). Hence, the disposition researchers should take entering a learning study is one of openness and a willingness to learn (Bell, 1998). In doing so, through the joint process of inquiry, outside researchers can become a “participant” in collaboration with the insiders (Greenwood & Levin, 1998).

What was demonstrated in this section is how the conceptualization of the current study was shaped by my prior experiences, even as the dots of my historicity were connected to this study. As an insider-facilitator, with the knowledge of an outsider-researcher, I drew on my experiences as a student and teacher in Singapore, and as a doctoral student, to better understand the culture, rhythms, and challenges teachers faced in Singaporean schools. These challenges not only pertain to teaching biology, but are also related to professional development approaches as well. The emerged understandings resulted in a certain degree of the relinquishing of my agendas, extending to the occasional suspension of my own experiences and understandings – as

a way to learn to “de-centralize” and “de-throne” my work (Evans, 1996; Pedretti, 1996). The aim was to develop openness to how the participant should have their needs met and to pay greater attention to what the participants have to say about their own learning. I was also compelled to locate myself in the context of this research study as one who was constantly seeking a balance between being an “insider” and “outsider”, to a point of even absolving the dichotomy between them. In fact, I came to a realization that this “outsider-insider” dichotomy was not always clear. The “insider” knowledge that I drew on has in fact shaped the “outsider knowledge”, and vice versa. In this way, the inside/outside dichotomy seemed to be transformed into an “inside/outside dialectic”, whereby the perspectives, knowledge, and experiences would complement and inform the other (Pedretti, 1996, p.312).

3.7 Trustworthiness and issues of validity and reliability

This section highlights the considerations and steps taken to ensure the trustworthiness (Guba, 1981; Lincoln & Guba, 1985) in this research study. According to Lincoln and Guba, the basic issue in relation to trustworthiness directs one’s attention to how an inquirer can persuade his or her audiences (including self) that the findings of inquiry are (1) worth paying attention to, (2) worth taking account of; (3) drawing attention to the arguments, criteria invoked and questions asked that would be persuasive. The authors have refined and proposed criteria of credibility, transferability, dependability and confirmability, which were deemed to be fundamental to the development of standards used to evaluate the quality of qualitative inquiry. Taking the criteria into consideration, various approaches or principles to ensure validity and reliability in this current study - as were conventionally used in several phenomenographic studies, were also employed. Although there have been debates regarding the appropriateness of the use of validity and reliability, it is not the aim here to engage in such a debate. Rather, this

study supports that (1) notions of reliability and validity (originally derived from a positivist approach to research) still warrant attention from qualitative researchers (Åkerlind, 2002, 2005; Guba, 1981); that (2) the approach to ensure reliability and validity in qualitative studies may differ and extend beyond its application in quantitative studies, and is pertinent to ensure rigor in qualitative studies (Golafshani, 2003; Morse, Barrett, Mayan, Olson & Spiers, 2002).

3.7.1 Addressing issues of validity

Validity is widely regarded as the extent to which a study is seen as investigating what it aimed to investigate, or the degree to which the research findings actually reflect the phenomenon studied (Åkerlind, 2002, 2005). In other words, to demonstrate validity, one must therefore show that the particular operationalization accomplishes the purpose for which one intended to use it (Palys, 2003). The justification of validity lies in a full and open account of:

- (1) a study's method (Section 3.3) and results (Chapter 4) (Cope, 2002a);
- (2) acknowledgement of the researcher's background, revealing also the agendas for the research study (Section 3.6);
- (3) characteristics of the participants (Section 3.3.1) and the context of the study (Section 1.1 & 1.3);
- (4) steps in the study (Section 3.2.2); steps taken to collect unbiased data and to approach the data analysis with an open mind (Section 3.2.2, 3.4.1 & 3.7);
- (5) data analysis method with processes used to control and check interpretations (Section 3.5).

The aspects mentioned above were carefully incorporated into this current study. Such a practice is consistent with those exemplified in previous phenomenographic studies (e.g., Cope, 2002b; Sandberg, 1997; Wood, 2000). By providing these descriptions that make transferability

judgment possible on the part of potential appliers, it also illustrates how seeking for “transferability” (a criteria to establish trustworthiness (Lincoln & Guba, 1985)) could ensure validity. In addition, the account of this research study’s methods, accompanied by (1) the citation of large number or portions of interview transcripts that were used to generate the answers to the research question (Section 4.2, 4.3 & 4.4), and (2) the availability of data analysis documents which are on file, also sought to address the criteria of “dependability” and “confirmability” (Lincoln & Guba, 1985). In so doing, that an assessment of the quality of the integrated process of data collection, data analysis and of theory generation, and that an evaluation of how well the findings are supported by the data could be made.

3.7.2 Addressing issues of reliability

Replicability is a common criterion for measuring the extent to which the research results are reliable (Sandberg, 1997). Reliability can be deemed as reflecting the use of appropriate methodological procedures to ensure consistency and quality in data analysis (Guba, 1981). Marton (1986) commented that to ask whether phenomenographic findings are replicable or not is common amongst phenomenographers. He proceeded to highlight two issues related to the call for replicability: firstly, would other researchers reach the same categories of descriptions as the original researcher? Secondly, whether the other researchers can recognize the conceptions identified by the original researcher through the categories of description. Based on the argument that the original finding of the categories of description is a form of discovery that does not require replicability, Marton proceeded to argue that it is reasonable to require replicability for phenomenographic results in the second case but not the first. The categories, on the other hand, must allow for a high degree of interjudge reliability once they are determined.

Interjudge reliability, also known as interjudge agreement, intersubjective agreement, or “coder reliability check” (Åkerlind, 2002, 2005), is a form of replicability in the sense that it gives measurement of the extent to which other researchers are able to recognize the conceptions identified by the original researcher - by means of the categories determined (Sandberg, 1997). The reliability of the categories of description could be claimed on the basis of percentage agreement between all the researchers’ individual classification. Säljö (1988) mentioned that in most cases, the interjudge reliability is between 80 and 90%, while Johansson et al. (1985) deemed 75 to 100% to be satisfactory. Reliability checks, with varying degrees of methodical elements of interjudge reliability, were employed in several phenomenographic studies (e.g., Boulton-Lewis et al., 2001; Bowden, 1994a; Cope & Ward, 2002; Marton et al., 1993; Prosser et al., 1994; Trigwell et al., 1994), as well as in learning studies (e.g., Pang & Marton, 2005 – “communicability of categories”).

In view of the nature of this research study, a noteworthy issue that comes to the fore is a challenge that was posed to individual researchers who are working alone, without the availability of another researcher to check for reliability.

If the analysis is to be solely of the post-graduate student, under expert guidance, what is the validity of the individual process as opposed to the group process? Does the nature of phenomenographic research preclude less experienced individuals working alone, at least while they are still learning the techniques? (Walsh, 1994, p. 29)

A review of literature seems to indicate that the above issue has not been commonly addressed in an extensive manner. Despite not having employed interjudge reliability in this study, the issue of validity was addressed by borrowing from Lincoln and Guba’s (1985) concept of trustworthiness. The authors supported the use of peer debriefing as a technique useful in establishing credibility – as a way of exposing oneself and to explore aspects of the inquiry that

might otherwise remain implicit within the researcher's mind. Members in my research committee played the role similar to that of a "peer debriefer", although Lincoln and Guba cautioned that the debriefer should not be someone in an authority to the researcher. Their reservations stem from the power-relationships that might be present, which were addressed in this study. My research committee, comprising of another three professors in the Education faculty, played the salient roles of keeping me "honest"; playing "devil's advocate" and creating a space where "biases are probed, meanings explored, the basis of interpretations clarified" without me having to feel that my insights were not what they should be (Lincoln & Guba, 1985, p. 308-309). They also did not influence me to a greater extent than should be the case. In a way, my interaction with the committee also mirrored the principles drawn from interjudge reliability. Firstly, it shares the same principles as that of Åkerlind's (2002, 2005) "dialogic reliability check", which supports the use of group discussion amongst researchers (Bowden, 1994a). Secondly, similar to Bowden's suggestion (1994a), in an appreciation that I can be blinkered by my own ways of seeing, the space created between my committee and I allowed for me to be primarily responsible for the analysis and to explain the reasons for the categorization and description if necessary, while my committee members could test and probe. In the same vein, Corbin and Strauss (1990), in support of working with other researchers in the grounded theory approach, support that "an important part of research is testing concepts and their relationships with colleagues... Opening up one's analysis to the scrutiny of others helps guard against bias. Discussion with other researchers [with my committee, in this case] often leads to new insights and increased theoretical sensitivity" (p. 11).

3.7.3 Bracketing – addressing issues of validity and reliability

“Phenomenological epoché” underlies most forms of phenomenology and aims to ensure that the researcher withholds his/her theories and prejudices when interpreting lived experiences (Sandberg, 2005). The point behind epoché is to bracket knowledge that is relevant to the issue at hand; to set aside the researcher’s own assumptions drawn from the researcher’s personal knowledge and belief, as well as his/her theoretical presuppositions (Ashworth, 1999; Giorgi, 1990). In addition, the development of empathy, which requires a detachment from the researcher’s life world and an opening up to that of the participant, is advocated (Ashworth & Lucas, 2000). It is arguably pertinent in view of how the “correctness” of conceptions lies not in the conception itself, but in the values and interpretation of the historically and socially located researcher (Webb, 1997).

Because the construction of categories of description depends upon the participant’s very own descriptions of their relevant experiences (Ashworth & Lucas, 2000), bracketing is deemed as important. Sandberg (2005), following the principles stated by Ihde (1977), demonstrated how bracketing was practiced in his investigation into optimizers’ lived experience of engine optimization in the Volvo factory. The steps include:

1. an orientation to how the research object appears throughout the research process, enabling the researcher to be attentive and open to possible variations and complexities of lived experience.
2. an orientation towards describing what constitutes the experience under investigation, rather than explaining what constitutes the experience. In other words, the question of cause is bracketed (Ashworth & Lucas, 2000; Säljö, 1988).

3. treating all aspects of the lived experience as equally important in the initial steps of analysis (“horizontalization”). Sandberg (2005) explains that ordering some aspects as more important than others may distract the researcher away from a truthful interpretation, especially since a premature ordering of categories may increase the temptation to propagate the preferences, values and judgments of the researcher (as was similarly warned by Webb, 1997).
4. searching for structural features and/or meaning as a way to ensure that variation in interpretations of the data continues until the basic meaning of the lived experience is stabilized. This parallels the assertion to set aside the tendency to construct hypotheses and prior constructs, as was supported by Ashworth and Lucas (1998). The authors highlighted the danger of premature constructions of theoretical structures or other interpretations, or in too rapid foreclosure for the sake of producing categories of description (Åkerlind, 2002, 2005; Ashworth & Lucas, 2000).

In response to the assertions for bracketing, Richardson (1999) raises questions of the degree to which a researcher can fully bracket. In this research project, the position taken is similar to take of Richardson, and is shared by other researchers as well (e.g., Rennie, 2000). Such a position also draws support from hermeneutics’ position on “prejudgment” – Gadamerian’s “enabling prejudices” (Bernstein, 1983, p.128). Gadamer asserts that it is enabling prejudices that allow us to experience something, to encounter something (Bernstein, 1983). The argument can also draw support from Hodson’s (1986) underscore that observation is theory-dependent, and that “viewing an object or scene...depends also on the experience, knowledge and expectations of the observer” (Chalmers, 1999, p. 7). Rather than running in contention to the practice of bracketing, these assertions can be appreciated to appeal for a

delicate balance and constant negotiation between the drawing from one's own experiences and position to make judgments, to observe and to interpret, and on the other hand, to bracket these very assumptions and experiences. In other words, the inability to fully and perfectly bracket does not necessarily result in the dismissal of bracketing. In fact, the principles and goals of bracketing predispose the researcher, such as myself, towards being open and attentive to the participants. In other words, drawing from the principles and goals of bracketing inculcates an open disposition. It serves as a salient reminder of the necessitated avoidance of misinterpretation, underscoring my responsibility to understand the utterances of the participants. They also urged for an awareness and sensitivity to my own experiences, agendas and prejudices (as described in Section 3.6), thus enabling me to critically examine my roles, manage my possible prejudices, and to avoid manipulating the participants or the data. Concurrent to the allowance of much needed self-reflexivity (Rennie, 2000), sensitivity to the principles of bracketing has also served to remind of the need to ensure reliability and validity throughout this study.

3.7.4 Establishing credibility in the study

Guided by Lincoln and Guba's (1985) criterion of "credibility", the techniques of (1) prolonged engagement and persistent observation, (2) member checks and (3) triangulation were also applied to the current study.

3.7.4.1 Prolonged engagement and persistent observation

The duration of this research study afforded sufficient time for me to learn about the school culture and to understand the context in which the learning study was implemented. Prolonged engagement also allowed for the building of adequate trust and rapport without

“going native” (Lincoln & Guba, 1985). There was also sufficient time to become aware of the potential distortions that can emerge from my own a priori assumptions and my agendas (as discussed in Section 3.6).

The technique of “persistent observation” (Lincoln & Guba, 1985) was also employed in this study to identify the characteristics and elements that were most relevant to the inquiry. According to Lincoln and Guba, one important principle is that in the midst of sorting, the “atypical” is deemed to have importance. This was achieved in this study through the descriptions of each individual participant, thus allowing the particularities and the “atypical” aspects of participants’ experiences to emerge. Secondly, the approach of having all aspects of the experiences treated as equally important in the initial steps (akin to Sandberg’s (2005) “horizontalization”) also allowed for these “atypical” qualities to come to the fore. Calling for careful and thoughtful deliberations as to how these qualities would have influenced the participants, they were useful in the subsequent delimitation and testing of the themes that were constructed.

3.7.4.2 Member checks

Member checks allow for data, analytic categories, interpretations and conclusions to be tested by members from whom the data were originally collected, thus constituting a crucial technique for establishing credibility (Lincoln & Guba, 1985). In view of the importance of the first set of interviews - that were drawn upon in the organization of the learning study as well as the interpretation of teachers’ experiences (in subsequent interviews and other sources of data), member checking was employed (as was described in Section 3.3.2, Meeting 2).

3.7.4.3 Triangulation – use of multiple sources of data

Multiple sources of data was used in this research study to enhance the completeness and richness of the data (Dall’Alba, 1994), and to serve as a source of triangulation – as a way to establish the credibility of the findings and interpretations (Guba, 1981; Lincoln & Guba, 1985). Researchers have often used interviews with other sources of data, such as observations, drawings, written responses, and historical documents (Marton & Booth, 1997). The use of the Genetics Questionnaire in the current study, for example, was similar to that of Koballa et al.’s (2005). With the aim to uncover novice teachers’ conceptions of teaching science, the authors’ study entailed the use of interviews as well as a survey. Similarly, the complementarities of interviews and journal/reflective pieces, as used in this study, were also evident in other (phenomenographic) studies (Govender & Grayson, 2008; Van Eekelen et al., 2005). In the context of a learning study, student pre-lesson and post-lesson tests were often conducted alongside student interviews as a way to capture students’ understandings (e.g., Lo et al., 2004, 2006; Pang & Marton, 2003, 2005). These were likewise used in the current study.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, the results are presented and discussed. Three of the participating teachers' individual experiences are described, followed by the discussion of five themes that served to capture the variation in the teachers' experiences in the learning study.

4.1 Results and discussion

The individual experiences of the participants were analyzed and described. As described in the previous chapter, the analysis borrowed largely from a phenomenographic perspective that focused on the experiences of the participants. A second-order perspective was also assumed. In using theory of variation as a framework, the description also captured how the participants experienced different aspects of their teaching and professional lives differently from before (in more enriched or different ways). The variations might have brought to their awareness how they learnt in that process as well. The descriptions were guided by the following questions:

1. What are teachers' understandings of their own teaching and learning practices before participating in and experiencing a learning study?
2. How does participation in the learning study influence teachers' pedagogy and experiences of learning as a form of professional development?

These guiding questions serve to elucidate the ways teachers, in participating in the learning study, learnt and were developed professionally. They were crafted in response to the

following research question: “How does Singaporean teachers’ participation in a theory of variation-framed learning study affect their learning about their own pedagogy?”

In this chapter, the individual experiences of Chris, Amy and Pam were described. These descriptions were chosen because of the variations in teachers’ experiences that were illustrated in them, and because the three teachers taught the research lessons. Although the description of Kate’s individual experiences was not included, the description of her individual experiences was used in the construction and discussion of the themes. The chapter concludes with a description of these themes.

4.2 Chris’ experience of the learning study

Chris was deemed as one of the most experienced teacher in the team. Having taught for a total of 14 years, he has taught Grade 9-10 biology for five and a half years. Chris was also the only teacher in the team who taught life sciences for Grade 7-8.

4.2.1 Chris’ understandings of his own teaching and learning practices before participating in the learning study

According to Chris, helping students scaffold and build a strong foundational knowledge of biology was important. This was evident in his emphasis on students needing to know biological terms and to understand the basic concepts of biology well.

(C1) Chris: For me... I am more concerned about the students understanding the concepts. But I stress to them the first thing they need to know - the basic stuff, like terminologies, which I feel many of the students will have problems; getting the right terms and the structures and functions stuff like that...

Because biological content was viewed as foundational for subsequent learning and the development of a more holistic understanding, addressing students' misconceptions (excerpt C2) and helping students establish links between different concepts learnt (excerpt C3) were also priorities for him. Thus, students having to appreciate the big picture or overview were also regarded as important. What is of interest, however, was that the establishment of links was often done "unconsciously".

(C2) Chris: ...So one of my role is to get their perceptions right. They may be curious about certain things, but they may have certain misconceptions or misunderstandings about what they have seen or heard... And if they are wrong, that's easy to clarify and, you know, place them on the right track...

(C3) Chris: ...we don't tell the students, but hopefully by the end of it they will learn to be able to see systems - how things are linked from one system or one part of the body to another. Because when we teach the subject, we teach digestive system, then we teach respiratory system and so on so forth. And unconsciously, I'll try to lump and link them together...

In prioritizing students' development of a holistic approach to biology, and in stressing the importance of mastering content knowledge, Chris often employed questioning as a technique to draw students' prior understandings and to subsequently clarify them. He also drew from students' questions to guide his own pedagogy. As revealed in the interviews, these practices were also reflective of Chris' understanding of how he tried to gear his teaching towards student-centered approaches. For example, the introduction of "anecdotes" into Chris' lessons was dependent on their relevance to the questions asked by the students (excerpt C4). Chris also occasionally started his lessons with lesson overviews, prior to going into the parts (excerpt C5).

(C4) Interviewer: Yeah, you were talking about looking at students' previous knowledge, right? So how does that play a role in your planning of lessons or the way you are teaching?

Chris: ...When I plan the lesson, a lot of anecdotes [real-life examples, case studies or stories], you know. So these are built, you know, acquired along the way - from reading websites and other books and documentaries. So it just come(s), you know. I just “plonk” it into the lesson. It’s not like in the lesson plan, “I must say this”... students ask certain questions and then you’ll bring on certain anecdotes...

(C5) Chris: I feel that they will benefit more if they see the whole picture. So as far as possible, though I (I) don’t think I did it for all the topics, as much as I can, I would like to give them the whole picture first.

Chris also perceived the goals of teaching biology to include helping students develop an appreciation for living things (excerpt C6). This could be achieved through the use of anecdotes, which in his case, referred to real-life examples, case studies and stories. His pedagogical strategy of using anecdotes aimed at establishing relevance. In other words, students are able to apply the biological concepts learnt to real-life settings.

(C6) Interviewer: So is that your ultimate aim of teaching biology?

Chris: Yeah. Appreciating life – not just themselves, but plants, and other animals as well.

Interviewer: So what are the strategies that you would use to help them to achieve this?

Interviewee: Strategies?

Interviewer: Or approaches...

Chris: Approaches... story telling is one of them – making things more alive for them. Um, if I can get hold of relevant tapes or video clips, then yeah...

As revealed in excerpt C7, Chris actually deemed helping students develop an ability to apply scientific principles, to see their relevance and hence appreciate life as pertinent in leading to the larger goal of scientific literacy. That is, students are empowered for future action – in understanding scientific phenomena, the world around them as well as themselves (e.g., understanding why they fall ill). In response, students can act accordingly by drawing on scientific understandings (e.g., protecting the environment, taking proper care, development of empathy).

(C7) Chris: I think if they are able to understand why certain thing happen(s), like why they fall ill; why do they sweat, or you know, why a person faint(s), you know, when they exercise... that (that) will be... I will consider that will be a success already. So what happens after that depends on the girls themselves. If they are really interested, if it's like a relative getting ill – diabetes and all those things, like what we are teaching now - excretion; homeostasis, then they may want to go further, as in, taking care, you know, proper care, like ensuring proper diet. And then, empathy – like pain going through dialysis; why that person has to go for dialysis 3 times a week... I think appreciating and able to use their knowledge to explain the situation is already a success. So if they can do something about it, or if they can empathize with the situation or the person, then I think that is way up. Yeah.

4.2.2 How participation in the learning study influenced Chris' pedagogy and experiences of learning as a form of professional development

As illustrated in the excerpts below, the collaborative planning of curricular flow was deemed a valuable experience that allowed Chris to become aware of the different ways of interpreting the new genetics curriculum (“So the value of others - their input, their experience and their perspective” – excerpt C8). The process also allowed him to move beyond a heavy reliance on the textbook for curricular interpretation. He valued the opportunities to be able to link the different genetic topics and determine their flow in a way that was different from the textbook. The process also encouraged reflection on the prescribed curriculum (“is there any way, better way of doing it” –excerpt C8) and the exploration of new “possibilities”. This step in the learning study has allowed for increased clarity and coherence in his approach to curriculum interpretation. It has also served as a springboard whereby future organization of topics and students' learning can likewise be planned (excerpt C9).

(C8) Interviewer: Okay. Could I also direct your attention to this [points to script] - can you please help me clarify these two points [“getting a team of teachers to discuss and make a decision”; “not following the textbook flow blindly”] that you've put under the “Determination of curricular flow” [section in the overall reflective piece submitted]?

Chris: (Reads)... this first point is about involving others in making decisions. So the value of others - their input, their experience and their perspectives. So that is one. This is not following the textbook blindly [points to script]. So.... I can follow the textbook,

there's nothing wrong with that. But I think sometimes we would want to question why is it done this way. Or we want to explore whether it is possible to work another way – whether we can be more effective. I don't think there's anything wrong with following the textbook. Just that, is there any way, better way of doing it? Or, just to explore possibilities.

(C9) Chris: Okay. What I've learnt is in the planning stage, where we mapped out the whole lesson flow and all this... And involvement of other teachers comes in. Most of the time, we, you know, because of whatever reason, we do it ourselves or we just follow what is available to the book...

Interviewer: So... does this give you an opportunity to do your planning differently in the future?

Chris: Yes, in the future, yes. Not all the time, not all the topics - that's like impossible. So maybe just build up starting from genetics and then, you know, genetics can be repeated next year, and then next year maybe can do something else. And then after a few years you have a nice package.

(C10) Chris: ... If I look at the whole... the few topics together, there's one big chunk on genetics. So planning different [curricular] flow helps, because it gives me a very clear picture.

Another experience of the learning study that stood out for Chris was the use of student pre-lesson test to uncover students' prior knowledge. Frequently using questions to draw out these understandings instead, student pre-lesson test was typically not employed. In the learning study, Chris valued how the pre-lesson test revealed students' conceptions that were often "taken-for-granted" (Marton & Booth, 1997, Marton & Tsui, 1994). For example, Chris' former assumption was that students would have had a good grasp of the structure of genetic biophysical entities (such as chromosomes, DNA and genes), since these were introduced in earlier grade levels. However, the pre-lesson test revealed gaps in students' understanding. This affected how Chris planned his lessons to allow opportunities to specifically re-address these gaps, and to pitch his teaching to students' initial levels of understanding. (The other team members also similarly shared his former perception, and they, likewise, planned their lessons to deliberately address the gaps present.)

(C11) Chris: I think the pre-test was very helpful. *I didn't expect the percentage to be that low...* So that means I have to pact my standard lower and then start, you know, and then start from almost entry level... To that extent, it has *affected the teaching and the lesson planning*.

Interviewer: So did you, at any point of time, teach specifically to address some of the conceptions that arose from the pre-tests?

Chris: Yeah, the structure is one – the gene and DNA portion. So I spent a bit of time, a little bit more time on that... [emphasis mine]

The administration of student pre-lesson test to ascertain students' understanding also allowed for common ground (Marton & Booth, 1997; Marton & Tsui, 2004) to be quickly established. Being able to quickly establish common ground was highly valued by Chris, and was compatible with his teaching practices of drawing from students' prior knowledge to guide his teaching. What is illustrated here was how rather than merely employing the use of questions *per se*, the use of student pre-lesson tests constituted a different way for Chris to establish common ground - thus afforded learning opportunities for him. The positive experiences Chris had in administering student pre-lesson tests helped shape his view of the value of pre-lesson tests, and his intentions to apply them in the future.

(C12) Interviewer: ...So is there anything that is in the theory that supports what you are already doing, and what you believe about teaching or students learning biology?

Chris: ... students would want to learn if they are interested. So what makes them interested is, I feel that if the common ground has been established, and we don't pact it above it. If the common ground is established, then if we are able to build from there, then we will be able to get the students interested to learn. And the theory of variation comes in if we can identify this common ground and then identify the critical aspects to change; to vary... Pre-tests - this is not done frequently. But I think every time I do it, it's always beneficial. Cause the pre-tests give me an understanding of their common ground, um, trying to establish the common ground, and what misconceptions they have. So I think that is important and that will... should help in planning.

As demonstrated above (excerpt 12), the determination of critical aspects of the object of student learning was dependent on students' prior knowledge. Consequently, the patterns of variation and invariance to be enacted in the research lessons likewise drew from students'

initial understandings. This allowed the deliberate application of theory of variation to provide structure to the lesson enactment. Included below is a description of Chris' research lessons. (The description provided drew heavily from the audio-video recordings of the research lessons; recordings and notes of the post-lesson conferences; researchers' field notes including lesson observation notes; as well as the interview transcripts of both students and teachers.)

Research Lesson 1: Introduction to genetic biophysical entities (1period, 30minutes)

Chris implemented the research lessons in one of the top classes, comprising 26 girls. These girls were in the school's gifted program. As observed in this lesson, Chris employed a variety of questions to elicit students' prior knowledge and students' answers. Questions were also used to scaffold students' answers. With respects to the enactment of patterns of variation and invariance in accordance to theory of variation, Chris varied the levels in which genetic materials could be understood (e.g., chromosomal, DNA, gene level) while keeping the notion of genetic materials invariant. Another pattern of variation employed was to constantly shift between the structural and functional aspects of genetic biophysical entities (of which the idea of biophysical entities, or reference to a specific biophysical entity was kept constant).

Chris started the lesson by introducing the term chromosome and differentiating it from sister chromatids, since students were often confused by the two terms. The concept of "homologous chromosomes" was subsequently introduced. Chris proceeded to prompt students to differentiate chromatin, chromosome, sister chromatids, DNA and genes. The girls were given the task to order the terms according to their relative sizes (a similar task was included in the pre-lesson test). Students were called upon to volunteer their answers, and the different answers were compared. This part of the lesson allowed for clarification of students' conceptions.

Students were then asked to discuss what a gene is – Where is it found? What is gene made up of? What is its function? How many genes are there in a human? The questions served to uncover students' views of chromosomes, DNA and genes. They also helped to shift students' view from the chromosomal level to the DNA and gene level, and to shift from the structural aspects of these entities to the functional aspects. The latter not only shifted students' attention to the nucleotide level, it also encouraged students to establish the structural and functional relationships between the different genetic entities. Chris subsequently prompted students to think about whether all cells in the human body contain the same genes – thus leading to the notion of gene expression.

Using a book analogy to help students become simultaneously aware of the structural and functional aspects, the different levels in which the components of a book could be understood were compared with the different genetic biophysical entities – allowing a focus on the parts while positing a simultaneous focus on the “collective whole” (Marton & Booth, 1997) (like the whole book). The foregrounding of the structural aspects included, for example, that chromosome is a book; the sentences in the book are the DNA; and that each gene is a sentence. The functional aspects were also focused upon, for example, by relating words to the sequence of the gene; that the order of the words is crucial for the sentence to make sense. Chris proceeded to show an example whereby nonsensical words were interspersed within sentences, thus illustrating the coding and non-coding regions of the gene.

Research Lesson 2: Functional aspects of genes: transcription and translation (3 periods, 90minutes)

The second lesson was implemented a week after the first one. In this lesson, the original intention was to help students focus simultaneously on the structural and functional aspects of genes. But due to students' confusion between the biophysical entities introduced in the last lesson, Chris had to spend more time than originally planned on the clarification of these entities. As consistent with his

teaching goals of helping students establish links between “parts” and the “whole”, he also devoted some time to help the students link “disparate pieces” of information by constructing maps on the whiteboard.

Chris started off the lesson by asking students to draw a simple concept map to illustrate the relationships between nucleotides, genes, DNA, chromosomes and chromatin, as well as to differentiate between homologous chromosomes and alleles. This served as a way to stimulate recall of the learning points in the previous lesson. Different students were then asked to present their maps, with Chris providing feedback on the maps and how they could be improved – based on the relationships between the entities and their structural and functional relationships.

The first activity revealed that some students were still confused about the differences between chromatin, chromosomes, sister chromatids and homologous chromosomes. The relationship between chromatids and the number of copies of DNA and genes was also unclear. So Chris decided to spend more time to further clarify some of the confusion, by mapping on the board the relationships between the entities even as the class discussion proceeded. Chris also introduced the term “histones”. The map also allowed students to include “bases” and “sugar-phosphate backbone” as components that make up nucleotides. (During the post-lesson conference, how Chris employed theory of variation in this activity was brought to the attention of the team by the researcher. That is, together with the students, Chris explored the varied conceptions students had on the differences between chromatin, chromosomes, sister chromatids and homologous chromosomes. He did this by mapping on the whiteboard different student understandings and subsequently guiding the students to arrive at conceptions that were more closely aligned with the canonical science of genetics. The strategy and variation employed here was explained to the team as being similar to the “postman route” lesson” (Runesson & Mok, 2004).)

Chris proceeded to shift students’ attention to the functions of genes and how they are involved in the production of proteins - on how genes produce RNA through the process of transcription, and the

RNA subsequently results in the formation of amino acids during translation, and the proteins subsequently affect the traits that are expressed. The key concepts around gene expression were focused upon via the exploration of the relationships between genes, traits, proteins, amino acids, RNA, transcription and translation - even as the discussion resulted in a co-constructed concept map by Chris and his students. The key concepts of gene expression were then summarized through a PowerPoint slide presentation. The presentation also allowed Chris to introduce more details of the process of transcription and translation that were not previously discussed. The students were then shown an animation (online video clip) illustrating the transcription and translation processes. Prior to a second viewing of the same clip, Chris took the opportunity to explain certain parts in order for students to develop a clearer and more accurate interpretation of the clip. During the second viewing, Chris strategically stopped the animation at various points to highlight or explain certain steps. As consistent throughout the lesson, Chris employed the use of questions. Whenever appropriate, Chris would also vary the mode of presentation by illustrating the same concepts on the board- through concept maps or diagrams drawn. At this point, new terms that would be reviewed in the next lesson were also mentioned. In this way, different details pertaining to the genetic processes of transcription and translation were layered. (During the post-lesson conference, the pattern of variation and invariance enacted here was highlighted to the team - whereby concepts of transcription and translation were kept constant while the representation of the processes, such as the use of PowerPoint slides; videos, were varied. Through this, other examples in which theory of variation was enacted were brought to the attention of the teachers.)

Towards the end of the lesson, Chris highlighted a newspaper article featuring how some people suffered from heart conditions that were due to a single faulty gene, linking the condition to the production of an abnormal heart protein formed. The article also foreshadowed the pattern of variation to be employed in the next lesson, which would include the mutation process. Chris also brought up another two articles focusing on the harvest and use of stem cells, in order to link what was learnt to the Grade 8 life sciences course.

Research Lesson 3: Functional aspects of genes: the genetic phenomenon of mutation (3 periods, 90minutes)

This lesson was implemented a week after the second lesson. Employing theory of variation, Chris designed and enacted a game, the “Scrabble” game, to help students deepen their understanding of the functional aspects of genes. The game also served to help students establish relationships between the structural and functional aspects of genes. Variation was applied to the letters making up different words, akin to variation in nucleotide bases making up the nucleotide sequence of a gene – as was similar to the genetic phenomenon of gene mutation. In other words, the variation in the nucleotide sequences of the gene, which would result in variation of the products of transcription (mRNA formed) and translation (protein formed), was the pattern of variation and invariance used here. In this lesson, Chris also used a pattern of variation to introduce the different types of mutation, foregrounding how the formation of abnormal mRNA and abnormal protein, or amounts of them, could be attributed to different changes in the genes or chromosomes. In this case, the genetic phenomenon of mutation was kept constant, while the ways in which mutation could be brought about were varied. The lesson was conducted within the first hour of the lesson. In the last thirty minutes of the lesson, the student post-lesson test was administered.

The lesson started with the “Scrabble” game. Starting with seven tiles, the students worked in pairs to form as many words as possible. With each tile placed on the board, new tiles could be picked up. The pairs were instructed to score the awarded points according to the length of number of words formed. Thus, the first part of the game served to direct students’ attention to the importance of nucleotide sequences in the gene.

The second part of the game shifted students’ attention to what would have happened when the nucleotide sequences were varied. It entailed the switching of partners, whereby the “new” member was to inflict “damage” to the words formed on the board. The “damage” was determined by a list of

instructions that students would randomly pick. The new member of the group, according to the stipulated damage, such as the substitution of letters of a word, would then enact the new changes. The loss of proper words due to the changes would correspond to losses in the points awarded. At the end of the game, Chris encouraged the students to share about the insights gained. The learning points were written on the board. The correlations between the learning points and genetic concepts were then made. Student responses included “a single change in letters can result in high damage” and “a single letter plays an important role” - both of which demonstrated how students deemed the sequence of letters as important, extending to the idea of coding and non-coding sequences as well. Students’ responses also included “single change in letter could actually result in damages, although damages may not always happen”. This demonstrated the potential for developing an appreciation that while a single change in nucleotide can cause the gene to be expressed abnormally, it is not always the case. Chris used these subsequent learning points to scaffold the rest of the lesson, highlighting these points whenever relevant. It is noteworthy that during the post-lesson interviews with students, it was commented upon that the game was effective in helping them realize the importance of the sequence of bases, and they were able to reiterate some of the learning points that they have acquired from the experience.

Using a PowerPoint slide presentation, a discussion in class was then facilitated with the use of questions as prompters. Students were led to describe and explain the process of mutation in terms of changes in nucleotide sequences in the coding regions of the DNA, that is, changes in the structure of genes. Chris also introduced the different types of mutagens and mutations – the latter corresponding to substitution of bases, deletion of bases and gene addition/deletion. Students’ attention was thus shifted to focus on changes in gene sequences or number of gene copies, which can bring about a change in the expression of gene. Different examples were used to illustrate the different mutation processes:

- Nucleotide substitution (example of sickle cell anemia) – changes in gene sequence
- Nucleotide deletion (case study on heart diseases) – changes in gene sequence
- Gene addition or deletion (example of Down Syndrome) – changes in gene copies

To further demonstrate the impact of altered amounts of proteins on the expression of traits, students were also shown examples of triploid watermelon. It is noteworthy that Chris' intention was to help students develop the understanding that if there were changes in gene sequences or copies, changes in the products of transcription and translation will follow. However, these aspects, while being mentioned, were *not* as deliberately varied or highlighted.

The deliberate application of theory of variation resulted in the collective decision of including mutation into the topic of gene expression, as was demonstrated in Chris' research lessons. The topic of mutation was formerly taught together with another chapter, and links with gene expression were seldom made. Not only did the inclusion of mutation help Chris teach the processes of transcription and translation, its inclusion has also helped him make sense of the entire genetics unit, while concurrently adding coherence to the lessons (excerpt C13). This opportunity to establish links between topics constituted a new experience that was more deliberate (compare with excerpt C3).

The application of theory of variation also resulted in Chris having to enact patterns of variation and invariance in more systematic ways. Previously, Chris would instinctively use variation, albeit in a "more scattered" manner (excerpt 14). In addition, new resources were prepared. For example, real-life examples that would fit into the pattern of variation were researched on and deliberately included into the lesson (excerpt 15). Not only was this consistent with Chris' practices of including anecdotes, but the use of anecdotes in this study was more intentional and well planned than before (compare with excerpt C4).

(C13) Interviewer: ...There's this particular part where we talked about the theory of variation... could you clarify this part [pointing to interview transcript] about the theory being useful to make your lesson more cohesive?

Chris: Okay. What I meant was, when we sat down to discuss, we plan out the pathway, the route we were going to take. So in that sense, we see more... we make more sense in the structure or the arrangement of the lesson. So that will help the teacher after that to plan the lessons, Yeah. So, yeah, that's what I meant.

(C14) Interviewer: ...Can we also look at the organization of the lessons? You talked about how it has actually helped to make the planning more focused, when you used the theory of variation. So could you elaborate a little bit on that?

Chris: ...So instead of digressing and then coming back, because of this [theory of variation], I am kept in check that I need to follow through the variation that I have made all the way... And I can make a different variation and show the students any similarities and differences. *So it becomes very focused in using variation. In the past, it will be, well, more scattered...* sometimes I tend to digress – go on to bring in other concepts or other parts of the lesson, and then I'll come back... So it becomes disjointed. So with this, I tried doing just solely on, you know, the TOV [theory of variation]. So that way it's more focused. Or rather, *I'm more focused in executing the TOV.* Yeah. [emphasis mine]

(C15) Chris: ...in the planning, because I want to use the TOV [theory of variation], so I can research on the few examples that I can use. So that will make my flow of lessons more intact, rather than what is from the book, or what is from my experience. Then I will join the lessons together, then I will join the various parts together... I can research on what are the mutations that result from all these changes. So I have real-life examples, rather than saying, "Okay, change of proteins... change of sequence... change of whatever" without the link to the real thing...

As illustrated, the deliberate application of theory of variation has allowed Chris to experience the enactment of the whole genetics unit as well as the individual lessons in a more coherent way. The application of the theory has helped him organize and implement students' learning experiences. Believing that students' learning can be enhanced (excerpt C16), the experience of deliberately applying theory of variation was also regarded as the acquisition of a skill that can be incorporated into his repertoire of pedagogical strategies, whereby the future application of the theory to guide the enactment of lessons could be more "rigorous" and "streamlined" (excerpt C16).

(C16) Chris: "I've learnt that students can benefit more from the lesson when they see changes one at a time and their effects" – that's TOV [theory of variation]... So you change and what's the result? So that's more on the understanding and the application part. So what I meant is the students will benefit more if they can.. if we can take things one at a time. I think it's quite obvious... If there's an opportunity to apply TOV in

certain aspects of my lessons, then I will be more conscious about it. That means that the effort will be more rigorous and more streamlined, like digging for examples...

When asked to reflect on his experiences in the learning study that would constitute his own learning as a form of professional development, Chris highlighted the experience of collaborative inquiry into his and his colleagues' research lessons. Through the experience, he felt that his current teaching practices were supported, and that he also gained new insights on how to improve his pedagogy. The opportunities to observe colleagues' lessons allowed an experience of the different ways in which theory of variation-framed lessons could be enacted. Coupled with the post-lesson conferences, whereby these differences were highlighted and discussed, Chris' understanding of the theory deepened (excerpt C17). According to Chris, what was particularly helpful was that "unplanned" examples in which theory of variation were employed were also pointed out by the researcher. The overall experience influenced Chris' perception of the fruitfulness, as well as his willingness, to apply the theory in future lessons. In addition, the widening of perspectives also served to further support, while adding a sense of clarity and meaning to, his former instinctive attempts to apply variation in his teaching.

(C17) Chris: ...I think through at least the two sessions of evaluation, I can see how TOV is used not just directly in teaching, but in other aspects... what are some of the less obvious examples of TOV [theory of variation] used in the other teachers' lessons were discussed. So it made me aware that "Oh! You mean that is also TOV."

The opportunities to observe colleagues' classes also allowed Chris to experience learning through the eyes of his students (excerpt C18). This enabled him to evaluate students' learning more efficiently and to more precisely pinpoint areas that needed further clarification.

(C18) Interviewer: ...So we are looking at the observation of your colleagues' lessons. You mentioned that it is "good to observe how theory is applied to another class..." So how did this actually impact your own teaching, your pedagogy, or maybe your future teaching of the topic?

Chris: Okay. I've written here I have the luxury of looking at the students and also, in certain cases, interacting with the students while the teacher is ... doing her stuff. So that will give me an insight on how the student is feeling or what she is thinking of at that point of time, after the lesson or that part that is being taught... it will help me if I need to empathize with the student... So I can see the teacher teaching something and what the student is feeling immediately after that. But if I am teaching it, I am also thinking of what to say next... and I wouldn't be able to interact with the student at all. Yup.

During the last interview, Chris was asked to review the Genetics Questionnaire that was completed at the beginning of the study, and to comment on how his views shifted, were challenged or were supported by his experiences in the learning study. One of the noteworthy points brought up was how he now deemed students being able to establish links with real-life phenomenon as more important than before.

(C19) Chris: ... I will rank number "4" ["encourage students to establish links with real-life phenomenon that is related to genetics] as number "3" [more important]. I think in order for biology to be real to them, they must see the links to real-life phenomena, instead of just studying it in the classroom...

Interviewer: And now you change it to "3" [ranked as being more important]. So was there anything in the learning study that made you switch? Like, was there a support for the switch?

Chris: I think the more you see the students responding to the real-life examples and case studies... I think that will probably... that will tell me that that is a more powerful tool to use in learning...

Interviewer: So what is the "real-life example/s" that you think you used?

Chris: The one that came to my mind, and we discussed, is the mutation part...

The inclusion of mutation when teaching the concept of gene expression has further deepened Chris' prior conviction about needing to help students establish links with real-life phenomenon and apply what is learnt beyond the classroom context. Chris' experiences in the learning study have also led him to refine his belief. When measured against the goals of helping students to excel in examinations and thus to teach the stipulated content, generation of students' interest and his wider goal of scientific literacy was now more important than before.

(C20) Chris: If given a choice, I would like to move "5" ["to help students understand and 'judge' reports of genetic-related issues made available through various media, such

as the newspaper”] and “6” [“to generate students’ interest in genetics”] higher. Yup, more important... But you know, having these [“to enable students to be better prepared to answer the genetics questions in the exams”; “to help student develop an understanding of the genetics content in the syllabus/textbooks”] the same, and raising this [“to help students understand and ‘judge’ reports of genetic-related issues made available through various media, such as the newspaper”; “to generate students’ interest in genetics”] up to this level...

4.2.3 Chris’ learning about his own pedagogy

What is demonstrated in the previous section was how Chris’ participation in the learning study granted him varied experiences that allowed him to experience his own learning as a form of professional development. His professional beliefs and pedagogy were also influenced in different ways. The experiences have allowed him to have his current beliefs and practices supported and refined. They also constituted new experiences that he could draw on in future to improve his own pedagogy. The experiences that seemed to stand out for him, particularly, were opportunities to:

- (1) collaboratively determine the curricular flow, which granted increased clarity and coherence to curricular interpretation. The experience also allowed for a way to move beyond a heavy reliance on prescribed curricular materials and towards more authentic lesson planning.
- (2) elicit students’ prior understandings through the administration of pre-lesson tests. This influenced how Chris deliberately addressed students’ problematic conceptions and effectively established common ground with the students.
- (3) deliberately employ theory of variation to guide the enactment of his lessons, even as the theory added greater coherence between the genetic topics and within the lessons. Chris also experienced different ways in which theory of variation was employed in his colleagues’ lessons. Both of these experiences supported his use of variation previously,

while enabling him to experience a more systematic use of variation to further enhance his teaching. The deliberate use of the theory also resulted in the creation of new curricular resources and activities. Consequently, Chris came to a deeper conviction of the usefulness of the theory in enhancing students' learning.

(4) deepen his previous convictions about what good biology teaching would include, that is, to establish links with real-life phenomenon.

What is also worth noting was how the influence of the learning study on Chris' pedagogy and professional learning was viewed to be stronger than in some other professional development arrangements. This was attributed to how the learning study was implemented within the context of the teachers' own classrooms - providing the teachers with opportunities to personally inquire into their own teaching practices; be engaged in a "hands-on" manner, while concurrently being immersed within a collaborative setting. Thus, Chris' experiences likewise support the assertion of other researchers that underscore the importance of teacher collaboration (Arbaugh, 2003; Lieberman, 2000; Shulman & Sherin, 2004; Wineburg & Grossman, 1998) and teachers' inquiry into their own classroom as professional development (Nelson & Slavit, 2007; Smylie, 1989; Stigler & Hiebert, 1999). Similarly, this supports the critiques in literature pointing to the deficiencies in "one-shot" professional development approaches (see Clarke and Hollingsworth (2002) for a review).

(C21) Interviewer: So how did this experience [participation in the learning study]... how did it help you to learn about your own pedagogy?

Chris: Okay. The first thing that comes to my mind is the effectiveness, or the takeaway will be much greater than going for a two-day course – to sit down and listen and then, someone to share about, you know, the experiences. Yeah. Because it's a (it's a) team effort, so you get to see other's perspectives, although it is more time-consuming that way. *The other thing is that you get to execute it. And then, you know, evaluate it soon after.* So the learning curve is steeper than, yeah, like going for a course. So that part, *the impact is stronger or greater.* Yeah. [Emphasis mine]

4.3 Amy's experience of the learning study

With three years of experiences teaching Grade 9-10 biology, Amy was regarded as one of the less experienced teachers in the team. She has taught the new genetics curriculum only once.

4.3.1 Amy's understandings of her own teaching and learning practices before participating in the learning study

According to Amy, helping students develop an interest in and to enjoy biology were of most importance. She believed that the development of interest would aid in content retention, and would motivate her students to learn (excerpt 1). This belief affected how she would use games and other activities in her lessons, even if it meant that less learning was yielded (excerpt A2).

(A1) Interviewer: So why do you think enjoyment is so important? What's the benefit that you see that it has?

Amy: I think in order for them to even want to study for that subject, they must enjoy whatever that they are reading, so which is why it is very important for me to *inculcate in them that interest* in whatever that they are reading. So if... when the next time they read that topic and they can at least recall back that we did this during class, I'm hoping that that will at least motivate them to read and, you know, understand the concepts a little bit better. Yeah.

(A2) Amy: ...when I teach, I prefer to include like games... what's important in my lesson at the end of the day is that my students enjoy that time that's spent thinking about bio [biology]... even though certain games might not necessarily yield a lot of learning on the students' part right, I think it's the interest that I really want to build in them.

Amy also believed that students' enjoyment, interest and love for biology were necessary for the development of an appreciation for life.

(A3) Amy: ...all I want is for them to develop an interest in bio, a love and interest in bio. Yeah, that is my ultimate goal, I mean, above and beyond the (GCE) "O" Level (examination) grade...

Interviewer: So what do you think, then, is the learning outcome that you really hope to see in your classrooms?

Amy: I think that would be my big goal – to be able to appreciate life; to be able to appreciate creation. Yeah.

Despite Amy's larger goal of helping students develop an appreciation for life, the sharing of her own teaching experiences during the first interview revealed that during lesson planning and enactment, the focus was largely on the delivery and learning of content. For example, she viewed that good biology teaching required lessons to be well organized in order that content could be clearly presented to reduce confusion (excerpt A4). Believing that the organization of presentation slides directly influences students' ability to link different concepts, great attention was also paid to the arrangement of PowerPoint slides, of which she utilized heavily in her teaching.

(A4) Interviewer: ...so why is it important for content to be clear?

Amy: So that there will not be any... they will not feel confused... I think that the presentation of the content has to be clear. So if, whether you are teaching from slides or from the textbook or anything (else), it has to be presented in an organized manner...

What is worth pointing out is that Amy's preparation and organization of her lessons relied heavily on prescribed curricular materials. This was also illustrated in how she translated the stipulated content in the prescribed curriculum into questions (excerpt A5). The excerpt below also reveals how she relied on the prescribed curriculum to help student prepare for tests and examinations, thus suggesting her view of the curriculum as an assessment-driven one.

(A5) Amy: Okay, I will look at the syllabus [prescribed curriculum], so that's something I will include into my slides. Then after that I will question - I will then try to translate them into questions like "What is the purpose of, say, the excretory system?" - for example. And that's how I then organize my slides – into questions, and then with these questions, (then) my slides will then give them the answers.

Interviewer: So why bother to convert them into questions?

Amy: I think because it (it) will help them when it comes to answering like test papers and exams papers. Yeah.

Amy also believed that good biology teaching entailed teachers creating a safe space for students to ask questions. She believed that students will ask questions when they understood what was taught. Hence, students' questions constituted a way for Amy to elicit feedback from students (excerpt A6). In other parts of the interview transcripts, Amy also mentioned the use of worksheets to check for students' understanding.

(A6) Amy: ... Which is why right now when I teach my students (also), I always emphasize on this fact that "if you have any questions please by all means come to me". Yeah. And like, just, there isn't like any question that is too stupid or too dumb to ask. Yeah.

Interviewer: So why are you willing to entertain the questions?

Amy: I don't want them to be afraid of even asking, yeah.

Interviewer: So what is the benefit of them being able to ask?

Amy: What is the benefit of them... I think when they are able to ask, that's when they really understand. Yeah.

The development of students' capacity to apply biological concepts beyond the context of the classroom to "real-life example" (excerpt A7) also constituted Amy's perception of good biology teaching – an aim related to the broader goal of scientific literacy. Moreover, students' demonstration of such a capability would reflect that they have understood the lessons, and thus served as a means of feedback for Amy.

(A7) Amy: ... Well I think that I (I) feel quite good when I'm with a group of students and they like... something happens, say someone falls, and they are able to, maybe just for the fun of it, they (just) start to think about the clotting mechanism or something like that. It goes to show that *they have understood what has been taught*, and now when they actually *see a real-life example*, they are able to, you know, *explain with confidence*. *So to me that is really applying what they have learnt in class...* [emphasis mine]

According to Amy, she constantly drew from the Internet to find suitable examples that she can use to help students apply the biological concepts learnt. She also varied the use of different phenomena in which the same biological concepts or mechanisms can be applied to ("bring in new scenarios" - excerpt A8).

(A8) Amy: ...in terms of the application... for example, we recently covered excretion, so we'll talk a little more about kidney transplant, peritoneal dialysis, things that, you know, help to apply... You know, it's still applying the idea behind diffusion and all that. So *it's like bringing a new scenario in but we'll still focus on the same mechanism*. Yeah. [emphasis mine]

Amy's classroom practices seem to be largely focused on content and the mastery of it. Her deep conviction of the importance of good content delivery also shaped how she felt that the gap between her current teaching practices and what she deemed as good biology teaching hinged on her lack of teaching experiences. She believed that increased years of teaching would result in better content delivery.

4.3.2 How participation in the learning study influenced Amy's pedagogy and experiences of learning as a form of professional development

Amy deemed the opportunity to collaboratively determine the curricular flow as a valuable experience. In her reflective entry, she expressed that although the process of determining the curricular flow was long, that it "allowed me to plan the content that I wish to cover in each lesson to allow a smoother flow, as compared to previous experiences where my teaching objectives are affected/aligned to the syllabus order". When probed in the subsequent interview for an example of what she meant by a "smoother flow", Amy explained that previously, disparate pieces of information found within different genetic topics were taught at different times. In contrast, in the learning study, these topics were rearranged and were taught together in order to help deepen students' understanding of gene expression.

(A9) Amy: Oh... You see like gene mutation, previously I wouldn't cover it under this chapter. I will only come to that when I teach inheritance. So in that sense, this allowed me to... allowed me to connect it nicely. Yeah.

What is illustrated above was an experience of increased clarity and coherence in Amy's approach to curriculum interpretation. The clarity and coherence was also brought about through the forging of a common understanding ("common platform" – excerpt A10) amongst the team as to what was important in the genetic lessons. The scope and depth of the new genetics curriculum were collaboratively explored and determined. This was brought about through the collaborative determination of curricular flow and subsequent planning of research lessons (excerpt A10 & A11). (Excerpt A11 also suggests that Amy's former interpretation of the prescribed curriculum was a content-driven one, and how she has shifted to focus on students' understanding as opposed to the content *per se*.)

(A10) Amy: ...this time round because there were three of us [the three teachers teaching the research lessons], it was good that we had this common platform to really write down what we want to do.

(A11) Amy: In that sense that was *always at the back of my mind, like, "What was the main focus?"* So even though I was covering the same details...I did not focus overly, like, too much on them. Yeah. Instead, *I try to draw it back to how we always want to help them understand the links; the gene, and its place in this whole topic...* [emphasis mine]

Interviewer: So was this a new focus compared to the last round when you taught the topic?

Amy: Yes, definitely. Because last year when I taught, it was more like I followed very closely to the syllabus and the sequence. So that was more of (like) addressing what the syllabus wanted, and I just covered it in that sense...

In addition, learning study's focus on helping students develop a specific capability (object of student learning) also granted Amy greater clarity and coherence in her approach to curriculum interpretation (excerpt A12) - although her view of the object of student learning was synonymous to "critical aspects", thus conferring slightly different meanings to the terms as would be prescribed in research literature.

(A12) Amy: I like the emphasis on finding a “critical aspect” [referring to the object of student learning] as that makes it very clear on what we need to focus on across the entire series of lessons... the emphasis on a specific capability was very useful for me as that allowed me to look beyond the syllabus to focus on a concept that is necessary for a better understanding of genetics to be developed. [from Amy’s reflective entry]

The increased clarity and coherence in Amy’s approach to curriculum interpretation was further brought about through opportunities to observe one another’s lessons. As mentioned in Chapter 3, it was deliberately organized such that Chris would implement his research lessons before Pam and Amy. In this way, Pam and Amy could participate in the observation and evaluation of Chris’ lessons prior to enacting their own. Such an arrangement has allowed Chris, who was a more experienced teacher, to serve as a resource whereby his experiences, expertise and views were drawn upon. As revealed in excerpt A13 (and other parts of the transcripts), Amy thought that prior to participation in the learning study, she was not very clear about “how much to teach; and what to teach; and what to focus on”. This illustrates how she felt that there was a lack of clarity when she initially approached the curriculum. But in observing Chris’ lessons, she eventually became clearer as to “how much to cover, the depth to cover”.

(A13) Interviewer: Can we also look at teacher collaboration, where you actually mentioned about being able to “draw on each teacher’s strength and content knowledge” [mentioned in Amy’s reflective entry]? Can you elaborate a little bit more about that?

Amy: I think it was about how when we first started, we weren’t very clear about, say, gene expression – how much to teach; and what to teach; and what to focus on. So, Chris being more experienced in this... So when I sat in his class, that gave me a good idea of how much to cover, the depth to cover with them as well...

What was demonstrated is how Amy’s engagement with interpreting the curriculum was not relegated to the initial steps of the learning study, but was a constant process that took place right through the enactment and observation of the research lessons. The experiences of collaborative planning and lesson observations constituted new ways for Amy to experience her

approach to curriculum interpretation, that is, with greater clarity and coherence. The experiences have also allowed for a more authentic lesson planning experience that moved away from a heavy reliance on the prescribed textbook (excerpt A12). These experiences were also enriched by her experience of systematically inquiring into students' prior knowledge. The student pre-lesson test results allowed her to have a better understanding and "to be more sensitive to their misconceptions/areas of confusion" (taken from her reflective entry), thus affecting her lesson planning. The excerpt below, taken from her reflective entry, demonstrates how she drew on students' understanding to determine the focus of her lessons. Rather than "focusing on everything" (as prescribed by the curriculum), which she would have done in the past, she could now hone in on certain aspects that she felt warranted greater attention.

(A13) Amy: The data collected allowed me to read and have a better understanding of what they know or what they think they know. This gave me a clearer idea of their prior knowledge and that helped in the way I structured my lesson, by choosing certain aspects to focus on instead of focusing on everything.

Having been more sensitized towards students' "misconceptions" (a term used by the teachers to define students' conceptions that may not be consistent with canonical science) and areas of confusion, Amy reorganized her slides to address students' problematic conceptions. She also planned to use her curricular resources differently from before. For example, having developed an appreciation that it was important to "start at a point that students can experience/relate" (as mentioned in her reflective entry), in her research lesson, a video was viewed thrice instead of only once. The first time round, the video was used to establish common ground, and to form connections with students' prior knowledge without being weighed down by biological terms (excerpt A14). In the subsequent viewings, links between students' prior knowledge and new concepts to be learnt could be established, even as different

aspects that students have to simultaneously attend were layered. In a similar manner, Amy came up with an activity that required students to map the relationships between traits and genetic biophysical entities, with the aim to establish links between the structural and functional aspects that were often absent in students' understandings.

(A14) Interviewer: Okay. So how did you address their [students'] conceptions in your lessons?

Amy: ...I think it's more of like the focus of my slides, yeah. And like, for example, when I taught the protein synthesis portion also, that was something that I felt that they were really quite lost initially. So that was why I thought of doing it [a video clip] over three stages, to help them maybe reconnect from Sec. two first, through the first round. Then slowly add on with the next few rounds.

Amy's experiences of systematically inquiring into students' prior knowledge, and subsequently using them to guide her classroom teaching, have resulted in her disposition towards using student pre-lesson test in the future. When sharing about how the learning study influenced her pedagogy and her own learning of it, Amy also explicitly mentioned that she has learnt how to plan and use a pre-lesson test (including the range of questions to include) to aid in the teaching process.

The employment of theory of variation, serving as a source of structure, has also largely influenced Amy's experience of planning and enacting students' learning experiences in her research lessons. A description is provided to illustrate Amy's enactment of theory of variation-framed lessons.

Research Lesson 1: Introduction to genetic biophysical entities (3 periods, 90minutes)

Amy implemented the research lessons in a higher ability class within the school, comprising 28 girls. Amy established common ground with the students by approaching the topic using the notion of traits, which, as was informed by research literature and the results of student pre-lesson test and

interviews, was a common way for students to approach the topic of genetics. Results from the student pre-lesson test and interviews also indicated that students faced challenges in establishing structural relationships between chromosomes, DNA, genes and nucleotides, as well as the lack of functional relationships being evident in their understanding. Similarly, the notion of genes being switched “on” and “off” was often missing in students’ conceptions. Amy drew upon these understandings and deliberately addressed them in her lesson. Within this lesson, Amy has also employed a pattern of variation and invariance - systematically varying the levels in which genetic materials can be understood (e.g., chromosomal, DNA, gene level), while keeping the notion of genetic materials invariant. Consistent with her belief that helping students establish links between concepts are important, Amy shifted between the structural and functional aspects of the biophysical entities. In addition, she crafted an activity (“The Incredibles”) to encourage students to simultaneously focus on and establish relationships between the different levels in which genetic materials can be understood.

Amy started the lesson by showing students a picture of comic superheroes (“The Incredibles”). Using it as an entry point and to establish common ground, she posed the question “What makes us all unique?” In answering the question, students described the differences in terms of visible traits - for example, whether hair is curly or straight; skin color; eye color. Amy proceeded to define “notable traits” and related it to the concept of genes. She then proceeded to help students consider the impact of environmental factors on the expression of traits.

The next part of the lesson focused on the structural aspects of genetic materials. Looking into the components within the nucleus, Amy proceeded to introduce chromosomes. However, at this point of time, a student raised a question as to whether the gene for eye color is found only in the cells of the eye. Amy diverted the question to the rest of the class, with most of the students expressing their views that all cells contained the full set of genes. Amy then guided students towards a brief understanding that the genes responsible for eye color are expressed only within the eye cells. She then proceeded to return to

her original focus of introducing the chromosomes, and constantly linked it back to how they are involved in the expression of traits. The structure of the chromosome was shown to the students (uncoiling of the chromosome to expose the DNA strand and histones) and discussed in detail. Amy then proceeded to help students link the chromosomal level to the DNA level, by asking students to think about how many DNA molecules form one chromosome. Students were then shown another diagram, which illustrated that one DNA molecule is coiled to form one chromosome. The same diagram was also used to establish the structural relationships between DNA, chromatin and chromosomes. This part of the lesson concluded with an introduction to “karyotype” (whole set of chromosomes arranged in pairs and sorted according to type and size) and related concepts (e.g., autosomes and sex chromosomes; homologous chromosomes).

Varying the level in which genetic materials can be understood, Amy then proceeded to help students shift their attention to the DNA level. Students were to share with the class what they already know about DNA. Students’ answers revolved around the structural aspects of DNA, such as DNA containing nucleotide bases, and that it has a double helix structure. Using PowerPoint slides, Amy taught the structure of DNA in detail. The presentation was also used to bridge the DNA level to the nucleotide level, encouraging students to simultaneously keep within their focal awareness the structure of DNA and the nucleotides. With the use of the whiteboard, Amy introduced the concept of complementary base pairing.

Shifting the levels again, the gene and nucleotide levels were focused upon. The structure of a gene, including nucleotides, was discussed in detail. Students were then shown a diagram illustrating different coding regions on a segment of a DNA, and how the different regions coded for different corresponding proteins. The idea that genes can be turned “on” or “off” was introduced.

Amy proceeded to summarize the lesson, prior to setting the students the task to be completed before the next lesson. The class was separated into 5 groups, and the students were given the task of identifying the traits of “The Incredibles” that made them “superheroes”. On a large piece of paper, students were to use their imagination to map out the karyotype of the character assigned to them; identify specific genes on the DNA; and to name the proteins that were involved in giving the “superhero” his/her special powers. The aim of this activity was to help students establish the links between the different genetic entities, and to link the structural aspects to the functional aspects - by focusing on the concept that genes will produce specific proteins that will result in the expression of traits, and in this case, the special powers conferred to the “superheroes”. The remaining time was allocated to students to complete this task.

Research Lesson 2: Functional aspects of genes: transcription, translation and mutation (3 periods, 90minutes)

The second lesson was implemented a week after the first one. The functional aspects of genes, focusing on the processes of transcription, translation and mutation, constituted the focal point of the lesson. Different types of gene mutations were also introduced. Within the lesson, Amy also employed patterns of variation and invariance in the way she screened a video three times, and varied the representations in which the processes of transcription and translation could be understood (use of whiteboard, video, on PowerPoint slides). What were also evident were Amy’s deliberate attempts to utilize students’ prior knowledge.

Serving to stimulate recall of the previous lesson, students were asked to share what they learnt in the last lesson. Questions were posed to guide students through describing genetic key terms (e.g., chromosomes, chromatin, histones, DNA, genes, nucleotides). In highlighting the production of proteins and its relationship to the expression of traits, links between the structural and functional aspects of genes were also established. Students were then told that they would be focusing on the processes that

occur prior to the production of proteins. Focusing on the question – “How are proteins made?” Amy drew on the whiteboard a sequence of nucleotides. Drawing on students’ prior knowledge of complementary base pairing, students were guided to “transcribe” the sequence written on the board, and subsequently to translate the transcribed sequence into the corresponding amino acids. Amy proceeded to show a set of keywords that students were instructed to copy on a blank piece of paper. Amy then screened a video regarding the process of transcription and translation, without the sound. In pairs, students were to jot down what they have observed in the video. As the video was played, Amy provided prompts in terms of questions to help students focus on various parts of the video. (Subsequent post-lesson conference and teacher interviews revealed that Amy’s intention was for students to make sense of the video via observation, without having to worry about the appropriate terminology. During the post-lesson conference, the team also commented that this step was effective in encouraging students to connect with their prior knowledge.)

During the second viewing, students were to layer their observations and notes with the set of keywords formerly copied onto their pieces of paper. Again, the video was played without any sound. Subsequently, the class discussed about the video, and the steps observed in the video were mapped out onto the whiteboard. It was observed that students started to modify their notes to include information that was missing. In this part of the lesson, students’ attention was thus directed from what they previously knew to new terms and details of the processes. During the last viewing, the video was played with sound. The links that students have formed between their prior knowledge and the new concepts could thus be reinforced. Any problematic conceptions that students had could also be further clarified. (As interpreted by the team during the post-lesson conference, the second and third round of viewing granted students opportunities to fill gaps in their understandings and to make linkages. It was also valued that the video has allowed students to posit a simultaneous focal awareness on (1) the general principles of transcription and translation that they have encountered in lower grade levels, which focused more on traits, and (2) the new details of transcription and translation (as stipulated in the new

genetics curriculum) that would require students to posit a focus on gene and nucleotide levels.) As a summary of the processes, Amy varied the representations in which the genetic processes of transcription and translation could be understood through the use of a diagram.

After a short break, the lesson shifted to focus on another guiding question – “What if an error occurs?” Thus, the process of mutation constituted the focal point of this part of the lesson. Students were introduced to the concept of gene mutation as well as chromosomal mutation through the use of PowerPoint slides. With regards to gene mutation, the variation within the process of mutation - nucleotide substitution, nucleotide inversion, nucleotide deletion and nucleotide addition were focused on. Amy then proceeded to highlight a case study that was included in their prescribed curriculum – sickle cell anemia. The changes in the nucleotide sequence, affecting the mRNA formed in the transcription process, subsequently changing the amino acid sequence formed in translation and thus the protein formed, were systematically presented. (During the post-lesson conference, Pam highlighted this systematic variation as being effective for students’ learning.) Extending the case study to another topic found in another chapter, Amy proceeded to briefly explain about the inheritance of traits. Amy also related it to the notion of genes being turned on and off. With respects to this part of the lesson, what is noteworthy is that there was no explicit attempt to help students systematically move through the levels in which gene mutation can be understood. In other words, students did not adequately experience a pattern of variation (apart from the brief PowerPoint presentation). Consequently, believing that this resulted in persistent gaps of understanding (as was discussed during the post-lesson conference and as reflected in students’ post-lesson test and interviews), Amy revisited this part of the lesson later on (excerpt A22). Varying the ways in which mutation can occur, Amy proceeded to briefly introduce Down Syndrome as an example of chromosomal mutation. Showing a karyotype of a person with Down Syndrome, the extra chromosome found within the 21st pair was clearly pointed out. Amy did not, however, link the extra chromosome to the transcription and translation process. To conclude the lesson, mutagens were then introduced.

As illustrated in the description of lessons above, the employment of theory of variation as a source of structure on lesson enactment served to increase coherence between the different genetic topics (e.g., the inclusion of mutation to increase coherence between genetic topics - excerpt A9) as well as the coherence within the lesson itself. An example of the latter is the enactment of a more deliberate and systematic variation of the structural aspects of genetic materials, allowing Amy to enact teaching this part of the lesson different from before. Formerly, she would quickly browse over this aspect using one PowerPoint slide to explain the differences (excerpt A15 & A16). Amy's decision to focus and emphasize this aspect in her lesson was partly due to the research literature introduced during the learning study to highlight students' learning difficulty in relation to the different levels of organizations (Bahar, Johnstone & Hansell, 1999; Duncar & Reiser, 2007; Mbajorgu et al., 2007; Marbach-Ad & Stavy, 2000), and in part due to students' pre-lesson test results. What is worth noting is that in Amy's reflective entry, she highlighted "changes in delivery of lessons" as a key difference in the way she experienced the teaching process in the learning study. She also explicitly mentioned that a way in which participation in the learning study has affected the learning about her own pedagogy was that she has gained a clear understanding of a theoretical framework (theory of variation) that can be used. In addition, she has learnt to be more explicit in teaching aspects that are important – both in focusing on the critical aspects to be varied as well as the enactment of more deliberate and systematic variations (excerpt A15 & A16). In the interview, Amy has also expressed her willingness to employ theory of variation in future lessons.

(A15) Interviewer: So how helpful was it to apply a theory to the planning and the implementation of the lessons?

Amy: How useful was it... Um, I think for this theory it was like... for me it was helpful because *it gave me structure to tell me that, "Hey, this is something I should deliberately do"*. Yeah, so in that sense, that helped me. Yeah, *I knew that I had to change; something I had to be very explicit about it*. Yeah. [emphasis mine]

(A16) Amy: ...I made a conscious effort to move it from something macro down to the smaller part. So like I (I) discussed the structure of the DNA only towards the later part, and then I brought in the gene at the very end...I feel that that helped the students to understand that in terms of structural differences –which is larger, which is smaller, something like that. Yeah.

Interviewer: So how different was it the last time you taught it?

Amy: I think the last time we did a really quick one. It was just like one slide to explain the differences between your... the DNA, chromosomes and chromatin – with just one diagram. To show what happens when you unwind it.

Another aspect that came to the fore of Amy's experience of her own learning as a form of professional development was related to the opportunities for Amy to inquire into her own, and her colleagues', teaching practices. Apart from learning from a more experienced colleague (such as Chris – excerpt A13), Amy also benefitted from observing her peer's (such as Pam's) lessons (excerpt A17). The opportunities to observe colleagues' lessons allowed Amy to personally experience the different ways in which theory of variation-framed lessons could be enacted. Not only did it allow for clarification and strengthening of Amy's own understanding of biological content to be taught, it also allowed for the generation of insights on how to improve her own teaching practices (such as the picking up of Chris' questioning techniques and his use of concept maps to benefit student' learning).

(A17) Amy: ...I mean the (the) lesson observation was good, yeah - allowed me to see and learn from the others who had more experience [Chris]. I mean, even for Pam, even though her knowledge of the topic might be the same as me, right, the way she taught her lesson was also very *different*. *So that also showed me how I can possibly do it differently, yeah.* [emphasis mine]

Interviewer: So... are there any strategies that your colleagues have used, and that you have observed, that you might want to use the next time round you teach genetics?

Amy: I actually like Chris' way of questioning, and just using the whiteboard, yeah, to capture the teaching [and students' learning]... So that's something which I think is very helpful and useful, which I will want to do.

As demonstrated above, participation in the learning study has granted Amy an experience of how questions could be formulated and utilized in a classroom discourse differently – standing

in contrast with how she typically would craft questions through a heavy reliance on the textbook (excerpt A5). Her understanding of how questions could be used also deepened (excerpt A18), fuelling her desire to likewise develop effective questioning skills.

(A18) Interviewer: Okay. You've talked about the skills that you have learnt, or you have picked up. So could you reiterate some of the skills?

Amy: ... I think essentially the major thing that I've learnt was about effective questioning. Yeah, that was one of them.

Interviewer: So what do you think effective questioning is based on, or what constitutes effective questioning?

Amy: I think it's the type of questions that you ask - to be able to come up with questions that can cover a wide scope, and at the same time, there's a smooth continuation from one point to the next. Yeah. And to vary it in such a way that you are able to narrow... zero in on what you are looking on, rather than asking questions that give you very wide and very vague answers. Then those aren't very helpful.

The post-lesson conferences, whereby feedback and suggestions for improvements of enacted lessons were provided, also encouraged Amy to become more aware of her own teaching practices and how her pedagogy could be improved. For example, deeming it to benefit students' learning, Pam highlighted Amy's use of a pattern of variation to systematically demonstrate the cascading effects of variation in nucleotide sequences – presented through a diagram used in Amy's PowerPoint presentation. This allowed the deepening of her conviction to continue to employ various pedagogical strategies and resources to benefit students' learning.

(A19) Interviewer: Okay, let's look at the post-lesson meetings. You talked about it making you "aware of parts of the lessons that could be improved, and concrete ideas of ways to improve them" were suggested by your colleagues [mentioned in Amy's reflective entry]. Can you give some examples?

Amy: ...when I prepared my slides for, what you call that, for gene mutation; the sickle cell and all that, I actually just did it because I thought it made logical sense to look at the cell and all that. But when Pam actually pulled it out that it was helpful, then it made me more aware that "Hey! This is something I should do, yeah."

Similarly, during the post-lesson conference, the researcher explicitly highlighted to the team how theory of variation was enacted in Amy's research lesson – the viewing of a video on

transcription and translation three times. A strategy that was similarly employed in Marton and Tsui's (2004) book was highlighted to the teachers. The teachers were also provided with the relevant chapter in the book that described the strategy, underscoring the need for purposeful repetition as a tool to foster reflective learning (Linder & Marshall, 2003; Marton & Trigwell, 2000). Similar to Chris' experience, this deepened and enriched Amy's former "instinctive" attempts to apply variation in her teaching, and thus served to support her current teaching practices (excerpt A20). The feedback received helped shape her perception of the usefulness of theory of variation, as well as her willingness to apply the theory in future.

(A20) Amy: ...I feel encouraged to know that it [the screening of the video] worked for my students ...last year when I taught my Sec. 4s, I showed them a video as well. But I only showed them once. And in that sense, I can actually feel that my kids this year were able to understand the processes better, by using this method. So I will still redo it...

The use of student post-lesson test results and interviews to ascertain the impact of the research lessons on students' learning also served as a form of feedback that Amy could draw on – both to reflect on her own teaching practices as well as to evaluate student learning (described in her reflective entry, see also excerpt A21). In doing so, she drew support for the use of various pedagogical strategies that she was employing. In addition, the analysis allowed identification of areas and gaps in learning that warranted further attention and clarification. For example, having identified that some students still had difficulty relating the process of gene mutation to gene expression, Amy re-visited that part of the lesson (excerpt A22).

(A21) Interviewer: Okay. Shall we move on to the analysis of the post-lesson tests and interviews? You said that it gave you the opportunity to understand what worked for your students during the lessons. Could you share an example of something you thought "worked"?

Amy: ...the main thing that I pulled out was the video [that she screened three times] for most of them. So yeah, that was what I was thinking of here.

(A22) Interviewer: Okay. So how about the aspect that you taught was still unclear [comment from reflective entry], and then you went on to clarify it? So can you elaborate a little bit about what you did, and what were the aspects?

Amy: I think it was the mutation and pulling it back to transcription and translation when there was gene mutation. So I went back to class and I deliberately asked them then, “Once you get this mutation, what happens at that level?” – which as something that I didn’t cover. Yeah.

The demonstration of shifts in what Amy considered valuable to the benefit of student learning illustrates how her experiences in the learning study have promoted her professional learning. They were evident in how Amy subsequently viewed and approached the prescribed curriculum differently. Amy was asked to review the Genetics Questionnaire that was completed at the beginning of the study, and to comment on how her views have shifted, were challenged or were supported by her experiences in the learning study. One of the points highlighted was how she has learnt to be clearer in terms of her lesson focus, having “narrowed what was essential” (excerpt 23), as opposed to trying to cover everything. The clarity was appreciated to have enhanced student learning. As a result, the view of presenting a lot of facts as important also became less important.

(A23) Amy: I think *previously I would try to give them like a very comprehensive coverage of the entire topic* because I was just very afraid that there are certain things that I will... you know, that might be lacking. But I think that after this round where *we narrowed what was essential*, so we didn’t cover like the specifics of your transcription and translation and knowledge of all that. And in the end *the girls are able to understand the process better*. So...*I don’t think this idea of presenting a lot of facts is as important now...* [emphasis mine]

Another demonstrated shift in what Amy considered valuable to the benefit of student learning pertained to Amy’s former use of games - as a way to make her lessons enjoyable and interesting, even if it resulted in less learning (excerpt A2). The excerpt below is demonstrative of her emerging conception of how games could be used to engage students and still yield a

considerable amount of desirable learning. This prompted her to likewise learn to use games in a similar manner.

(A24) Interviewer: You also mentioned about being able to pick up certain good skills from your colleagues that you hope to master in time. So could you elaborate on some of these good skills?

Amy: ...I like his [Chris'] "Scrabble" game also ...usually for me, whenever I design or prepare games for my class, it was more of like, something more entertaining – higher entertainment value. I mean there's still learning. But if you were to put like a percentage it would be like 60-40 kind of thing. Chris' one was more... like there was a really great emphasis on what needs to be learnt...that was something that I believe I found very useful.

Amy's participation in the learning study has also resulted in her learning to be more open to her colleagues' comments and sharing about her lessons. She expressed how her experience of collaborative lesson observations and post-lesson conferences has actually allowed her to "gain quite a lot" (excerpt A25). This led to a realization that despite being a less experienced teacher, that "every person in the department can play a part" in influencing each other's pedagogy. Thus, Amy's ideas around the nature of collaboration and collegiality seemed to have shifted. Equally noteworthy was how the lesson observations organized within a learning study allowed teachers to escape the sense of critiquing the individual teacher (Stigler and Hiebert, 1999). Similar to lesson studies, the collaborative lesson planning resulted in a joint product whose ownership was shared by all members in the team, allowing for inquiry and critique of lessons to focus more pointedly and deeply on the merits and deficiencies of the lesson; on revisions and improvements (Stigler and Hiebert, 1999).

(A25) Amy: I think like... I think because I'm still like fairly new, so to me, like observation and all that sounds very daunting. And so when I first heard that, okay, you were going to come in and all that, it felt very scary for me. But now that I've gone through one round, it's not that bad. And I realized that I can actually gain quite a lot from an experience like this. So yeah, I feel like I've learnt to be a little bit more open. Sharing about my lessons... I'm just like a beginner... in terms of teaching wise, I don't think I have a lot to share, as compared to someone who is more experienced. Yeah. But

this experience has showed that *there is still some little bits that you can pick up from one another*, even though I'm not the most experienced person and all.

Interviewer: So do you see yourself as being a contributor, then, to the experiences of your colleagues and helping them to, you know, to learn more about their own pedagogy as well?

Amy: I think it's something that *every person in the department can play a part*, yeah... [emphasis mine]

4.3.3 Amy's learning about her own pedagogy

With respects to how participation in the learning study has influenced Amy's learning about her own pedagogy, the experiences that seemed to constantly come to the fore of Amy's awareness were, namely, the opportunities to:

(1) collaboratively determine the curricular flow and to plan the lesson. Coupled with the opportunity for Amy to observe her colleague's lessons, it allowed for an experience of increased clarity and coherence in her approach to curriculum interpretation. The clarity and coherence has also allowed her to focus clearly on what the team collectively deemed as important for student learning, as opposed to the conventional heavy reliance on prescribed materials. This has allowed her to feel more empowered to plan a "smoother flow" when she was preparing her lessons, and to enact her lessons in a more authentic way. Coupled with the patterns of variation and invariance that she has employed, which were ascertained by her colleagues and the post-lesson test results to be effective, Amy felt that she has learnt to be more explicit in planning and enacting the teaching aspects that she deemed important.

(2) elicit students' prior understandings through the administration of pre-lesson tests, which influenced how she deliberately addressed students' problematic conceptions and areas of confusion. Concurrently, using the theory of variation as a guide, she established common ground with the students. Thus, she deemed the opportunity to learn how to

systematically collect, analyze and apply student data as useful in informing and improving her own teaching practice.

(3) deliberately employ theory of variation to guide the enactment of her lessons, and to experience different ways in which theory of variation was employed in her colleagues' lessons. Amy found that the deliberate application of the theory provided structure for her lessons, guiding the organization of her PowerPoint slides. It has also helped her focus on the object of student learning and critical aspects through the patterns of variation enacted. These experiences deepened her conviction that theory of variation was useful in helping students focus on the critical aspects that she wanted them to, and she thus deemed the gaining of a clearer understanding of how to use the theory as a valued experience.

(4) inquire into her own teaching practices and that of her colleagues'. The former has allowed her to receive feedback from her colleagues (through post-lesson conferences) and students (through post-lesson test and interviews) as to what constituted good teaching practices. The areas in her teaching that could be improved were also brought to her attention. These affected how she viewed herself to have learnt to be more open to others' comments about her lessons at the end of the study. The opportunities for her to inquire into colleagues' teaching practices have also allowed for an increased awareness of how she could likewise apply various pedagogical strategies in her own class. Her experiences resulted in her feeling that she has picked up certain good skills from her colleagues as a way to improve her own pedagogy. They have also provided direction for her future professional development.

(5) encounter her own beliefs and teaching practices through reflection and participation in the learning study. Demonstrated shifts in what she would deem to benefit students'

learning occurred. Examples include her view that games should yield more learning; that what is more important for student learning is that students gain an understanding of the object of student learning and critical aspects, as opposed to the mere coverage of all content stipulated in the prescribed curriculum.

4.4 Pam's experience of the learning study

Pam was also regarded as one of the less experienced teacher in the team, having joined the school around the same time as Amy. It was her third year teaching Grade 9-10 biology, and this was the first time she was teaching the newly prescribed curriculum.

4.4.1 Pam's understandings of her own teaching and learning practices before participating in the learning study

Pam's primary goals in teaching biology included inculcating and sustaining students' interest in biology, as well as helping them see the relevance of biology in everyday life (excerpt P1). She believed that these would eventually help students to remember what was learnt. Thus, to engage students' interest, she would even teach what was beyond the prescribed curriculum. The desire to generate interest for her students, in order that they may be further motivated to learn on their own, also propelled Pam to "stay in touch with current knowledge" (excerpt P2). In doing so, Pam was also able to utilize relevant examples and case studies in her teaching.

(P1) Pam: ... I normally go beyond [what is stipulated in the syllabus] ...I try to bring them to (like) more relevant examples of (like), um, yeah, how they can relate to them. *And for me, I feel like the main thing in teaching is (that) you really need to generate their interest. So that's always (like) the primary concern...* I think the main thing that always comes to mind is how I can make it interesting... [emphasis mine]

(P2) Pam: I think you also need to want to look beyond the textbook sometimes - it's so easy to tailor your (your) lessons to specific syllabus... But I read (like) "Science Daily", and you know, little bits of information, and (like) case studies that I can just

give to the girls. So I think the constant need to want to stay in touch with the current knowledge is important... To generate the interest for them to read up on their own.

Believing that pedagogy is a tool to help deliver content in a way that would develop student interest, Pam often varied her pedagogy (excerpt P3 & P4), and would even elicit feedback from her students about her own teaching.

(P3) Interviewer: So how would you see the relationship between content, pedagogy, and your objective to teaching biology?

Pam: I think my (I think my)... The content, definitely, as our job as biology teachers, is what we have to deliver. I think the overriding idea is how I can deliver the content in a manner that interests them, so that's where the pedagogy comes in. Yeah.

(P4) Interviewer: So why do you want to vary your pedagogy?

Pam: Because I think that... I mean like I've said, sustaining interest is very important... I do (I do) my fair share of "teacher-talk". I think most of us have to do some teacher talk. But you know, I don't like them to "zone-out". So I try and (I try and) assess... in fact, I (I like) really try my best through every half-year, get them to write down what they feel were good about the (the) lessons, what you think that you can improve.

Pam's goal of generating students' interest and to increase their perception of the relevance of biology can be appreciated as ways in which she tried to establish connection with her students. Deeming it important to "relate to your target audience" (excerpt P5), the choice of games and media, such as videos and movies, were thoughtfully included in her repertoire of pedagogical strategies. Pam also attended to different student learning styles – "visual-kinesthetic" or "audio" (excerpt P6).

(P5) Pam: I mean, we watched movies – current blockbusters of interest, and we see how a lot of the science can be found through it... I find (like) you need to relate to your target audience. Use a media that kind of appeals to them...

(P6) Interviewer: ...why is it important to be able to connect with your target audience?

Pam: Because only then would you be truly able to teach... a lot of them are "visual-kinesthetic" people, which is why I came up with the idea that they write while they teach; um (I mean) they write while they look... Some of them are "audio" [auditory

learners], so I allow them not to be copying notes, and I won't take it as they are not listening... So, I try to work to the way that they learn, in that sense, yeah.

Pam was also committed to forming connections with her students, by deliberately forming links with their interests and prior knowledge. For Pam, student prior knowledge was often regarded as what has been taught previously. Consequently, the establishment of links and seeing similar patterns within different topics was an important aspect for her teaching, since this was analogous to helping students form connections between what was learnt and their own prior knowledge. For example, Pam would deliberately link the chapter of digestion to that of excretion (excerpt P7). In the same way, Pam would employ questions to draw out students' prior knowledge and in doing so, that students could connect their learning with prior knowledge for themselves (excerpt P8). Pam was also disposed to encouraging students to ask questions, believing that it was a form of dialogue that allowed students to pursue topics that interest them (excerpt P9).

(P7) Pam: ... So once I get their interest and things like that, I'll always bring it back to (like) prior knowledge. Like for instance... I teach (like) excretion I'll talk about how one of the excretory waste product is bile pigments. So I'll relate it to (like) how the bile is linked to... like one of the excretory organs, which is the liver, and how it's related to digestion. So I'll bring it back to digestion. And I'll teach them about (like) "Remember how the liver produces bile?" And that's um.... "so we have this thing - the breaking down of the red blood cells that produce(s) the bile pigments; and that helps the formation of bile" and things like that. *So I'll always bring it back to prior knowledge.* Yeah. [emphasis mine]

(P8) Pam: As in, do I draw out the knowledge from them instead of telling them about it? Yeah, I do that sometimes. (So) I mean, it's by questioning, like simple questions in the introduction...

Interviewer: So the "drawing of the answers", the sole intent is to...?

Pam: Drawing of the answers for their prior knowledge...? It's just to make them make the link.

(P9) Pam: ... You need to allow them to question a lot, I find... So it's to allow them constant questioning; to not be afraid of questioning, because there is a lot of things

about themselves and their environment that they are very intrigued about... I let them question a lot. It's a constant dialogue...

Interviewer: So why do you think it's important to let them ask questions and to maintain that dialogue?

Pam: Because I don't want them to be passive learners where they (really) just sit there and listen to me.

What is illustrated in this section were, in fact, Pam's beliefs around the importance of students taking ownership of their own learning, and thus her goals of inculcating students' interests and the establishment of relevance of learning biology. These goals shaped Pam's attempts to steer her pedagogy away from teacher-centered approaches and towards more student-centered ones, and her establishment of connections with her students. In the process, students were encouraged to move away from being passive learners, whereby they "just sit there and listen" (excerpt P9), to becoming active learners whereby they can "draw parallels"; "see the relevance"; apply their understandings; and "ask questions" (excerpt P10). And in this way, students can engage in "active learning".

(P10) Interviewer: So how would you define active learning?

Pam: I think it's about taking ownership of your own learning... It's about from that information that you get, how you can draw parallels; how you can see the relevance in it... if I get all the information being planted into my head, but I don't know how to (to) use it, then it becomes really passive, like I'm forced to remember this. But if I have information that is given to me, and I ask questions, which allow me to further draw parallels on my own, then that's active learning.

4.4.2 How participation in the learning study influenced Pam's pedagogy and experiences of learning as a form of professional development

As similar to Chris and Amy, Pam deemed the opportunity for collaboration as instrumental to her own professional learning. When asked to share about her experiences, Pam mentioned about how the collaborative determination of the curricular flow helped her to

approach the curriculum with greater clarity and coherence. Especially since this was the first time she was teaching this new topic of genetics, and since the prescribed curriculum was deemed to be vague, she found it particularly useful to “sing a common tune” (excerpt 11) and to “find out where the focus would be” (excerpt 12). The experiences in the learning study thus differed from her past ones, whereby curriculum interpretation was previously relegated to her own interpretation and heavy reliance on prescribed curricular materials, with less clarity on the scope and depth to be covered. In the same vein, Pam mentioned about how she would have conventionally posited a different focus, missing out certain emphasis (such as the establishment of structural and functional aspects, thus including the topic of mutation), while covering other parts (such as the genetic processes) in more detail than was necessary.

(P11) Pam: It’s [collaborative determination of curricular flow] definitely helpful because I haven’t done it before... *it’s always good to sing like a common tune*, I guess, in a way. Yeah. It definitely is helpful, if not when I look at this topic, it’s I mean my own interpretation.

(P12) Pam: ... I think for us it’s what we interpreted from, let’s say, the general syllabus that was given to us. *How much emphasis was put into the different topics was actually... we didn’t know...* So I guess, in a way, through this [determination of curricular flow], you can actually *find out where the focus would be*. I mean, if I were teaching this without knowing what I should focus on and things like that, it will be mainly about the processes – like for me, the transcription, the translation. Perhaps not so much attention will be put onto the mutation, and you know, the certain parts, which was actually deliberately pointed out that we should do this. [emphasis mine]

Pam also highlighted (in her reflective entry) how the determination of the curricular flow resulted in her being “better able to draw students attention to various parts” and “guide them to draw links for themselves so they understand better”. This was consistent with her belief that it was important for students to draw links between different topic areas. Thus, Pam particularly valued the opportunities within the learning study for discussion of these links.

The observation of her colleagues' lessons, and participation in the post-lesson conferences thereafter, also granted Pam greater clarity for the emphasis of her lessons. For example, having realized that some students struggled to draw links between biophysical genetic entities (in Amy's lessons), and between mutation and the transcription and translation processes, Pam deliberately stressed on these links in her own research lessons (excerpt P13).

(P13) Interviewer: So you've talked about how the post-lesson meetings were important for you to review your lessons, in order to be able to teach better. So could you give me an example of one of the reviews that actually impacted the way that you taught?

Pam: Okay, I mean... just let's say about... for Amy's one, I mean when she was doing the game, the "Incredibles" game thing, and then you know like she reviewed it... we realized that they were seeing it as discrete things, not drawing links together and things like that... Maybe about when they did mutation they didn't link it to transcription and translation - I think that was what you told me to focus on... So in a way, that helped me to sort of really do my own flow chart for the girls - how your DNA eventually leads to your particular phenotype, and how it's actually what we call gene expression...

What is also worth noting was that Pam, like Amy, valued the opportunities to observe both an experienced teacher's lesson (Chris') as well as that of her peer's (Amy's). As compared to how the convention was for more experienced teachers to observe less experienced teachers in order to evaluate their teaching, the learning study has thus afforded a different kind of lesson observation experience, whereby (1) teacher assessment was not the focal point, and (2) opportunities to sit into colleagues' lessons were afforded irrespective of seniority.

(P14) Pam: ...I mean we all know how much we can benefit by sitting into somebody as experienced as Kate, or say like Chris... you sit into their lessons, you learn new things. We never had the opportunity to do it [previously], because it's usually like the more senior teachers observing you, not like you going in to observe anybody's lesson. So in a way, I guess this time, it was kind of turned around, so you get to actually see people like me and Amy...

The collaborative inquiry and evaluation of colleagues' and Pam's own research lessons have in fact allowed for Pam to reflect on her own pedagogy. It also allowed for the "widening

of the perspectives”- both in the ways in which the prescribed curriculum was interpreted and how it was taught (excerpt P15). In other words, the experience of variation in curriculum interpretation and enactment widened the space of learning, and allowed for the expansion of the individual teacher’s own repertoire of pedagogical strategies. It has also allowed Pam to deliver lessons that were more consistent with her beliefs of what good biology teaching was (excerpt P16).

(P15) Pam: The collaboration part. I mean what was good about this study was the collaboration; widening of the perspectives in terms of the ways in which this topic is taught; or the way that the syllabus is interpreted by different teachers. That, I mean, is much like professional sharing. Yeah.

(P16) Interviewer: So what aspects of this learning study and your participation has helped you to actually deliver what you think good biology teaching is?

Pam: ... the main thing that helped me, I feel, was the perspectives of the different teachers, which can bring a lot more dimensions to the teaching. For instance, the analogy one – Chris brought up about the book... I always knew that like you can use analogies, and I use it a lot, but verbally. But I think it’s quite good to look at scales and the structure. So from the perspectives of the teachers you can come up with activities...

According to Pam, the different perspectives of the teachers brought varied dimensions to the teaching experience, thus creating opportunities to learn “many new ways to vary teaching style” (mentioned in her reflective entry). In elaborating on this point, she described the opportunity she has had to observe how Chris enacted the “Scrabble” game. In contrast to how Chris only revealed the student learning outcomes at the end of the activity, she would typically have explained the rationale and learning points prior to the activity. The perceived effectiveness of Chris’ strategy, as revealed through students’ post-lesson test and interviews, persuaded Pam to try Chris’ pedagogical strategy. Similarly, Pam also highlighted how she deemed Chris’ use of analogies to be effective for student learning. In her own research lesson, Pam modified the “analogy” activity to help students represent the relationships between structural aspects of genetic materials – to look at “scales and the structure” (excerpt P21).

Another key experience highlighted by Pam was how her pedagogy was influenced by Chris' use of questions (excerpt P17). Pam arrived at a realization that some of her students, like that of Chris, may be auditory learners that would benefit from Chris' teaching style. Moving away from how she usually taught by drawing from her own learning experiences as a student, her new insights resulted in her resolution to vary and expand her own pedagogical skills in order to further benefit the auditory learners in her class.

(P17) Pam: ...what I'm teaching them is purely what I learnt... what I'm imposing, sort of, on my student is kind of my learning style when I approached this chapter... formerly, I wouldn't use this kind of questioning so much, because I'm not audio [that is, not an auditory learner]. And you know, but I realize that some of my girls might also be audio. So as much as I keep using all my flow charts and things like that... they might want to hear things. ...it kind of amazed me to see how Chris' girls can actually listen ...in ways that even I cannot, because I'm not audio. But the fact that there are some girls [in Chris' class] at that level who can do that, will probably mean that there are some of my girls who can do that. So, yeah, I guess to vary [my pedagogy] sometimes...

Throughout the learning study, Pam was also constantly focused on identifying and addressing students' misconceptions (a term Pam used to describe students' conceptions that may be inconsistent with the canonical science). She appreciated the ample opportunities within the learning study to focus on students' learning. For example, the collective determination of the object of learning allowed for students' gaps in understandings to come to the fore of teachers' attention, even as teaching experiences to address them were pooled and examined. At different points in the learning study, the team also drew from research literature that focused on students' prior experiences and knowledge of genetics.

The administration and analysis of students' pre-lesson test and interviews were also experienced differently - as an important and more systematic way to inquire into students' understandings and experiences, and thus allowed for clearer understandings of students'

misconceptions to emerge (excerpt P18). According to Pam, the clarity was further brought about through observation of colleagues' lessons. In comparison, identification of students' misconceptions used to rely on teacher's "head knowledge" (excerpt P19), or the use of "simple questions" (excerpt P8) in class.

(P18) Pam: I mean last time we use to do this [uncovering of students' prior experiences and understandings] subconsciously. You wouldn't, let's say, have a pre-test, post-test, and find out a certain percentage of people who say has a certain misconception... it's probably verbal... So in a way, I guess through this study... you have a clearer understanding of what are some of their misconceptions. Yeah, it's a more (like) structured kind of question and answer...

(P19) Interviewer: ... How did your own experience in this learning study impact the way that you learn about your own pedagogy?

Pam: I think for one, I guess in a way, it's a *making it more deliberate and structured* in the way that I'm teaching. Previously... it's a lot of head knowledge – *you are not so deliberate about it*. But your intention is always the same – to learn about somebody's misconceptions, address them, allow them to address them on their own... But I guess in a way through this study, you (you) learn about the effectiveness – for me, *it's like doing this but in a more deliberate sense*. Yeah. [emphasis mine]

As illustrated above (excerpt P19), opportunities to gain greater insights into students' prior knowledge has propelled Pam to more deliberately address students' misconceptions, thus influencing her pedagogy. The confirmation of her prior views on students' learning difficulties in genetics, such as the difficulty to move between the different levels in which the structural aspects of genetics can be understood, contributed to how the team collectively decided that it was pertinent to systematically vary the different levels to benefit students' learning- "break it down to molecular level; the chromosomal level, kind of thing". (excerpt P20). Similarly, the anticipation ("pre-empting") and drawing from students' misconceptions (excerpt P21) allowed Pam to formulate and better scaffold her questions. The former allowed an expansion of her repertoire of questions (excerpt P22), and the latter, to further hone her questioning skills. What

is noteworthy was that some of the questions from the student pre-lesson test were also adapted for use in her other classes.

(P20) Pam: I mean the.. the.. confusion of genetics in terms of the different scales was definitely quite true. If we didn't like exactly break it down to the molecular level; the chromosomal level, kind of thing, they won't be able to see it that clearly... and from previous years, the misconception was that they keep jumping the scales. And I think when we did the pre-test, we had the "rearrange..." - the order one, which kind of showed that even though they learnt it in Sec. 1 and 2, they are still very confused...

(P21) Pam: ...from the studies from these particular girls [pre-lesson test and interviews], you can actually see where it's actually leading to. So it's kind of like preempting you to their misconceptions and things like that. Yeah...

(P22) Pam: ...looking at the different surveys that you have... like you have created, in a way is like more structured questioning, which helped me in my questioning during class... it was more like, perhaps, using the misconceptions that were learnt from the study [pre-lesson test], how I would then scaffold my own questioning...

Pam's experience of systematically uncovering students' prior knowledge has also resulted in more deliberate attempts to highlight students' problematic conceptions. She also deliberately created opportunities for students to encounter and change their own conceptions, and subsequently to "reflect on what they used to think, what they now know, and how that has changed" (excerpt P23). In this way, her pedagogical practices shared similar goals with the conceptual change model (Posner et al., 1982). They were also consistent with Pam's beliefs about the importance of establishing links with students' prior knowledge, and were compatible with her previous attempts to employ more student-centered approaches and to encourage active learning.

What is illustrated was how the constant focus on students' learning throughout the learning study has resulted in authentic lesson planning. This served to deepen Pam's experience of enacting more student-centered lessons (as were desired), and hence reflects a move towards

a greater sense of ownership and teacher empowerment. Pam's experiences have thus resulted in a reinforcing and refining what she deemed good biology teaching to be - that it is a two-way process whereby students' conceptions are drawn to scaffold and benefit students' learning (excerpt P24).

(P23) Pam: I think it's powerful when you actually repeat their [students'] misconceptions to them, and... from there help them to see how it was wrong...they may have a lot of misconceptions and you may teach them the right thing, but if you don't point out what were their misconceptions, they may not even know that that was it. So I guess in a way, *it's to help them also like reflect on what they used to think, what they now know, and how that has changed.* [emphasis mine]

(P24) Interviewer: How did your experience in the learning study further refined what you think good biology teaching is?

Pam: I think it has to be a two-way process and the learning study is... in a way, it's like drawing on student's misconceptions, using it to help them scaffold their learning... That means like it's not one way, like what I think you should learn, but it's like you... you ask them exactly what their thoughts are about it, quite purposefully. And then you schedule it around it, so that they see it better. Yeah

The employment of theory of variation as a theoretical framework has also enriched Pam's experience of enacting students' learning experiences in her research lessons. Descriptions of Pam's lessons are provided below to illustrate how theory of variation influenced Pam's pedagogy. They also demonstrate how Pam has more deliberately addressed students' problematic conceptions and gaps in understandings.

Research Lesson 1: Introduction to genetic biophysical entities (3 periods, 90minutes)

Pam implemented the research lesson in a higher ability class within the school, comprising 29 girls. In this lesson, Pam constantly tried to draw from students' prior knowledge through the use of guiding questions. These questions were modified from the student pre-lesson test administered. In engaging students in class discussions, Pam created opportunities for students to encounter and reflect on their own conceptions, and have them changed if they were inconsistent with the canonical science of

genetics. Within this lesson, Pam systematically varied the levels in which genetic materials could be understood, while keeping the notion of genetic materials invariant. Another pattern of variation employed was the shift between the structural and functional aspects of the genetic entities. This served as a precursor to her subsequent lessons that focused on the functional aspects of genes. To conclude the lesson, Pam used an “analogy” activity to allow for structural relationships of genetic materials to come to the fore of students’ focal awareness.

Pam started the lesson by showing students the learning points from the prescribed curriculum, and highlighted the areas that they were introduced to in lower grade levels. Focusing on the structural aspects of genetic materials, students were given some time to discuss with their partners what they knew about chromosomes. The following questions were used as a guide: 1. What is chromosome made of? 2. Why do we need chromosomes? 3. What organisms have chromosomes? 4. How many chromosomes does a human cell have? 5. Are there different types of chromosomes? Engaging students in a class discussion, students volunteered their answers. Students’ answers were subsequently jotted on the whiteboard, and were layered with more details. This part of the lesson served to draw out students’ prior knowledge and to link them to new information related to the structural aspects of genetic materials. Students were then shown a PowerPoint slide of the karyotype of humans, and the concept of karyotypes was discussed. Pam also proceeded to clarify the “x”-shape that was often observed in diagrams, in order to address the confusion between duplicated and non-duplicated chromosomes – as was elucidated in the student pre-lesson test.

Shifting the focus to the DNA level, students were then asked to discuss with their partners the following questions: 1. What is it (DNA) made of? 2. What is its purpose? 3. Why does it coil in a specific manner? The answers were likewise jotted on the whiteboard and discussed. Students related the function of DNA to traits (as was commonly reported in literature and revealed in the pre-lesson test). Students also mentioned about genes. Pam helped students to link the two answers by briefly bringing in

the processes of transcription and translation into the class discussion. The coiling of DNA around histones was then focused on. Subsequently, the students were shown a video that focused on the structure of DNA - animating the coiling of DNA to form chromosomes. Pam would make comments as the video was screened, as a way to reiterate what was discussed in class. The video also illustrated how DNA contains information in the form of bases. Pam proceeded to use a PowerPoint slide presentation to help students to include the nucleotide level into their focal awareness, by looking at how the nucleotides were arranged within the double helix DNA – with the emphasis also on the genetic information that existed in the sequence of nucleotides on each strand of DNA. This thus linked the structural aspects of genetic materials to the functional aspects. The idea of complementary base pairing was also introduced. Focusing next on the coiling of DNA, how DNA coils to form chromosomes was discussed in detail. As a way to reiterate the key points to this part of the lesson, Pam proceeded to screen the same video on the structure of DNA again. Pam concluded this part of the lesson by introducing to students the human genome project.

Shifting students' attention to the gene level, students were to, once again, engage their partners in a discussion around the following questions: 1. Where is a gene found? 2. What is a gene made of? 3. How many genes do humans have? 4. What is the purpose of a gene? Subsequent to a class discussion, Pam introduced the concepts of coding and non-coding sequences, and that different genes code for different proteins. Thus, students were again given opportunities to link the structural and functional aspects of genes. Pam proceeded to ask students a series of questions that revealed gaps in students' understandings – gaps that were surfaced in the pre-lesson test and discussed during the collaborative meetings. For example, "Do all cells in a person have the same DNA? Do all cells have the same genes? Why do cells differ in function?" Engaging students in a class discussion, students were guided to uncover their own "misconceptions". In this way, Pam was able to directly address students' problematic conceptions that were revealed in the pre-lesson tests. To conclude the lesson, students were then shown a video that summarized what genes, DNA and chromosomes are - focusing on both the structural and

functional aspects of these biophysical entities, and the relationships between them. Students were also assigned homework. In groups of four, students were to come up with analogies that would represent the terms bases/nucleotides, genes, DNA, chromosomes, nucleus, cells, organism. Each group was tasked to come up with one analogy based on the notion of books, pages, sentences, etc., and another one of their own.

Research Lesson 2: Functional aspects of genes: transcription and translation (2 periods, 60minutes)

The second lesson was implemented a week after the first one. In this lesson, Pam focused on the functional aspects of genes - on the processes of transcription and translation. In the lesson, videos were used alongside PowerPoint presentations - as consistent with her belief that the use of videos aids to better connect with students. Together with the use of the whiteboard, Pam also varied the modes of representation to illustrate the key steps in transcription and translation. Not only did the different modes of representation serve as a way to vary students' approaches to the genetic processes, but it has also served to scaffold the details of the processes, progressively requiring students to hold more details in their focal awareness. As consistent with the last lesson, Pam was also focused on identifying and addressing students' conceptions. She actively drew from students' prior knowledge, through her questioning and engagement of students in class discussion. Students' prior knowledge was used to quickly establish common ground, and to scaffold the new genetic content that students needed to learn.

Pam started off the lesson with students presenting their analogies to represent the terms bases/nucleotides, genes, DNA, chromosomes, nucleus, cells, organism (homework from previous lesson). For each presentation, feedback was provided. Pam also highlighted to her students the patterns that have emerged from their analogies, based on the notion that repeating units can similarly be observed in the structure of genetic materials. She then proceeded to show some other examples to illustrate potential student "misconceptions". Using the book analogy to reiterate the structural

relationships between the genetic biophysical entities, Pam also extended the use of the analogy to illustrate the functional relationships - as was suggested in the post-lesson conference preceding this research lesson. This allowed for students' focal awareness to simultaneously include the structural and functional relationships of genetic materials.

In the next part of the lesson, the roles of genes in the determination of traits were explored. Using the whiteboard, Pam engaged students in a discussion – a co-construction of a flowchart to briefly show the sequence of events in gene expression and determination of traits. Students were told that the lesson would focus in detail on the processes that result in protein synthesis. Using the flowchart, details of the processes of transcription and translation were then included, even as Pam drew out students' prior knowledge of these processes through the use of questions. Using a PowerPoint presentation, the key steps were reiterated. The slides were also layered with details that were new to the students.

In order to deepen students' understanding of transcription and translation, their attention was then shifted to the nucleotide level. The notion of codons; how codons code for specific amino acids; mRNA formation; and the formation of polypeptides and proteins were introduced. Serving to consolidate the key learning points, a video was then shown. But because the speakers were not working, the audio part of the clip was omitted. This resulted in Pam verbally explaining what was seen in the video while it was being played. Subsequently, students were given the key terms that related to various parts of the genetic molecular processes. Based on their prior knowledge and what they have seen, they were asked to provide more details of the processes. Pam also furnished students' answers with even more details of the processes. Using a flowchart, the transcription and translation processes were also represented. The students were also subsequently shown a second video that similarly illustrated the transcription and translation processes. As such, the animations in which the molecular processes were illustrated were varied. Terms that students have just been introduced to in greater detail were also deliberately mentioned as the video was viewed, that is, explanations with more genetic-specific

terminologies were used. Because students also asked questions during the viewing of the video clip, opportunities for clarification of students' conceptions arose. Subsequent to the video shown and as a way to conclude the lesson, Pam proceeded to diagrammatically represent and explain the different steps presented in the video on the whiteboard.

Research Lesson 3: Relating the structural and functional aspects of genes: transcription, translation and mutation (3 periods, 90minutes)

The third lesson was implemented a week after the second one. In this lesson, Pam continued to make use of different modes of presentation to help students learn the processes of transcription and translation – as was reviewed in the post-lesson conference as being beneficial for students' learning. In this lesson, Pam also employed a pattern of variation that required the systematic variation of nucleotide sequences, thus relating transcription and translation to the genetic phenomenon of mutation. Pam also varied the types of mutations. In addition, and as observed in previous lessons, Pam also deliberately addressed students' problematic conceptions.

At the start of the lesson, students were given a list of key terms relating to the processes of transcription and translation. A simple flowchart was then constructed on the whiteboard to stimulate recall of the steps in the processes. Students were also shown the same video that was viewed in the last lesson. In reiterating the steps, Pam drew another diagram (with more details) to represent the processes of transcription and translation. During the construction of the diagram, students were asked questions to elicit their prior knowledge. Inferences were occasionally drawn to the video as well.

In the next part of the lesson, students “played” an online game. Students were required to 1. unzip the DNA, 2. make a copy of the gene through the production of mRNA, 3. match the sequence of the mRNA with the correct tRNA, and in the process, 4. to determine the amino acid sequence that formed the polypeptide. The game thus provided variation as to how the process of transcription and

translation could be experienced by the students. Drawing on the same steps and principles of the game, students were provided with more examples that they needed to, likewise, determine the corresponding mRNA and amino acid sequences.

Using the notion of traits, students' focus was then shifted to the formation of proteins. Through the use of a flowchart, the process of protein synthesis and the determination of traits were explored. As a precursor to the enactment of the pattern of variation and invariance determined collectively by the group, that is, to vary the nucleotide sequence or gene structure, Pam deliberately mentioned that a change in gene structure would change the mRNA produced, and hence the proteins formed. Consequently, the traits will be affected. A PowerPoint slide presentation that reiterated the same learning points was then shown.

Shifting students' attention to changes in nucleotide sequence, students were given time to discuss in pairs what they thought would happen when there is an error in the genetic code. Subsequently, using an online game - "name" activity, the parallels between proteins formed and that of names were made. Each letter of a name would represent a specific amino acid making up a gene sequence. When a student's name was typed in, the computer program would then provide the corresponding nucleotide sequence. Using the game, various types of mutations can be selected, for example, nucleotide deletion. The program would then show the effects of the mutation. The changes in the nucleotide sequence as well as amino acids, affecting the changes to the name, were illustrated. Pam then used the resultant changes to explain what happens when nucleotide deletion occurs. Using other examples, such as nucleotide insertion and nucleotide substitution, the process of mutation was again illustrated. The pattern of variation employed here also extended to the illustration of "silent mutation" – that changes in the sequence in nucleotide need not always necessarily result in changes in the proteins. Students were thus given opportunities to experience variation in nucleotide sequences, as well as the different types of mutations. The different gene mutations illustrated in the game were also highlighted

and explained through the use of a PowerPoint presentation. Using the mutation examples, students were instructed to write out the sequences of the corresponding mRNA and polypeptide chain produced in transcription and translation respectively. This was the homework that students were required to complete. Using another diagram, Pam reiterated the key changes that occurred subsequent to changes in nucleotide sequences. Pam also stressed to the students that the common “misconception” was that students often focused on traits (effect of mutation) rather than the process of mutation itself (changes in gene sequences).

Focusing on the case study of sickle cell anemia to further demonstrate gene mutation, students were then systematically shown what happened at the gene level (focus on the products formed in transcription), and subsequently the effects at the protein level (focus on the products formed in translation). Students were also shown the effects of the mutation at the cellular level. Extending to the chapter on hereditary, Pam also briefly introduced the differences between someone with the sickle cell disease, and someone who is a sickle cell carrier. Pam proceeded to briefly introduce another type of mutation – Down syndrome. To conclude the lesson, students were given a worksheet (homework) containing a diagram that illustrated the transcription and translation processes. Students were instructed to jot notes corresponding to what they have observed in the diagram. The answers were to be discussed in the next lesson.

As illustrated in the descriptions above, the employment of theory of variation has enriched Pam’s enactment of teaching the genetics lessons in ways to benefit students’ learning. The theory has provided structure for the enactment of Pam’s lessons, helping Pam to focus on the important points (critical aspects) that could be highlighted through the enactment of patterns of variation and invariance. The inclusion of mutation as part of the patterns of variation and invariance to be employed was in fact consistent with her belief that good biology

teaching includes the inclusion of real-life phenomena, that would subsequently encourage students to see the relevance of what they are learning (“making it real” – excerpt P25).

(P25) Pam: I think, first of all, *“making it real” is very important*. So if we talk about the part about transcription and translation... and we brought in mutation then, I thought that was like helping them see what would happen if, you know, things go wrong. And that *will help them build up their (their) ideas about transcription and translation*. Yeah. [emphasis mine]

What is noteworthy was that Pam’s experience of applying theory of variation to guide the enactment of her lessons was different from that of Chris’. Pam’s main focus was not on the employment of patterns of variation as a way to draw students’ attention to the critical aspects of the object of student learning (unlike that of Chris). But rather, what came to the fore constantly for Pam was the goal of explicitly addressing students’ problematic conceptions and gaps in understanding. Nonetheless, the collective decisions made during the meetings (“principles that were picked up” – excerpt P26) influenced her pedagogy. For example, the critical aspects of the object of student learning and patterns of variation to be employed allowed Pam to clearly derive the main points of her lessons; to better organize her lessons (including the “pauses” and “repeats” – excerpt P27); and to prepare her curricular resources (such as her PowerPoint slides).

(P26) Pam: Actually frankly speaking when I was planning my lessons, I didn’t really think “Theory, theory” and how to vary it and that kind of thing... the principles that were picked up from this theory were sort of said during these meetings, which I actually used in my slides...

(P27) Pam: They [the critical aspects of the object of student learning] definitely formed the main points of my lessons, what to focus on, I mean, the general consensus on what to focus on. Definitely I worked my slides around it and the pauses, and like the repeats were before a new concept is being taught, that kind of thing.

Of interest as well was how Pam felt that the employment of variation was something that she has done previously. Nonetheless, she felt that the deliberate application of theory of variation has allowed her, firstly, to more clearly direct her students' attention to the critical aspects (main points of the lessons) through patterns of variation and invariance. Secondly, the pattern of variation afforded students the opportunity to apply concepts learnt to various contexts, even as the contexts were varied. (This was consistent with what Pam deemed as good biology teaching.) Thirdly, Pam also experienced the application of theory of variation as an enactment of "a more guided and deliberate approach" than before (mentioned in her reflective entry). When probed further for examples to illustrate what she meant by "more (guided and) deliberate" (excerpt 28), Pam described how students' description of mutation could include the process of gene expression and the related changes, rather than just relating the phenomenon to observed characteristics (phenotype) and "monsters". Thus, students could now describe mutation with greater explanatory power that was more consistent with the canonical science of genetics, drawing on the principles of transcription and translation. In this way, students' understanding of the principles of these genetic processes could be reinforced, even as they were applied to real-life genetic phenomenon of mutation. (Such a capability exhibited was in fact a desirable student learning outcome – see excerpt P1 & P10) As observed in the lessons described, Pam also deliberately used the "name activity" (online game used in her third research lesson) as well as flowcharts to systematically bring about patterns of variation. Receiving feedback that the theory-guided pedagogical strategies were effective for students' learning, this influenced how Pam perceived their usefulness to benefit students' learning and thus her decision to continue using them – "things I will keep" (excerpt P29).

(P28) Interviewer: So can you give me an example whereby you were actually more "deliberate" than you would usually be?

Pam: ...when we taught mutation they link it immediately to like Down Syndrome. So it's like the phenotype. Or like when you ask them about mutation, they will talk about your monsters and things like that... So in this case, I guess it was more of a complete picture... So I mean drawing them to what exactly is the gene expression that leads to the phenotype change – I guess that was the more deliberate part. Yeah.

(P29) Pam: ...I think making clear flowcharts about certain... so in a way like when we actually draw the flowcharts and show them deliberately what happens when you change something... what this leads to – all those things I will keep.

Pam's experiences in the learning study have also resulted in demonstrated shifts in what she considered valuable to the benefit of student learning. For example, when Pam was asked to review the Genetics Questionnaire that was completed at the beginning of the study, she highlighted how she now viewed students' learning of content different from before (excerpt P30). Previously, she felt that the outcomes of genetics were expressed in terms of students knowing *more* content. But an appreciation of the importance of helping students to learn the content *differently* seemed to have emerged. An example of the latter would be the use of genetic phenomenon of mutation to help students deepen their understanding of DNA structure.

(P30) Pam: The outcome of genetics is expressed in terms of students knowing (more content or content differently). I think it's a bit of both now. I mean, they need to know more, definitely... But the "content differently" part, I think "yes" because... for example, through this, the mutation one, then they learn more about the DNA structure, so I think it's a bit of both.

4.4.3 Pam's learning about her own pedagogy

What were illustrated and discussed in the above section (Section 4.4.2) are the ways in which Pam's pedagogy were influenced by her experiences in the learning study, and the ways in which she experienced learning as a form of professional development. The key experiences that constantly emerged from Pam's description of her own experiences were:

- (1) the emergence of a sense of clarity and coherence in Pam's approach to curriculum interpretation. According to Pam, this was brought about by the opportunities to collaboratively determine the object of learning and the curricular flow, and to plan the lessons using theory of variation as a theoretical framework. Coupled with the experience of observing her colleagues' lessons and participating in the post-lesson conferences, she was able to posit a clearer focus when planning and enacting her own research lessons.
- (2) the experience of authentic lesson planning that moved towards more student-centered approaches, and thus fostered greater teacher empowerment and ownership. Having to rely less on prescribed curricular materials, Pam's experience was enriched by her constant focus on students' learning. That is, on how to more deliberately and effectively identify and address students' problematic conceptions. According to Pam, the administration of student pre-lesson test has granted her several learning opportunities. For example, she modeled the questions found in the pre-lesson test to create her own questions. The questions in the pre-lesson tests also helped scaffold her own questioning in more structured ways, in order to more effectively draw out students' prior knowledge and to address the gaps in their understandings. Pam also explicitly mentioned that her experiences of addressing students' problematic conceptions were more structured and deliberate.
- (3) the deliberate application of theory of variation as a source of structure on Pam's lesson enactment to benefit her students' learning. The critical aspects and patterns of variation and invariance determined collectively were applied in her class. They resulted in an increased focus and a smoother flow both in lesson planning and enactment, and guided her preparation of curricular resources (class activities and organization of slides). In

addition, they also allowed her to posit a greater focus on addressing students' "misconceptions" during lesson enactment.

(4) the collaborative inquiry into Pam's own teaching practices and that of her colleague's.

The observation of colleague's classes and her participation in post-lesson conferences were catalytic in the reexamination of her own teaching practices. It also resulted in the generation of new insights on how to improve her teaching. The platform for reflection thus provided the matrix for demonstrated shifts in what she considered valuable to the benefit of student learning. The widening of perspectives also allowed for the acquisition of new pedagogical strategies, such as the modification of Chris' use of analogies to construct a class activity.

(5) the opportunities Pam has had to enact the research lessons, coupled with the use of student post-lesson test results and students' interviews to reveal good pedagogical practices, also encouraged the demonstrated shifts in what Pam considered valuable to the benefit of students learning. An example would be how Pam viewed good biology teaching to include both students learning more content and different content.

4.5 Themes capturing the variation in the participants' experiences

In the process of carrying out the description of the participants' experiences and the "overall" analysis, which borrowed largely from a phenomenographic perspective, the following themes were constructed:

1. Increasing clarity and coherence in approach to curriculum interpretation.
2. Authentic lesson planning resulting in the emergence of a sense of ownership and empowerment over the teachers' own lessons.

3. Deliberate application of theory of variation as a source of structure on the lesson enactment.
4. Collaborative inquiry into research lessons allowed for examination of one's own teaching practices, leading to the emergence of new insights on how to improve one's teaching.
5. Demonstrated shifts in what was considered valuable to the benefit of student learning.

Each theme is discussed in greater detail below.

4.5.1 Increasing clarity and coherence in approach to curriculum interpretation

The participants have expressed their state of anxiety over the lack of clarity in the syllabus, pointing to how they perceived the learning outcomes stipulated in the prescribed curriculum to not always clearly specify in detail the scope and depth to be covered (see excerpt A13 & P12). The teachers also felt constrained by the standardized national examinations that students sit for after Grade 10, which affected the way they have approached the curriculum. Hence, an increased clarity and coherence in the teachers' approach to curriculum interpretation was an important experience of the learning study.

Two key experiences in the learning study were highlighted by the teachers in relation to the teachers' approach to curriculum interpretation, namely, (1) the experience of collaborative planning (determination of object of learning and curricular flow, and planning of the lessons using theory of variation as the theoretical framework); and (2) observation and collective evaluation of the research lessons. These experiences resulted in the development of a common understanding of the emphases and details that would be appropriate for the research lessons. The emphases constituted the focal points of the research lessons, while the details, the scope and depth of the lessons. The development of a common understanding was also experienced through the collective establishment of relationships and links within and between genetic

topics. The re-ordering of genetic concepts and topics spanning across the different chapters in the prescribed textbook propelled teachers to reflect on the order in the prescribed curriculum, and to explore new possibilities in trying a different curricular flow. In doing so, the teachers experienced a move away from the conventional heavy reliance on the textbook or prescribed curricular materials, while concurrently making meaning of the prescribed curriculum for themselves. What also emerged from the discourse was a clearer and bigger picture of the new genetics curriculum, thus allowing the teachers to develop a more holistic approach to curriculum interpretation.

The collaborative discourse has allowed for the pooling and interrogation of different perspectives and experiences, and the arrival of consensus. The sharing of a common understanding in the team's approach to curriculum interpretation has in fact allowed for clarification of the individual teacher's own ideas, beliefs and perspectives, and thus greater clarity and coherence for the individual participant's interpretation of the genetics curriculum. This sense of "unity" can be appreciated to draw its power from the very diversity that was simultaneously experienced within the group. In other words, the nature of the teacher collaboration involved both the variation of experiences and perspectives, as well as how it subsequently lends power to the convergences of these perspectives, whereby the generation of ideas could be explored, examined and embraced. Thus, the learning context in this learning study, afforded by collaborative endeavors, underscores the importance of a discourse whereby different "meanings are negotiated and disambiguated, as well as a process in which common grounds [amongst the teachers] are established and widened" (Tsui, 2004, p. 167). The former highlights the need for diversity and variation, and the latter, for unity.

Another key experience of the participating teachers foreground the space created within the learning study for lesson observations and post-lesson conferences. What is noteworthy was that the process of curriculum interpretation was an ongoing process throughout the teachers' participation in the learning study. In addition, the arrangement of having Chris to start off the research lessons encouraged the tapping on the expertise and rich teaching experiences of more experienced teachers. This contributed to the ways Amy and Pam experienced the evolution of clarity and coherence in curriculum interpretation. Through the observation of colleagues' lessons and the post-lesson conferences, participants experienced variation in the ways the lessons were enacted. The experience of different pedagogical strategies deepened the connection between the approach to curriculum interpretation and its subsequent implementation. As such, intended learning outcomes that were related to the use of specific pedagogies came to the fore of teachers' attention. And upon reflection, they allowed teachers to gain a clearer understanding of the ways their colleagues have approached and interpreted the new genetics curriculum. These understandings consequently (re-)shaped their own approaches to curriculum interpretation.

The experiences of the participants in the learning study thus mirror those in research literature. The outcome space of teacher learning could likewise be interpreted as the coming to a shared understanding of the impacts of the teachers' pedagogical decisions and practices on their students, even as the teachers shared their varied understandings, pooled their teaching experiences, and collectively explored their beliefs and values about teaching and learning (Lave & Wenger, 1991; Pang & Marton, 2003,2005; Putnam & Borko, 2000). This consequently allowed for teachers to develop their approach to curriculum with greater clarity and coherence, and thus allowing them to learn professionally.

4.5.2 Authentic lesson planning resulting in the emergence of a sense of ownership and empowerment over the teachers' own lessons

Another way in which the participating teachers experienced learning while enacting the new genetics curriculum was through authentic lesson planning. The meaning of the term “authentic” took its reference from the interpretations of the teachers themselves. Although the teachers were not asked for formal definitions of what they thought authentic lesson planning were, their ideas around it were derived from what they thought good biology teaching and learning were. The interpretation of “authentic” lesson planning in this study, in accordance to the participating teachers, could be appreciated as one that was geared towards student-centered approaches. In the description of good biology teaching, the teachers also mentioned about the use of pedagogies that moved away from teacher-centered ones, and from a heavy reliance on prescribed curricular materials (e.g., excerpt P2). The teachers themselves viewed the prescribed curriculum as being content and assessment-driven (see excerpt A5 & A11), thus resulting in their use of more teacher-centered approaches. These perspectives have shaped the teachers' own understandings of “student-centered” approaches. In recognizing the gap between what they perceived to be good teaching practices and their current planning practices, the teachers often attributed the gap to the lack of time; an over-crowded syllabus; the pressure of examinations; and thus their conventional reliance on prescribed curricular materials (as was revealed through the teacher interviews). This gap is similarly highlighted in literature, emerging as tensions whereby teachers are constrained from implementing a curriculum that is consistent with their personal beliefs (Elliott, 1991; Evans, 1996; Hodson, 1993). The teachers, in expressing their desire for their pedagogies to be more student-centered, have also shared about their attempts before participating in the learning study to enact more student-focused

lessons (e.g., excerpt C4, P6, P7 & P8) (The teachers' own ideas around student-centered approaches were used in the analysis and interpretation of their experiences).

When describing how the teachers have experienced curriculum interpretation in a more enriched way than before (in Section 4.5.1), it was correlated with a move away from the conventional heavy reliance on prescribed curricular materials. This experience could be interpreted to have overflowed into the planning of the lessons. Feeling that their lesson planning in this learning study was geared towards a greater focus on students' learning, the teachers felt that there was greater consistency between their lesson planning and their own beliefs about good biology teaching. This resulted in a sense of greater teacher empowerment and ownership. The teachers have expressed how a collaborative discourse around the specific object of learning in the learning study resulted in a greater focus on students' learning and development of a capability (object of student learning). Concurrently, the collaborative planning of the curricular flow was a space carved out for the emergence, exploration and examination of varied ideas that centered around student learning - to explore how one might deliberately address students' learning needs through an organization of the concepts to be learnt. Again, enhancing students' learning was the central focus.

The employment of theory of variation to guide the lesson planning also encouraged attention to be paid to student learning. Attempts to understand and utilize students' experiences, and considerations on how to enhance student learning through the creation of patterns of variation and invariance (in accordance to theory of variation) were made. Thus, the discourse within the learning study has allowed for students' conceptions and experiences, and their challenges in learning genetics, to constantly come to the fore of teachers' attention. The

constant focus on students' learning and conceptions was also brought about through a systematic inquiry into students' prior knowledge and experiences – that is, through the administration of student pre-lesson test and interviews. This can be appreciated as a way to ground the inquiry of the teachers' own classroom practices on “classroom-based data” (Nelson & Slavit, 2007). In addition, the results were supported with the use of literature that foreground students' prior knowledge and their challenges in learning genetics. As mentioned in Chapter 1 (Section 1.3.2), research literature may not always be readily available to teachers (Bencze & Hodson, 1999; Pedretti & Hodson, 1995; Rosenholz, 1989). In contrast, thus, was how the participating teachers' professional learning in this study appeared to be enriched by deliberate attempts to incorporate research literature to inform and affect the teachers' teaching practices.

In elucidating the ways in which students approach and experience genetics, the teachers were able to draw out students' misconceptions (a term they used to refer to conceptions that were inconsistent with canonical science) and uncover gaps in students' understandings. The teachers felt that this experience was different from before, whereby previously, the elucidation of students' prior knowledge often relied on “verbal questioning” of their students in class, or on the teachers' prior teaching experiences. The opportunity for a systematic inquiry into students' conceptions allowed for the confirmation of their own perceptions of students' “misconceptions”, while concurrently allowing some of their taken-for-granted assumptions about students' prior knowledge to be challenged. In addition, not only did the participating teachers feel that they were learning a new skill - how they could more systematically inquire into students' prior knowledge, but they were also more deliberate in using students' knowledge to guide their lesson planning. Their experiences were similar to Marton's (1986) description of the mapping of students' thinking at the start of a unit, which helped focus teachers' attention on

information that might not be part of students' knowledge. The sensitivity to learners' prior knowledge and experiences - whether students could make sense of the critical aspects through their previous knowledge and experiences, was paid attention to. In other words, what the participating teachers have experienced was how the determination of the object of learning and critical aspects (and subsequent lesson planning) drew from students' real experiences, such that the characterization of the variation between the qualitatively different ways of experiencing genetics did not rest on an a priori analysis, but was empirically grounded in students' experiences (Marton & Booth, 1997).

As the teachers' understanding of students' conceptions deepened, there was also an increasing sense of motivation and need to deliberately address some of students' understandings that were not consistent with the canonical science of genetics. Teachers deliberately created opportunities in their lessons for students to confront, examine and change their own conceptions, for example, through the use of key questions. The teachers also explicitly highlighted these "misconceptions" to the students. In fact, it was observed that the teachers' use of strategies were consistent with that of conceptual change theory (Posner et al., 1982; Tanner & Allen, 2005). In addition, teachers' curricular resources, such as their PowerPoint presentations, were also modified accordingly. Thus, what was experienced was how the systematic inquiry into students' prior knowledge resulted in the planning and implementation of deliberate and focused interventions.

The establishment and widening of common ground (Bowden & Marton; 1998; Marton & Booth, 1997; Marton et al., 2004; Tsui, 2004) also constituted the deliberate interventions that the teachers took. With a clearer understanding of students' prior knowledge and experiences,

the teachers felt that they were able to establish and to widen common ground more quickly and effectively. Their overall lesson planning experiences were also enriched by the pitching of their lessons more appropriately to the level of students' understandings; and the teachers were able to use effective entry points to introduce new concepts in more meaningful ways. The teachers' pedagogies thus reflected the principles underlying the notion of a "relevance structure" (Bowden & Marton, 1998; Marton & Booth, 1997; Marton & Tsui, 2004), as well as the importance of making connections with the students' life experiences and what they learn in science (e.g., Meyer, 1998). This resulted in both the creation of new curricular activities (e.g., Amy's "Incredibles" activity) as well as a more effective use of previously acquired curricular resources (e.g., the viewing of a video three times instead of one). Consequently, in widening the space of learning, student learning was enriched.

In the introductory chapter, in explaining the context of teacher professional development in Singapore (Section 1.3), I have highlighted a concern amongst Singaporean educators. That is, a prescribed curriculum, and a society that places great emphasis on performance in assessment, may result in teachers merely attending to the technical aspects of implementing decisions made by central authority about the curriculum (Pedretti & Hodson, 1995). Signs of a similar phenomenon was also observed in this study – for example, Amy's heavy reliance on the textbook to organize her PowerPoint slides (excerpt A5); or Pam's mentioned of how easy it was to tailor her lessons to the prescribed curriculum instead of looking beyond it (excerpt P2). What was described in this section is how the participants have experienced authentic lesson planning. This could be experienced as a move away from a heavy reliance on prescribed materials, and a move towards more student-centered approaches – the latter being expressed by the teachers as approaches that were more consistent with their beliefs

about good biology teaching. Similarly, in Pang's (2006) study, most of the participating teachers were reported to have shifted their focus from a teacher-centered to a more student-focused approach; from teaching towards student learning.

The results of this study also demonstrates how authentic lesson planning that is compatible with teachers' personal beliefs about good biology learning and teaching was experienced in this learning study. Such compatibility lends the power for teachers to develop a deeper sense of ownership and empowerment over their own lessons. Hence, what is demonstrated is the potential of learning study to encourage teachers to move beyond being mere receivers of curriculum wisdom who should readily change their ways to respond to new curriculum directives or rhetoric (Hodson, 1988), or would merely attend to the technical aspects of implementing these directives (Pedretti & Hodson, 1995). It urges teachers to be involved in their own curriculum development and planning through "thinking" and "doing" (Connelly & Clandinin, 1998, p.4), and for teachers to exercise judgment to make their own meanings (Elliott, 1991) as practitioners who take "action" (Grundy, 1987, p. 65).

4.5.3 Deliberate application of theory of variation as a source of structure on the lesson enactment

The deliberate application of theory of variation served as a source of structure on the participating teachers' lesson enactment. Its application allowed for increased focus and coherence across the genetic topics (such as gene expression and heredity), as well as within the topic of gene expression (including the newly introduced transcription and translation) itself. With regards to the former, the employment of the theory has allowed different critical aspects of the object of student learning to be determined, bringing together these aspects from different

chapters in the prescribed textbook. For example, in enacting a pattern of variation and invariance, the variation of the nucleotide sequence of a gene was employed. This variation in fact described the genetic phenomenon of mutation, which typically, would not have been included in the topic focused on. All the teachers found that the inclusion of mutation at this point aided students to develop a deeper understanding of the newly introduced genetic processes of transcription and translation, while benefitting students' learning of subsequent genetic topics as well. Thus, the inclusion of mutation helped them to better enact teaching the new genetics curriculum in a more holistic manner. In addition, a deepened understanding of transcription and translation in turn granted students greater explanatory power to explain the real-life phenomenon of mutation, by applying the principles of transcription and translation to explain the process of mutation. This was consistent with the teachers' beliefs about good biology teaching - the development of students' capacity to apply what they learnt to real-life contexts.

What is worth mentioning at this point is that the teachers' decision to include mutation, in order to further enrich students' understanding of the structural and functional aspects of genetic materials (including the processes of transcription and translation), is in fact supported in research papers (Lewis & Kattmann, 2004; Tsui & Treagust, 2004). What was valued by the teachers were the opportunities to improve the organization of genetic topics and thus to address the problem of poor organization of topics (Banet & Ayuso, 2000; Lewis & Wood-Robinson, 2000; Lewis et al., 2000b). Hence, the deliberate application of theory of variation as a source of structure provided an opportunity for teachers to "bring the disparate pieces together to give a holistic overview or to make the relationship between topics explicit" (Lewis & Wood-Robinson, 2000, p. 190).

What is equally noteworthy was that teachers' support for the inclusion of mutation was related to how the topic of mutation was actually part of the prescribed curriculum. Because Grade 10 teachers generally devote large amounts of their time completing the prescribed curriculum (as was revealed through the teacher interviews), there would typically be little perceived incentive to include topics that were beyond the scope of the prescribed curriculum. Thus, the notion of "curricular fit" is underscored here, whereby the introduction of topics through patterns of variation should not be perceived to increase the teaching load of an already content-packed curriculum. The caution against introducing new initiatives or programs (including teacher professional development opportunities) that might increase the workload of teachers was also raised in research literature (Fullan, 2001; Ungerleider, 2003).

The deliberate application of theory of variation also allowed for greater coherence within the individual lessons. The teachers themselves focused on the critical aspects of the object of student learning and the patterns of variation and invariance. Although the teachers felt that they have employed some form of variation in their classes previously, their experience of applying theory of variation in the research lessons resulted in more deliberate and systematic variations being enacted. The deliberate application of theory of variation in lesson planning also resulted in the modification or creation of curricular resources. These included the rearrangement of PowerPoint slides, the use of new examples and case studies in class, and the creation of new activities (e.g., Chris' "Scrabble" game). Thus, theory of variation served as a source of structure to lesson enactment through the following ways:

1. Drawing teachers' attention to key (critical) aspects and links that were to be made;
2. Shaping the lesson flow - as critical aspects (typically found in different topics in genetics) were introduced in specific sequences.

3. Affecting the curricular resources used, such as the PowerPoint slides, and the sourcing or creation of new activities.
4. The enactment of variation was more systematic and deliberate than previously employed. What the application of theory of variation contributed, as a theory of instruction (Lo et al., 2006), was how the patterns of variation and invariance enacted could help scaffold and benefit students' learning.

The experience of enacting lessons based on theory of variation has also allowed teachers to deepen their experience of enacting a more student-centered approach. In view that the constraints of a national examination and a prescribed curriculum often resulted in teachers employing more teacher-centered pedagogies, the opportunities afforded by learning study to encourage teachers to employ more student-centered approaches (desired by the teachers themselves) supports its use in teacher development.

In this study, what was experienced by the teachers is analogous to what Marton and Booth (1997) termed as a “pedagogy of awareness”, as was demonstrated in other studies as well (Fraser et al., 2006; Linder et al., 2006; Lo et al., 2006). The teachers were made aware of the variation in how students could make sense of the critical aspects through the students' previous experiences. This allowed for students' discernment of the critical aspects of the object of student learning through various pedagogical strategies, which included the enactment of patterns of variation and invariance in accordance to theory of variation. As such, mutual awareness (Marton & Booth, 1997) between the teachers and the students was made possible through a collaboratively created space of learning, whereby student learning could

subsequently be enhanced, while teachers would learn about the object of learning and how to handle it.

The experience of employing theory of variation as a source of structure on teachers' enactment of their research lessons thus allowed for enriched and different ways of experiencing their own teaching. The potential of applying theory of variation to guide teaching, towards a more student-centered approach, resulted in how the teachers deemed the employment of the theory as "practical", and as a way to acquire a new skill or tool. Not only did this result in the teachers' intent to similarly apply the theory in their future enactment of genetic lessons, but to other topics as well. This suggests the potential of the learning study to bridge the often perceived divide between theory and practice – as was similarly supported by Pang (2006), even as greater connections between theory of variation, classroom practice, and what teachers valued to benefit students' learning could be reinforced and experienced in more enriched ways.

Prior to concluding this section, it is also worthwhile to mention that, as was highlighted in the literature review in Chapter 2, one of the key differences between the learning study and lesson study, and between the learning study and collaborative action research studies, is learning study's employment of a theoretical framework. The experiences of the participants in this study serve to further elucidate the differences between the different approaches – that it is not merely the absence or presence of a theory that distinguishes the learning study, but the kinds of student and teacher learning that could potentially be yielded because of its application. Nonetheless, it was not the intention of this study to deem one approach as better than the other. Rather, that the teacher learning opportunities afforded by the learning study could be more thoroughly explored.

4.5.4 Collaborative inquiry into research lessons allowed for examination of one's own teaching practices, leading to the emergence of new insights on how to improve one's teaching

Opportunities to inquire into research lessons in a collaborative manner included:

1. the determination of object of learning and curricular flow;
2. administration of pre- and post-lesson tests and student interviews;
3. collective planning of the research lessons
4. participation in observation of research lessons and in post-lesson conferences. The latter allowed for an articulation and consolidation of good teaching practices.

The collaborative inquiry into teachers' research lessons, and thus their own teaching practices, served as a means for the participating teachers to receive feedback on their teaching. The post-lesson conferences allowed for the strengths of each lesson to be highlighted, thus supporting the teachers' use of similar pedagogical strategies in future lessons. Suggestions on how to improve the pedagogical strategies employed or the lessons, and how subsequent lessons could be organized to deliberately address potential gaps that might have emerged, were discussed as well. Because the learning study was organized in a way in which a post-lesson conference would take place prior to the implementation of the next research lesson (by the same teacher), subsequent lessons could be prepared based on the evaluations. As mentioned in Section 3.2.2, the collaborative nature of lesson study allowed for a "benchmarking process" that teachers could use to gauge their own skills, even as they reflected on their own practices and identified things that can be improved upon (Stigler & Hiebert, 1999). The experiences of the participants' in this study revealed similarities in their experiences of the evaluation and

reflection process, and it would thus be reasonable to assume that the potential of such a “benchmarking process” likewise resides in the learning study approach.

The participants’ experiences also underscored the collaborative nature of the inquiry that took place. The opportunity for collaboration allowed for an experience of variation in the ways the research lessons were enacted, while the object of student learning and critical aspects, including the patterns of variation and invariance collectively determined, were held invariant. Drawing from the principles of theory of variation, the experience of variation in the enactment of teaching may result in teachers’ awareness being focused on teaching aspects that were varied. That is, different ways of experiencing a series of theory of variation-guided lessons provided the platform that seeded reflections of the participating teachers’ own teaching practices. When comparing the enacted research lessons with their individual teaching practices, the differences in pedagogical strategies (as experienced by the teachers) often triggered deeper reflections, even as teachers dug deeper to comparatively examine differences between these pedagogies in terms of their strengths or weaknesses. The different kinds of student learning that were yielded by the different pedagogies were also deliberated upon. These experiences allowed teachers to become even more aware of their own teaching practices, and to be able to re-examine them in light of an experience of either enacting or experiencing colleagues’ lessons. In addition, insights that emerged could then be further examined during the discourse that took place in the post-lesson conferences or when the team collaboratively consolidated good teaching practices. As a result of this space carved out for teachers to learn about their own pedagogy, the emergence of new insights to improve their individual teaching came about through:

1. The deepening of an understanding of how the individual teacher's former pedagogical strategies could be improved to yield greater student learning.
2. The deepening of an understanding of a theory and how it could be applied.
3. The generation of new ideas to be applied in the teacher's own classroom.

An example of the first experience, whereby a deepening of understanding of how one's pedagogical strategy could be improved would be that of Amy's experience. In being able to experience how questions were used differently in Chris' class to draw out students' understandings, and how they can be used as scaffolds to build new knowledge, she expressed that she would like to employ a similar questioning technique and thus gain a new skill.

With regards to the second point, the participants' understanding of theory of variation and how the theory of variation can be applied deepened. The teachers also made specific mention to the researcher's highlighting of other instances in their classrooms whereby theory of variation could be used to interpret their teaching practices (during the post-lesson conferences). This further broadened their understanding of how the theory could be applied, and thus increased their perception of the relevance of theory of variation to classroom teaching.

With regards to the third point, the different teaching styles of the teachers also allowed different dimensions of teaching to be experienced, resulting in the generation of new ideas on how to approach the topic of genetics. The teachers were inspired to adapt some of the teaching styles and strategies to their own classrooms. An example would be how the teachers felt that the observation of Chris' "Scrabble" game granted them new ideas on how to teach genetics. Their desire to likewise employ the strategy was influenced by reflections on how the activity

was effective in making abstract ideas more concrete for the students, thus enriching students' learning experiences. The generation of new ideas also included those relevant to teaching in general. For example, Pam, Amy and Kate were all inspired by Chris' use of questions and concept maps to engage students in a co-construction of knowledge. In light of theory of variation, it could be appreciated that the three teachers have experienced an aspect of classroom practice in a more enriched way – that classroom practice was a “jointly constituted body of negotiative social interactions” that was experienced in terms of “the mutuality and reciprocity of its constituent activities and of its co-construction as teaching/learning” (Clarke, 2006, p. 378). Propelling the teachers' reflection of their own ways of using questions and visual organizers such as concept maps, as well as the nature of their classroom practices and interactions, all three teachers expressed that the experience of Chris' lesson enriched their own teaching practices, challenging them to learn the “skill” as a way to expand their own repertoire of teaching strategies.

What are demonstrated above are the teachers' experiences of collaborative inquiry into their teaching practices. They could be appreciated to be similar to Lord's (1994) “critical collegiality”, where collegiality “means more than simply sharing ideas or supporting one's colleagues in the change process. It means confronting traditional practice – the teachers' own and that of his or her colleagues...” (Lord, 1994, p. 192). What is worth noting is the experience of “synergy” (mentioned in Kate's overall reflection) lends the power to suggest that the learning study allowed for learning to take place amongst colleagues, despite differences in terms of seniority and teaching experiences. Typically, mentorship models set up in schools often tacitly imply that learning is unidirectional – from more experienced teachers to those who were less experienced. But the results in this study suggest that learning is more

multidirectional, since Kate and Chris, who were deemed as more experienced teachers, also expressed that they learnt from the younger teachers that they were supposed to mentor. Similarly, Pam and Amy felt that they contributed to Chris and Kate's learning. Thus, within the context of a learning study, the rigid authoritative barriers could be deemed to have broken down in the midst of a "synergistic" collaborative matrix.

Another point worth noting is that the experience of "confronting traditional practice" (Lord, 1994, p. 192) was enriched by the employment of theory of variation to make sense of and evaluate the teachers' teaching. The consistency in using theory of variation throughout the learning study to plan, implement and to evaluate the participating teachers' lessons has in fact allowed for what Stigler and Hiebert (1999) has described as the development of a shared and new language given to experience (see Section 3.2.2). In the course of participating in the learning study, the teachers were engaged in discussions using their new language involving "critical aspects", "patterns of variation and invariance", and the establishment of "common ground". This shared language has opened the collective's possibilities into new ways of thinking about learning (as was similarly reported in Davies & Dunnill's (2008) study), and hence new ways of reflecting on and describing their own pedagogy. What is thus underscored is how the application of theory of variation provided the basis for teachers to interpret and evaluate students' learning experiences, helping them to relate and compare the intended, enacted and lived object of learning. In doing so, teachers learnt how to use theory of variation to describe and evaluate their own teaching. The results of this study, and that of others (e.g., Arbaugh, 2003; Davies & Dunnill, 2008; Pang & Marton, 2003, 2005), thus suggest that the learning study has the potential to promote this aspect of teacher learning.

What was also reiterated and highlighted in the teachers' experiences described in this section was the importance of teacher reflection, and the opportunities to make their knowledge public and understood by their colleagues (Hiebert et al., 2002), and thus the collective knowledge explicit (Marton 1994b). In this study, the participants' experiences were consistent with what Bowden and Marton (1998) asserted, that teachers should learn from other teachers in terms of becoming aware of other people's ways of seeing, in order that their individual understandings are enriched and thus become more powerful. Thus, it is in this context of collaboration and reflection that a shared knowledge base (Hiebert et al., 2002) lends power to the teachers' experience of variation, whereby teachers' own awareness becomes linked when they articulate and demonstrate their personal knowledge to form a collective consciousness (Bowden & Marton, 1998). In other words, variation without reflection and the making of collective knowledge explicit might not result in powerful transformations. Pang (2006) likewise accounted for how teachers participating in his learning study had the chance to reflect and evaluate the research lessons. Together with this learning study, how professional knowledge could be shared in the context of a learning study, and how a "collective consciousness" (Bowden & Marton, 1998) within the community of teachers could be developed have been exemplified. This outcome space of learning is similar to that of "communities of practice" - the coming to a shared understanding of the impacts of teachers' practices on students and/or the larger educational community (Lave & Wenger, 1991).

What is noteworthy is that it is also in this very space of collaboration and reflection within the learning study that the kind of curriculum development that Elliott (1991) mentioned about can occur. That is, a process of teacher development that occurs through the reflective practice of teaching. In addition, the reflective process that has taken place in this study

illustrated the characteristics of Schön's (1983, 1987) reflective practice - reflection-in-action as well as reflection-on-action. An example of the former is how the collaborative discourse within the learning study encouraged teachers to constantly engage in reflection of their own teaching practices. The latter was demonstrated in how the post-lesson conferences were deliberately set up for teachers to reflect on the enacted research lessons. Similarly, the overall reflection granted teachers an opportunity to examine the learning of their own pedagogy.

The results of this study also underscore how such a process of teacher development and curriculum development (Elliott, 1991) could take place in a collaborative setting. As exemplified in this learning study, the improvement of teaching afforded in this learning study transcended simply getting better at implementing externally designed curriculum. For one, it was demonstrated how a collaborative discourse has allowed for participants' approach to curriculum interpretation to be enriched in a way that moved beyond a heavy reliance on prescribed curricular materials (section 4.5.1), moving towards increased student-centeredness and thus greater teacher empowerment and ownership. It was also demonstrated how the new meanings that emerged from this new approach to the new genetics curriculum have influenced the collective planning and implementation of theory of variation-framed research lessons (sections 4.5.2 & 4.5.3). In this section, it was also demonstrated how the experience of variation was catalytic in encouraging teachers to reflect, critique and construct their own professional practice and that of their colleagues. Seen in this very light, teachers inquiring into their own practices thus cannot be divorced from the collaborative and reflective nature of the learning study – the ingredients for effective curriculum development and implementation.

4.5.5 Demonstrated shifts in what was considered valuable to the benefit of student learning

Throughout teachers' participation in the learning study, there were ample opportunities for them to reflect on their beliefs about teaching and on their own pedagogy. This space of inquiry took varied forms, ranging from (but not limited to):

1. their participation in the teacher interviews, which the teachers themselves felt was a space for reflection,
2. to the collaborative discourse that took place throughout the learning study,
3. to the opportunities to personally experience their colleagues' lessons,
4. to opportunities to evaluate the research lessons, and verbally articulate and discuss the lessons during the post-lesson conferences,
5. to the overall reflection that was conducted during the last session of the learning study.

As was discussed in the previous section (Section 4.5.4), an outcome of the space of reflection was that teachers became more aware of their own beliefs and their teaching practices. In affording a space to encounter, to re-evaluate and to tinker with their beliefs, demonstrated shifts in what was considered valuable to the benefit of student learning were also experienced. This was further encouraged when teachers had the opportunities to personally experience the organization, enactment and evaluation of the research lessons in new or enriched ways.

The opportunities for the team to encounter their beliefs about their own teaching were also seeded by the diversity that was experienced through the collaborative discourse, as well as through lesson observations and post-lesson conferences. In other words, the experience of variation in teaching practices allowed for various aspects of teaching, formerly not paid

attention to, to be brought to the fore of teachers' awareness. Such an illumination allowed a close examination of these very aspects, which led to shifts in the teachers' beliefs. For example, Amy experienced the use of games in Chris' class in a way that was different from how she used to implement games. The experience propelled a change in her perception, motivating her to likewise use games to enhance student learning.

Demonstrated shifts in what teachers considered valuable to the benefit of students' learning were also experienced as the deeming of certain aspects of teaching or student learning as more important than before. For example, teachers became increasingly convinced that the inclusion of mutation into the research lessons benefitted students' learning of transcription and translation. They also believed that students developed a greater capacity to explain real-life phenomenon using scientific principles. Consequently, this deepened the teachers' conviction about what good biology teaching should include, that is, to help students develop the ability to establish links between different concepts, and to apply concepts learnt into real-life settings. The latter is related to the teachers' larger goals of helping students increase their scientific literacy. Another example would be how Pam, commenting on her responses in the Genetics Questionnaire, expressed that she valued students' "learning of content differently" as more important than before, whereby previously, the outcome of students' learning focused around students "learning of more content".

As exemplified, the shifts in teachers' beliefs can be appreciated to occur at different levels:

1. Those that directly affected the teaching of genetics (e.g., the inclusion of mutation).
2. Those that are related to goals of teaching - such as development of students' ability to apply and link concepts; students learning content differently.
3. Those that are related to broader and larger goals around scientific literacy.

What is worth mentioning is that the experiences of demonstrated shifts in what the teachers considered valuable to benefit students' learning were often accompanied by "how-to-do" measures (Evans, 1996). For example, the deepening of convictions about the importance of students' ability to establish links were accompanied by personal experiences of teaching mutation – as a pattern of variation and invariance. These patterns aided to develop students' capability to establish links between different genetic concepts. Another example would be how teachers' deepened conviction of the effectiveness of deliberately drawing from students' prior knowledge and experiences to improve teaching was coupled with their experience of how to systematically draw out students' prior knowledge through the use of pre-lesson test and student interviews. In being able to identify students' problematic conceptions and gaps in understandings, the teachers were more motivated to organize their lessons to establish common ground and to address specific areas of student learning more effectively. What is highlighted here, thus, is that the learning study can be appreciated to have the potential to be a professional development approach whereby teachers can gain new and enriched experiences in different aspects of their professional lives, and thus learn. Accompanying those experiences, and as a result of those experiences, are the very skills teachers have gained or honed in order to further improve their teaching practices.

CHAPTER 5

CONCLUSIONS, SIGNIFICANCE, LIMITATIONS AND DELIMITATIONS, IMPLICATIONS AND SOCIAL SCIENCE RESEARCH EXPERIENCE

The conclusions of the study, following the analysis of the results, are presented in this chapter. This is accompanied by a discussion of the significance, as well as the limitations and delimitations of the study. Subsequently, the implications are discussed. The thesis concludes with a discussion of the social science research experience of the researcher, foregrounding the messiness of the research study and how it urges one to ponder and report on it.

5.1 Conclusions

Effective actions spring from effective ways of seeing, even as we always act in relation to situations as we see them (Bowden & Marton, 1998; Marton & Booth, 1997). In the context of this learning study, the research question of “How does Singaporean teachers’ participation in a theory of variation-framed learning study affect their learning about their own pedagogy?” was addressed by exploring two guiding questions:

1. What are teachers’ understandings of their own teaching and learning practices before participating in and experiencing a learning study?
2. How does participation in the learning study influence teachers’ pedagogy and experiences of learning as a form of professional development?

By largely employing a phenomenographic perspective, as well as theory of variation as the theoretical framework, teacher learning was appreciated as the development of a capability to experience various aspects of the teachers’ own professional practice in more advanced or

powerful ways. These ways of enriching their teaching experiences resulted in improved teaching practices. The potential of learning study as a professional development approach was explored as a way to alleviate, if not overcome, the potential challenges faced by teachers in implementing the new Grade 9-10 genetics curriculum in Singapore. The perceived challenges include teachers' possible unfamiliarity with the new genetics curriculum; how there appears to be a lack of repertoire of pedagogical strategies that draw upon selected theories of learning; and how there also appears to be a lack of appropriate teacher professional development programs to help teachers enact teaching the new prescribed biology curriculum. What is noteworthy is that these challenges, while identified within the Singaporean context, are also similarly faced by teachers elsewhere.

The study was organized to help four participating teachers develop a capability to enact teaching the new Grade 9-10 genetics curriculum in the context of a Singaporean classroom. The interpretation of the new genetics curriculum, together with the organization, implementation and evaluation of students' learning experiences, constituted the critical aspects that would aid in the development of such a capability. Other aspects included elements of teachers' professional practices, such as opportunities for teacher collaboration and reflection on their individual teaching practices. These aspects could be experienced differently from before, even as they were deliberately "varied" and brought to the fore of the teachers' awareness through the various learning contexts afforded by the learning study. In doing so, teachers gained "new ways of seeing" (Bowden & Marton, 1998; Marton & Booth, 1997), subsequently bringing forth more effective actions to enhance student learning and improve the teachers' own pedagogies, thus suggesting the occurrence of teacher professional development.

Thus, the question is, how does Singaporean teachers' participation in a theory of variation-framed learning study affect their learning about their own pedagogy? Largely employing a phenomenographic perspective to analyze the data, what was captured were different ways in which the teachers experienced their own learning as a form of professional development. The ways in which the teachers' pedagogies were influenced by their participation in the learning study, and how they learnt about their own pedagogy were also uncovered.

The results of the analysis revealed the teachers' understandings of their own teaching and learning practices before participating in and experiencing the learning study. The teachers viewed students' learning of basic biological content and terminologies as foundational to their larger goals of teaching biology. Beyond the learning of content, and in order to gain a more holistic approach to the topics, the teachers encouraged their students to establish links between different concepts and topics. Students were also encouraged to apply their knowledge to different biological phenomena (including those that extended beyond the classroom contexts). Such capabilities were often seen as springboards to help students make meaning of their own learning and to generate their interest in biology, and thus propelling them towards self-motivated learning. The teachers also believed that such capabilities were pertinent to achieve the goal of scientific literacy, whereby students develop the capability not only to draw on scientific principles to understand the world around them, but also to be able to act accordingly as informed by these principles.

The participating teachers have also revealed how their beliefs have shaped their own classroom pedagogies. With the goals of generating interest and establishing the relevance of biology to everyday life, the teachers often engaged students through the use of games, videos,

real-life examples and case studies. Believing that student-centered approaches constitute good biology teaching, the teachers also expressed their desire and shared about their attempts to employ such approaches. However, the teachers felt that their classroom pedagogies did not always reflect their beliefs about good biology teaching and student learning. The teachers attributed the gaps to the pressure to cover the content-laden prescribed curriculum (in order to prepare students for the national examinations at the end of Grade 10), and how it often resulted in their employment of more teacher-directed pedagogies, as opposed to their desired student-centered ones. The teachers deemed that student-centered approaches constituted more authentic lesson planning and enactment, which would result in a greater sense of ownership and empowerment over their own teaching. What is also worth noting is the teachers' own interpretation of the prescribed curriculum as being content and assessment-driven. Despite the constraints and the perceived gaps between the teachers' beliefs and teaching, the teachers still tried to direct their teaching towards student-centered approaches. For example, through the use of simple questions, teachers tried to draw out students' prior knowledge and used it to scaffold their lessons.

The question is, how did the teachers' participation in a learning study influence their own pedagogy and their experiences of learning as a form of professional development? In gaining greater clarity and coherence in their approach to curriculum interpretation, the teachers were able to move away from their conventional heavy reliance on prescribed curricular materials to determine the flow of the topics to be taught. The teachers also developed a common understanding of the emphases and details of the genetics lessons, while approaching the curriculum in a more holistic manner. The teachers focused on students' learning right from the very beginning of the learning study as well. These experiences subsequently enabled the

teachers to experience more authentic and creative lesson planning that focused on students' learning. The opportunities to systematically draw from students' prior experiences served to deepen the teachers' understandings of students' prior knowledge. It also motivated them to use and address students' understandings, resulting in the enactment of student-centered pedagogies that was more closely aligned with the teachers' beliefs about good biology teaching.

The results of the study also illustrated how theory of variation was pertinent as a theory of instruction (Lo et al., 2006) to help teachers plan and enact students' learning experiences. In allowing greater coherence within and across the genetic topics, the deliberate application of theory of variation guided teachers' systematic enactment of patterns of variation and invariance to enhance their students' learning. In addition, the theory allowed for an evaluation of the teachers' own teaching practices.

Teacher collaboration and reflection also emerged as experiences that were salient for teachers to learn about their own pedagogy. It was demonstrated how the inquiry into the teachers' individual teaching practices, as a way to conduct research in their own classrooms, could be deeply enriched by opportunities for collaboration. Collaboration allowed for different perspectives and experiences, as well as different teaching styles, to come to the fore of the teachers' focal awareness. The pooling of these perspectives and experiences allowed them to be critically examined. Seen in this light, collaboration has offered experiences of variation that triggered reflection into individual teacher's own teaching practices. This resulted in teachers drawing from the reflections to further support their teaching practices or to have them challenged. Together with the opportunities to elicit feedback from colleagues about their individual teaching, the teachers became aware of other possibilities and new ideas to improve

their own teaching practices. What was demonstrated in this study is how teachers' experiences of collaboration and reflection were so intertwined with every aspect of the learning study that they became a basic tenet for the creation of conditions for teachers to learn. In this collaborative and reflective matrix, shifts in what the teachers considered to benefit students' learning occurred, even as some of the teachers' beliefs about good biology teaching or their own teaching were challenged, or were widened.

In answering the two guiding questions, five emergent themes that served to capture the varied ways in which the participating teachers learnt about their own pedagogy were constructed. These include

1. Increasing clarity and coherence in approach to curriculum interpretation.
2. Authentic lesson planning resulting in the emergence of a sense of ownership and empowerment over the teachers' own lessons.
3. Deliberate application of theory of variation as a source of structure on the lesson enactment.
4. Collaborative inquiry into research lessons allowed for examination of one's own teaching practices, leading to the emergence of new insights on how to improve one's teaching.
5. Demonstrated shifts in what was considered valuable to the benefit of student learning.

In the next section, the significance of the results of this current study to research is discussed.

5.2 Significance

The results in this study can have a significant impact on improving the teaching of biology and other subjects both in Singapore and elsewhere. In addition, this study has demonstrated the power of learning study as a tool for implementing unfamiliar curriculum content. It appears that this potential of the learning study has not been reported in earlier learning studies. The description of the individual teacher's experiences, as well as their collective experiences (captured as themes), illustrate how the teachers' participation in the learning study helped prepared and influenced their teaching of the newly implemented genetics curriculum. The results of this study thus demonstrate and broaden learning study's potential, promoting the learning study as an approach to help teachers enact teaching any newly reformed curriculum, which quite often is unfamiliar.

The results in this study are also significant in demonstrating how a learning study approach is effective in promoting teacher collaboration and classroom research. The learning study allowed the participating teachers to readily collaborate with their colleagues, and to participate in a joint inquiry of their teaching practices through classroom research. Spaces were deliberately carved out for teachers to readily pool their teaching experiences; to reflect on and to discuss the curriculum, content knowledge, pedagogy and pedagogical content knowledge (Shulman, 1986). These opportunities consequently promoted teacher learning as a form of professional development. The results of this study are thus significant by demonstrating the ease with which teachers can collaborate to learn about their teaching practices in a learning study.

The significance of the results also pertains to how the learning study affords the meaning of learning theories to be tested in practical situations, and to be appreciated by both teachers and students. The employment of theory of variation in this current study was perceived to have enriched students' learning of genetics. Coupled with the opportunities to enact theory of variation-framed lessons, the participating teachers' understanding and appreciation of the theory (as being practical and effective to enhance their classroom teaching) were deepened. The teachers also gained a new skill in learning how to employ theory of variation in their teaching. The results thus illustrate how a learning study could potentially be an effective vehicle for a learning theory to be understood in the context of teaching practice, and in doing so, that the gap between theories and practice could be bridged (Pang, 2006). Thus, The results of the current study also urge policy makers and school administrators to consider the employment of learning theory as a way to promote teacher professional development.

The current study is also significant in demonstrating and exploring in detail the variation in ways in which teachers can learn about their own pedagogy through participation in the learning study – especially in view of how such studies in Singapore appears to be lacking. The results also support the limited published research studies (e.g., Davies & Dunnill, 2008; Pang, 2006) that likewise demonstrate the potential of learning study as a form of teacher professional development.

This study draws attention not only to the possible areas of teacher learning, but also demonstrates how a learning study could potentially be organized to encourage teacher growth. The uncovering of varied ways in which teachers have experienced their own learning as a form of professional development draws attention to the organization and implementation of this

current learning study (as described in detail in Chapter 3). The strength of the current study could be appreciated as how easily teachers accepted and how readily they participated in the learning study. Not only did the learning study take place within the teachers' own school and classroom contexts, most of the meetings were also allocated for as part of their school's professional development program. Although not reported in detail in this thesis, when teachers were encouraged to share about the aspects of the learning study that encouraged participation, they highlighted the conveniences of having the learning study implemented in place of the "mandatory" school professional development program. This also reduced the commitments and "workload" of the teachers. The teachers also mentioned about the saliency of being able to implement the research lessons in their own classes – to encourage their own professional learning. Thus, this study also strongly supports the assertion of other research literature (Gu & Wang, 2006; Nelson & Slavit, 2007; Smylie, 1989; Stigler & Hiebert, 1999) that underscores the importance of teachers implementing research in their own classrooms – that in order to improve teaching, the most effective place to do so is in the context of a classroom lesson.

Another aspect of the learning study that contributed to the teachers readily accepting the learning study was that the steps in the learning study were similar to the activities that took place in the teachers' daily professional lives, or were desired by the teachers themselves. This study is thus significant in demonstrating how a learning study could be organized to proceed along lines that were compatible with teachers' professional culture, and the rhythms of life in school (Altrichter et al., 1993; Noffke, 1995).

The results of this study, significant both to research as well as to the professional teaching community (including teachers and policy makers), also serve as a platform to reflect

on the implications of this research study. These implications are discussed in the later half of this chapter.

5.3 Limitations and delimitations

In relation to ascertaining the impact of the research lessons on students' learning, a delimitation of the study was that the classes chosen by the teachers to participate in the study comprised the higher ability girls in the school. In addition, all the students that took part in the study were girls (since the school was an "all-girls" one). Thus, the elucidation of how theory of variation-framed lessons influenced students' learning of genetics was limited to this group of students, and could not be extended to uncover how it might have affected the learning for boys or students from lower ability classes. Nonetheless, although not reported in this thesis, the participating teachers expressed confidence that a similar enactment of the research lessons would benefit their students from lower ability classes. They have also expressed their intentions to enact similar lessons in these classes in future. From a researcher's point of view, it would be interesting and helpful to tease out the different types of student learning that could emerge with students of varied academic abilities and gender. In view of research literature that elucidates the differences between the ways of knowing and strategies employed by girls and boys to learn science (Pittman, 1999), this delimitation could be turned to a potential area for further research.

In a similar vein, a limitation of the study could be the small sample size of teachers that participated in the study. Because the number of teachers to be involved was decided by the school, and also by the grouping of the teachers in the original (school's) professional development program, the number of teachers were limited to four. Despite the limited generalizability of the results, the description of the teachers' experiences and the subsequent

construction of themes adds to existing research literature by probing deeper into the kinds of teacher learning that emerged. This provides a glimpse into the teacher professional development that could take place within the context of a Singaporean classroom setting, and elsewhere. The results also serve as a springboard for further studies that might continue to elucidate the different ways teachers have experienced learning in the context of a learning study. In addition, the results of this study are potentially useful for comparison with other learning studies, in order to uncover the similarities and differences in teacher learning in different countries, classroom settings and organization of the learning study.

Another limitation of the study could be attributed to the absence of comparisons between students' learning within a learning study research class and that of a "control" class. "Control" classes were not introduced into this study due to the teachers' expressed concerns for time and resources. This poses a challenge in terms of teasing out the difference between the influence of theory of variation-framed lessons on students' learning the same content because of "regular" classroom instruction. Despite the absence of such comparisons, the participating teachers have developed an appreciation for how students' learning was enriched not only because they learnt more content, but also because the quality of their students' learning improved. An example would be how Pam felt that through the research lessons, students learnt "different content" as opposed to merely "more content". In other words, the teachers' intention was to uncover the types of student learning as opposed to the amount of learning *per se*, and to focus on ascertaining the influence of their new pedagogical arrangements on students' learning. It is also noteworthy that because no control class was used, teachers were able to apply what they had learnt in the learning study to improve their teaching in other classes.

The length of the study, as determined by the teachers and the school, coupled with the constraints of the teachers' heavy workload, further imposed limitations on the study. These constraints affected how the influence of the learning study on students' learning could not be studied over a longer period of time - only one set of post-lesson test and student interviews were used. Granted the nature of the object of student learning determined in this current study, which was based on teachers' assumption that mastery of the object of student learning would eventually help students learn the rest of the genetic topics with greater ease, uncovering the influence of the learning study on students' learning over time would definitely have granted even more valuable insights. It would have been useful in ascertaining if the research lessons were effective in enhancing students' learning of the subsequent genetic topics

In the same vein, a limitation of the current study was that the influence of the learning study on teachers' learning about their own pedagogy could not be captured over a longer period of time. Not only was it difficult to conduct an interview in the middle of the current study - since teachers expressed their reluctance to be "held back" by the interviews, it also proved difficult to conduct the "delayed" interviews. Nonetheless, within the stipulated duration, two interviews (instead of one) were employed at the end of the learning study to probe for teachers' experiences of participating in the study. The use of two interviews also allowed for the checking of consistency in interpretation of the teachers' description of their experiences.

5.4 Implications

In this section, the implications for theory; teacher professional development; implementing future learning studies; curriculum; research methodology; teaching practice and future research direction are discussed.

5.4.1 Implications for theory

In this learning study, theory of variation was consistently applied throughout the learning study to help the participating teachers organize, implement and evaluate students' learning experiences. On a different level, theory of variation was also employed as a theoretical framework to guide the organization and implementation of the learning study. It was also drawn upon in the analysis that aimed to capture the variation in how teachers learnt about their own pedagogy. The literature review included in this thesis has also suggested that while theory of variation was used in the earlier context (thus focusing on students' learning), it appears that the latter context has been less explored. In this section, the implications for using theory of variation in the two different ways are discussed. It can be appreciated that this current study adds to existing literature by extending the use of the theory beyond a tool to plan, enact and evaluate teaching in a classroom. It supports the employment of theory of variation as an equally effective way to organize, promote and examine teacher learning.

The results of this study illustrate how teachers' individual teaching practices could be influenced by the use of theory of variation to help them organize, implement and evaluate students' learning experiences. Firstly, the theory offered teachers a way of looking at and facilitating learning that focused on students' experiences. This encouraged the shift of teachers' attention from themselves and their teaching to their students' learning.

Secondly, with the implementation of the new genetics curriculum, the employment of theory of variation as a theory of instruction (Lo et al., 2006) has helped to address the challenges of teaching genetics. This is supported by the teachers' own accounts of how they deemed the theory as pivotal in enhancing their students' learning of genetics. Coupled with the

use of theory of variation as an analytical tool, not only were teachers provided opportunities to inquire into their own practices and conduct research in their classrooms, they were also able to do so in light of theory-informed insights. In other words, what and how students learnt (lived object of learning) could be related to how teachers planned (intended object of learning) and taught (enacted object of learning) the lessons.

Thirdly, because the inquiry was conducted in the context of the teacher's own classrooms – together with the challenges and constraints that teachers face in everyday teaching, the application of the theory took place within the complexity of educational settings and situations to produce meaningful and useful outcomes (Trigwell, 1994). Thus, the teachers could more accurately evaluate how practical and effective the application of the theory was to classroom practice, and by extension, to the contexts of the specific school.

As revealed through the literature review, it appears that theory of variation has not been extensively applied to the context of students learning genetics, except for Lai's (1996) study that foreground the use of phenomenography as a theoretical perspective to understand students' conceptualization and approaches to the genetic topic of meiosis. This study thus extends the use of theory of variation to address the several challenges in students learning genetics, particularly to the learning of the genetic processes of transcription and translation. It also adds to the repertoire of pedagogical strategies and suggested interventions previously made in research literature to enhance students' learning of genetics (e.g., Lewis & Kattmann, 2004; Lewis et al., 2000C; Tsui & Treagust, 2004, 2007; Wood, 1993). As accounted for by the participating teachers, the patterns of variation and invariance that were enacted helped their students better relate the structural and functional aspects of genes. In addition, the teachers

believed that it aided their students' development of the ability to better explain genetic phenomenon like mutation, that is, with greater consistency with the canonical science of genetics. Consequently, students' understandings of transcription and translation also deepened.

By extension, theory of variation may be useful in the learning of other biology topics as well. As revealed through the first set of teacher interviews, the teachers' broader goals of teaching biology included increasing students' scientific literacy. In view of the nature of the subject, the development of students' ability to form links between biological concepts and to apply them to real-life contexts appear to be common goals of biology teaching. In this study, the teachers valued how the enactment of patterns of variation included phenomenon that was occurring in nature, such as the phenomenon of mutation. The inclusion of these "variations" helped students apply their understandings of genetic processes to real-life contexts. Phrased differently, the application of theory of variation to enrich students' learning supports the inclusion of real-life phenomenon when designing patterns of variation and invariance.

The participating teachers also valued the experience of being able to enact theory of variation-framed lessons because it allowed students to concretize abstract ideas such as the molecular processes of transcription and translation. This was similarly reported in students' learning of other subject areas (Fraser et al., 2007; Linder et al., 2006; Pang & Marton, 2005). In the course of this learning study, teachers have developed an understanding of the need for "variation" to be "experiential". This was evident in the activities that were enacted – for example, Chris' "Scrabble" game and Pam's "name" activity. What this points to and warrants is for greater deliberation as to what experiencing something would mean in the specific context

of what is being taught. Firstly, the need to establish common ground with students' prior experiences is emphasized. The importance of connecting students' experiences with scientific concepts to be taught has likewise been mentioned in research literature (e.g., Meyer & Woodruff, 1997) – although the focus of the lessons and means to encourage students' inquiry, discourse and experience of scientific phenomenon might vary from the theory of variation-guided lessons enacted in this current study.

Secondly, creating opportunities for students to “experience” variation of the critical aspects appears to be critical in promoting their learning. The assertion made here is similar to that highlighted in the literature review (Section 2.2.2). In comparing Lo et al.'s (2006) study and that of the “postman's route” lesson (Runesson & Mok, 2004), the latter afforded students opportunities to experience variations of the critical aspects. This was a missing step in Lo et al.'s study that might otherwise further enhance students' learning.

In the current study, it has also been demonstrated how theory of variation was used to guide the organization and implementation of the learning study, as well as to analyze teachers' learning experiences. Learning, as consistent with phenomenographic perspectives and theory of variation, can be described as a change between qualitatively different ways of experiencing something. The learner is able to experience the phenomenon in a more advanced or more complex way than before. What was highlighted in the results of this study is how the participating teachers experienced various aspects of their own professional lives in more enriched ways, thus elucidating how they learnt about their own pedagogy. Concurrently, learning can also imply that the teachers became more capable of discerning aspects of their professional and teaching practices that were previously not possible, and to be simultaneously

and focally aware of more aspects that influenced their teaching practices. For example, curriculum interpretation drew from the prescribed curricular materials, but also from students' prior experiences. This empowered the teachers to approach the curriculum in a different and more powerful way than before. Similarly, the enactment of the research lessons relied not only on teachers' prior experiences, but was also enriched by the perspectives and experiences of their colleagues'.

The view of learning presented here was similarly reflected in Pang's (2009) study. He employed a theory-based approach to enhance Grade 12 students' development of the generic capability to make informed and independent financial decisions. The ordering of categories was based on students' answers - on the number of dimensions of the variation of critical features considered. Answers that demonstrated the inclusion of more critical aspects of the phenomenon were deemed as more sophisticated. Although in my study the ordering of categories was not used to capture the differences in the ways in which the participating teachers experienced the learning study, support was drawn from Pang's study and other literature (Marton & Booth, 1997) to assert that the inclusion of more aspects in the participating teachers' focal awareness could be deemed as a more sophisticated and advanced way of experiencing teaching.

Research literature (as was reviewed in Chapter 2 – Section 2.2.2) has also highlighted the saliency of creating conditions in the classroom to encourage students to learn, through the enactment of patterns of variation and invariance so that students can be simultaneously aware of critical aspects. By extension, this study demonstrates that the deliberate creation of conditions in a learning study is equally important for teachers to learn. Deliberate enactment of

patterns of variation and invariance would not only allow for teachers to experience various aspects of teaching practices differently and in more enriched ways, but it would also encourage the development of teachers' capability to attend to *more* aspects that are critical to enhance students' learning. In addition, as was the case for teachers in the current study, the agendas of preparing students for the national examinations and to perform well in assessments could also be simultaneously incorporated into teachers' focal awareness.

Equally salient, then, is that if one shares in this perspective of learning offered by theory of variation and phenomenography, it could also be appreciated that it is the dynamic interactions and interrelations between the different aspects of teachers' professional lives that encouraged teachers to learn. Thus, what is recommended is the inclusion of all aspects of the learning study in order to encourage a diversity of experiences amongst the participating teachers - such as the collective determination of specific object of learning and curricular flow; theory-framed lesson planning that imposed structure on lesson enactment, lesson observations and post-lesson conferences; administration of students' pre- and post-lesson tests and interviews; collective determination of good pedagogical practices; opportunities for reflection and collaboration. Such a practice would thus reflect an attempt to harness the collective potential of these aspects to maximize opportunities for teachers to learn. Phrased differently, the results of this current study foregrounds the intertwining, dynamic and synergistic relationships between collaboration; systematic research approach; reflection; and employment of a theoretical framework to enrich students' learning. These are all salient in promoting teacher learning and professional development. The current study is significant in demonstrating how the theory of variation could be employed as a tool to encourage teachers to experience these aspects in more complex and enriching ways. Thus, the results encourage the

implementation of more studies that would similarly employ the theory to organize and implement teacher learning experiences, in order to further explore the effectiveness of the application of the theory to promote teacher learning as a form of professional development.

5.4.2 Implications for teacher professional development

The results of the study strongly suggest the potential of the learning study as an approach to help teachers improve on their own pedagogy. During lesson planning, teachers were able to move away from a conventional heavy reliance on prescribed curricular materials. In addition, the teachers were also able to approach the whole genetics curriculum in more holistic ways. The study also illustrates how the teachers' pedagogies have been influenced through the constant focus on students' learning both in lesson planning and enactment, which subsequently resulted in their employment of more student-centered approaches. Coupled with the use of a learning theory to guide the planning and implementation of lessons, teachers were able to more succinctly highlight the key concepts. Together with the opportunities to obtain feedback and collectively inquire into the individual teachers' teaching practices, the participating teachers were constantly reflecting on their own teaching while having them challenged or widened. These experiences, as accounted by the participating teachers, strongly support the use of learning study to improve teachers' pedagogy. Because the experiences that helped to improve the teachers' pedagogies were also the aspects of their teaching and professional lives that were experienced in more enriched ways, these very experiences constitute their experiences of learning as a form of professional development. Seen in this light, the results of this study strongly support learning study as a tool to promote teacher learning and professional development.

In this study, the spaces for teacher reflection have created opportunities for teachers to realize how they have been developed professionally through their participation in the learning study. These reflections are valuable in propelling teachers towards taking greater responsibility for their own professional development. In addition, the participating teachers have shared about how they have previously tried to develop themselves. For example, they would rely on the Internet to generate new ideas for teaching. Through the results of this study, it has been illustrated how professional development opportunities were further enhanced by the collaborative nature of the inquiry into the teachers' classrooms. These experiences suggest that the taking of responsibility for one's own professional development could potentially be shifted from that of the individual to that of the whole group. In the same way that the results of this study have highlighted opportunities for teacher learning that emerged only within a collaborative setting, teachers taking responsibility of their own professional development could likewise be collaboratively shared and catalyzed. This potential of the learning study is worthy of greater attention, thus providing a future direction whereby research studies could be headed.

In reflecting on the potential of learning study in promoting teacher professional development, it also compels one to also consider how the learning study could be organized. In the next section, some of these considerations are discussed in relation to the results of this study. They seek to provide some suggestions for the implementation of future learning studies.

5.4.3 Implications for implementing future learning studies

In this section, considerations for the implementation of learning studies in future are presented. The first part of the section focuses on the importance of understanding teachers' beliefs, teaching practices and prior experiences of professional learning before the implementation of the learning study. There is also a brief mention on how such an understanding was drawn upon in this study to reduce the researcher's biases during the analysis of results. The next part of the section appeals for the step of collective determination of curricular flow to be included in a learning study. Subsequently, the discussion focuses on the urge for careful deliberations over the choice of theoretical framework. The discussion that follows draws attention to the concern that the learning study or the theoretical framework may constrain teachers. What is underscored is the importance of empowering teachers to decide on which aspects of the learning they want to focus on.

When considering the implementation of future learning studies, the importance of understanding teachers' beliefs, teaching practices and prior experiences of professional learning comes to the fore. As illustrated in the results of the current study, the demonstrated shifts in what teachers considered valuable to benefit student learning were shaped by the deepening or challenging of their personal convictions of (1) what good biology teaching and learning should be, (2) their goals in teaching, and (3) their current practices. This study sheds light on these shifts and their relationships to the organization of the learning study. Along this vein, what is recommended is that the participants' understandings of their own teaching practices and their prior experiences of professional learning should be explored before they participate in the learning study. This was carried out in this research study through the first set of teacher interviews and the administration of the Genetics Questionnaire.

Just as the drawing of students' prior knowledge has helped teachers organize and implement students' learning experiences, teachers' perspectives and prior experiences can similarly be drawn upon to guide the researcher in organizing teachers' learning experiences. In order for various aspects of the teachers' teaching and professional lives to come to the fore of their attention such that they can be encountered, reflected upon and re-examined, these very aspects should be deliberately weaved into patterns of variation when organizing and implementing the learning study. The determination of what aspects to be varied can draw from an understanding of teachers' initial beliefs, teaching practices and prior experiences of professional learning. The subsequent creation of opportunities to experience these aspects in different or enriched ways may result in teacher learning - as was observed in how teachers' pedagogies and their learning of them were influenced in this study. An example of how this was carried out in the current study is illustrated in Diagram 5.1. The diagram shows how the learning opportunities that have emerged from teachers' participation in the learning study were in line with some of their goals for teaching. This in turn lends the power for the researcher to consider how aspects of the learning study, which could potentially support or challenge some of the teachers' own beliefs and teaching practices, can be even more deliberately weaved into the learning study to further support teachers' learning.

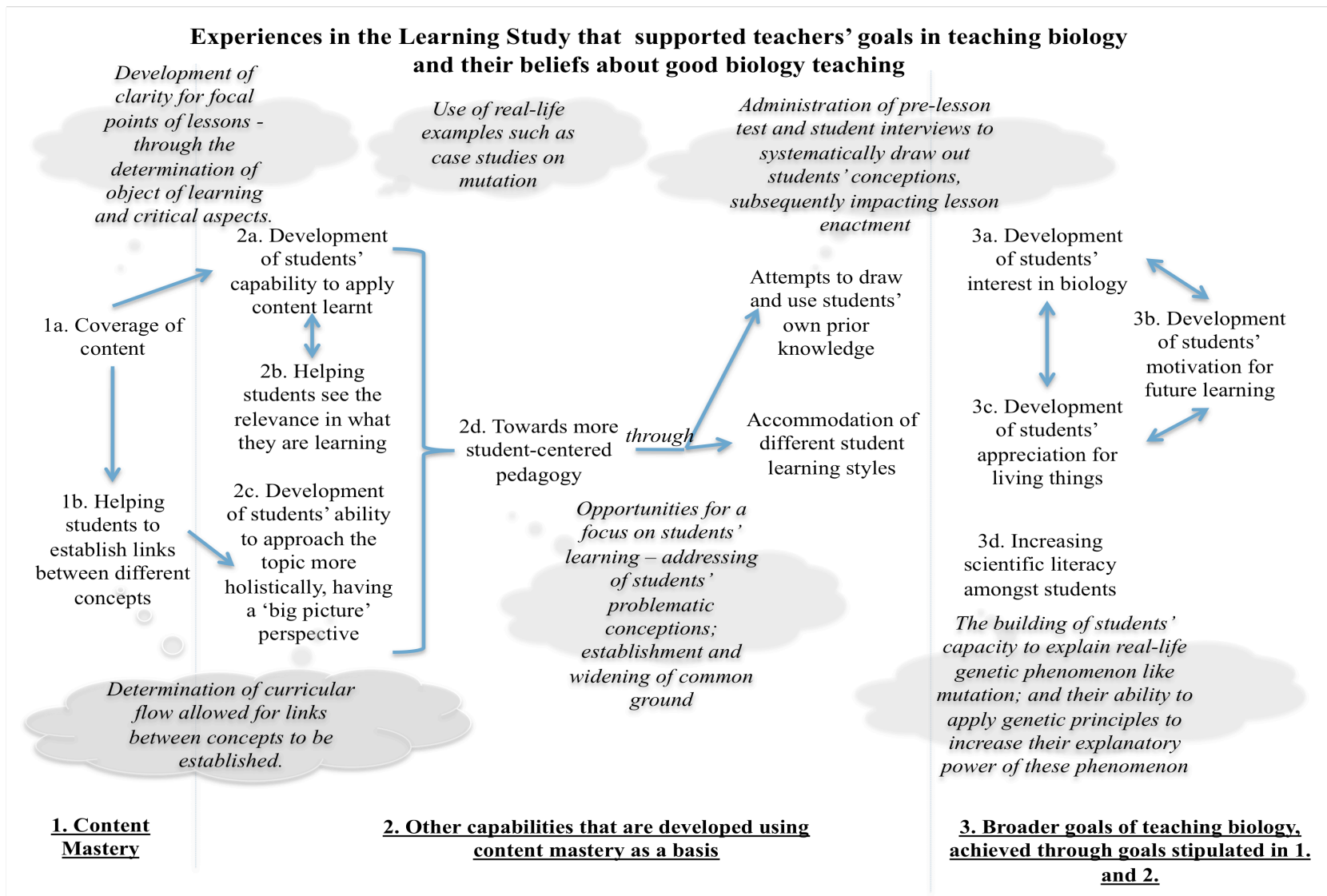


Diagram 5.1: Diagram illustrating some of the participating teachers' experiences in the learning study that supported their own goals and beliefs about teaching biology.

The participants' goals have been numbered, with '1' being what was most basic to their teaching, and '3' being their larger goals and beliefs about what good biology teaching is. Arrows illustrate the relationships between these goals. Included in the 'bubbles' are some of the ways in which the teachers have experienced various aspects of their teaching practices in more enriched ways.

In the same vein, it is also worthy of mention that in this study, the notion of student-centered pedagogy and what more authentic and good biology teaching would look like were taken from the perspectives and descriptions provided by the participating teachers themselves. This was consistent with phenomenographic perspectives. In taking a second-order perspective, the heart of such a methodology also reflects its intention to return the power of interpretation back to the participants themselves. An example of how such a perspective shaped the study pertains to the changes in teachers' conceptions of teaching and learning. The Genetics Questionnaire (Appendix D) was crafted by drawing largely from previous studies (Boulton-Lewis et al., 2001; Koballa et al., 2000; Prosser et al., 1994; Samuelowicz & Bain, 1992; Trigwell & Prosser, 1996, 2004; Wilson & Berne, 1999), and was supposed to be used to probe for changes in teachers' conceptions of teaching and learning (should they emerge from the results). The act of doing so has resulted in a tacit "expectation" on my part - I was sensitized to looking for conceptions of teaching and learning, and changes to them, that were similar to those described in research literature. In other words, the conceptions in research literature, rather than serving as a guide to help me make sense of my participants' utterances and experiences, could potentially pose a threat by becoming "dogmatic" shifts that I "should be" looking for. In addition, I ran into the risk of privileging one set of conceptions over another, based on literature alone. Realizing my biases and the potential "misuse" of literature on my part, I proceeded to draw even more deeply into the first set of teacher interviews that probed for teachers' own conceptions and meanings of good biology teaching. The analysis of the changes in their conceptions thus took into consideration what teachers themselves deemed as good teaching practices. In addition, the genetics Questionnaire was still used to help teachers share about possible shifts in their perceptions at the end of the learning study. But rather than using it

to directly probe for changes in their conceptions, thus constraining my understanding of the possible shifts in teachers' conceptions (which would be based on their responses to the Questionnaire after their participation in the learning study), it was used more as a platform to encourage teachers to share about how they think their beliefs about teaching and learning genetics have shifted.

When considering the design of future learning studies, the inclusion of the step of collective determination of curricular flow could also be considered. Results in this study have revealed how teachers have gained competency to deal with the new prescribed curriculum. What is noteworthy is how this current study has described in detail the development of teachers' capability to approach the curriculum in a way whereby they can construct their own meanings and develop their own curriculum. Rather than being developed to merely implement curriculum that was decided upon by central authority, the teachers have used the prescribed curriculum as a resource to help critique and construct their professional practices (Pedretti & Hodson, 1995). Seen in this light, the gap mentioned at the beginning of this study – regarding how it appears that appropriate teacher professional development programs to help teachers enact teaching the new genetics curriculum is lacking, might be addressed by looking into training of a particular kind. The results of this study suggest that these programs need not always precede teachers enacting the curriculum. Rather, the “situated” nature of the learning study suggests that teacher professional development can take place concurrent to the enactment of teaching the curriculum. Thus, the case made here is that the deliberate creation of certain teacher experiences are required to help teachers conceptualize teaching within curricular structures in more powerful ways. What is worthy of mention, then, is the collective determination of curricular flow. This appears to be a “new” step introduced in this learning

study that allowed teachers to approach and enact prescribed curriculum in more powerful ways. The current study adds to the body of literature by demonstrating how the inclusion of this step in a learning study approach further encouraged teachers to construct their own meanings of the curriculum.

The teachers also attributed the increase in coherence between different genetic topics to opportunities to collaboratively determine the curricular flow, thus lending further support for this step in the learning study. This step allowed teachers to make links between the different genetic topics. Consequently, they were able to develop an appreciation that students' mastery of the chosen object of student learning would eventually help their students learn the rest of the genetic topics in more meaningful and effective ways. Seen in this light, the collective determination of curricular flow allowed the teachers' view of the object of student learning to shift from being one that was specific to a particular topic to one that was more generic in nature. The latter is similar to Pang's (2009) recent study, being one of the first published studies to extend the object of learning to the mastery of a generic capability.

Along the lines of implementing the collective determination of curricular flow as a "new" step in the learning study, it is worth mentioning that this step emerged out of the learning study as a need - in order to address the perceived difficulties teachers were facing in determining the object of student learning. A review of literature seems to reflect the lack of accounts describing the difficulties in determining the object of student learning, thus giving the impression that this process appeared to pose less of a challenge for teachers' participating in other learning studies than in the current study. The reason for the challenges faced by the participating teachers in this study could be attributed to the nature of the genetics curriculum -

as being a huge topic (Lewis & Wood-Robinson, 2000). Coupled with its newness in the prescribed curriculum and the many challenges faced in teaching genetics, it is not surprising that teachers faced a certain amount of challenge trying to determine the object of student learning. What is thus underscored, firstly, is how this step served as a tool to help teachers manage the huge topic of genetics. By extension, future learning studies can also consider employing a similar step. Secondly, what is also highlighted is the saliency of the ways a learning study is organized to promote teacher learning. The emergence of the step of collaboratively determining the curricular flow was made possible because of the flexibility in determining the steps in the learning study. Rather than an *a priori* scheduling of the steps, what would take place in the next meeting was determined by preceding ones. In addition, the deliberate and conscious effort to empower teachers to share in the organization of the learning study and to direct their own learning also resulted in the emergence of this step in the study. The principles employed are in fact consistent with research literature (Altrichter et al., 1993; Carr & Kemmis, 1986; Hardy & Kirkwood, 1994; Kosmidou & Usher, 1991).

When considering the implementation of future learning studies, another point worth highlighting pertains to the careful deliberation and selection of a theory as the theoretical framework of the learning study. Although the teachers viewed theory of variation as being useful in guiding their lesson planning and enactment, the ways in which different aspects of the theory were focused on varied from individual to individual. This may also explain why the perceived fruitfulness of applying the theory to teaching differs from teacher to teacher. For example, for Pam, in being more focused on addressing students' conceptions, the theory was deemed useful in highlighting aspects of the genetics curriculum to focus on. These aspects were determined by drawing on the results of the pre-lesson test and student interviews. In

contrast, Chris was more deliberate in enacting the patterns of variation and invariance in accordance to theory of variation. As such, what stood out for him was how the enactment of variation was more deliberate and systematic than before, and how he has learnt to more skillfully enact variation as a pedagogical tool.

Because the employment of theory of variation was experienced differently in the learning study, a question of what degree the teachers understood the theory of variation emerged. This reflected a prior struggle I had while implementing the learning study – to what extent should theory of variation be introduced to the teachers? Does it suffice that they understand how it can be applied to the classroom? Or should it be extended to include the epistemological underpinnings behind the theory?

In view that it might be easier for the teachers to employ a theory that is more familiar to them, the application of theory of variation in the classroom (as opposed to the philosophical underpinnings of the theory) was emphasized in this study. The purpose was to encourage the development of teachers' appreciation of the relevance of theories of learning to classroom teaching. But is there the potential to further enhance teacher learning should the epistemological underpinnings behind the theory be explored further? If a new epistemology might hold the key to a dramatic improvement in learning and provide a completely new perspective on education (Brown, Collins & Duguid, 1989), such a potential might be worth exploring. However, what also comes to mind is how the participating teachers in the current study seemed to have naturally gravitated towards the application of theory of variation to guide their pedagogy, rather than an engagement with an epistemological discourse around the theory. Thus, this urges those who are committed to the professional development of teachers to (1)

seriously consider the usefulness of an epistemological discourse around the chosen theory, especially when measured against teachers' "natural" and reasonable tendencies to focus on classroom teaching; and (2) to likewise explore ways to encourage such a discourse should it be deemed a worthwhile effort.

The choice made to introduce theory of variation in a more applicable and familiar way in this current study has also influenced the teachers' perception of the theory. Through the interviews, the teachers have revealed how they feel that the theory was something they have implemented before; and that its application was "intuitive". Thus, despite teachers demonstrating an appreciation for the theory, and despite their willingness to employ the theory to guide their teaching in future, the introduction of a seemingly familiar theory have also resulted in some sort of "dissatisfaction" – although the sentiment was not a shared one amongst the team. For example, Amy raised a comment that she was hoping to gain more from the study. She anticipated that that might be achieved through the introduction of a new theory, "something that we have not done" before. On the other hand, Kate felt that introducing a theory that was more familiar would definitely help teachers ease into applying the theory in their classrooms. In light of the different views, there appears to be no easy answers. Nonetheless, considering the pivotal role the theory has in enriching both student and teacher learning experiences, the selection of an appropriate theory definitely warrants careful considerations.

When considering the implementation of future learning studies, another concern which may subsequently emerge is whether they are now subjected to another type of "imposition" – that of the learning study or of theory of variation. Did the teachers' move away from a heavy reliance on prescribed curricular materials subject them to yet another "constraint"? I would like

to argue not. Apart from the collective decisions about the object of student learning and the curricular flow to be implemented, teachers were given a free reign as to what they would like to focus on in their classes, and how they would go about teaching them. This practice was consistent with research literature (Lo et al., 2006; Pang & Marton, 2005). Consequently, the teachers have in fact emphasized slightly different aspects of the object of student learning. In the same manner, rather than “imposing” on the teachers, patterns of variation and invariance collectively decided upon served as a source of structure for teachers to scaffold their lessons. Moreover, it has been shown that the differences in how the object of student learning was handled and differences in how the patterns of variation were enacted have in fact allowed for the experience of diversity amongst the team. This subsequently enriched the teachers’ learning.

Still addressing the concern that the learning study, or various aspects of it, might excessively impose constraints on the participating teachers, the results of this study revealed how teachers chose parts of the learning study that were more applicable or meaningful to them as platforms for their lesson planning, enactment and evaluation. In other words, rather than allowing the learning study to constrain them, the teachers directed their own learning by determining for themselves the aspects of the learning study that were useful; that they wanted to focus on. In doing so, the teachers were observed to have taken greater responsibility of their own professional development. Phrased differently, due to the varying degrees of importance ascribed to the different aspects of the learning study, different aspects of the learning study resided in different levels of the teachers’ awareness, and were thus focused upon in varying degrees. Individual teachers valuing and consequently attending to different things have been acknowledged in literature (Clarke & Hollingsworth, 2002).

The participating teachers' valuing and thus focusing on different aspects have in turn shaped the types of teacher learning experiences they have had. For instance, as I have briefly mentioned, Pam highly valued and focused on addressing students' problematic conceptions throughout the learning study. Her experience resulted in her conviction that the administration of students' pre-lesson test was very useful. A significant part of her learning revolved around a move towards student-centered pedagogy by attending to and addressing students' prior knowledge in more deliberate ways. Chris, on the other hand, focused on theory of variation to a larger degree than Pam did. Focusing on enacting theory of variation-framed lessons, Chris found the application of the theory particularly helpful in ensuring that he was more systematic in bringing about patterns of variation and invariance. It is not surprising, then, that this experience of the learning study seemed to be more significant for him than for Pam. Hence, the point to be made here is that returning the choice of which aspects of the learning study to focus on back to the teachers has helped to empower the teachers rather than to constrain them. It has allowed for an "improvisational" (Sawyer, 2004) curriculum interpretation, development and implementation that reflected greater autonomy over the teachers' own learning and professional development. Similarly, in Clarke and Hollingsworth's (2002) model of teacher professional growth that demonstrated how teacher professional growth can occur through a variety of ways, what was underscored was that professional development programs should be deliberately designed to offer participants opportunities to be professionally developed according to their own individual inclinations and professional "learning styles".

5.4.4 Implications for curriculum

The results of this study serve to elucidate teachers' approach to curriculum interpretation and enactment. What consistently surfaced was how the teachers deemed it

valuable to move away from a heavy reliance on the prescribed curricular materials, towards approaches that were regarded as more empowering, and more student-centered. Interestingly, what this points to, and as mentioned by the teachers, was how the prescribed curriculum was seen as a constraint that has imposed itself on the teachers' pedagogy. This constraint was deemed to have resulted in more teacher-centered approaches, often constraining teachers to resort to the mere delivery of content. What is equally noteworthy was how the teachers themselves conflated teacher empowerment and autonomy, as well as authentic lesson planning and enactment, as moves away from heavily drawing from prescribed curricular materials. The perspectives of the teachers urge policy makers and those involved in the determination of prescribed curriculum to attend to how the curriculum could be crafted – a curriculum that would encourage teachers to forge their own meanings of the curriculum, and in turn, to empower students to likewise make their own meanings.

As was also elucidated in this study, teachers perceived the prescribed curriculum to be vague in terms of defining the scope and depth to be taught. While this can be seen as a shortcoming of the current curriculum, another perspective that could be taken is that the “vagueness” has actually allowed for teachers to create their own meanings of the curriculum. Thus, the results of this study point to the trajectory to be considered – that in crafting the prescribed curriculum, curriculum makers are also urged to ponder over the complementarities between the nature of the curriculum and the processes teachers could potentially engage in when they approach the curriculum. It urges one to ponder over the degree of “vagueness” in the curriculum that should be tolerated, such that it allows for more powerful interpretations without causing an excessive sense of frustration or anxiety amongst teachers.

At a deeper level, what is also urged for is an ontological shift in the nature of the curriculum from a product to be enacted to a process teachers could engage in. The assertion made here is similar to that of Elliott's (1991) - that it is about developing one's own curriculum rather than getting better at implementing an externally designed one. Seen in this light, how can prescribed curricular materials be used as an "enabling constraint" (Davis & Sumara, 2006; Davis, Sumara & Luce-Kapler, 2008), and subsequently, as a resource to help teachers critique and construct their professional practice (Pedretti & Hodson, 1995)? How can curriculum be crafted not only as a document that stipulates student learning outcomes, but also as a stimulus and resource to engage teachers in and discussion on (1) the nature of the topic, (2) the types of student learning that can be encouraged, and (3) bigger questions of epistemological nature?

The case made here, thus, is that in order to help build the capacity of teachers to conceptualize teaching within curricular structures in more powerful ways, the creation of opportunities for teachers to approach and enact prescribed curriculum in more powerful ways is desirable. But such an endeavor should not stop short in just focusing the efforts on teacher professional development. Rather, at the other end, curriculum makers should likewise take up the challenge to view their efforts in crafting curriculum as the creation of platforms for teachers to be the curriculum makers - such that transformative changes can take place within the classroom not only for students, but also for teachers, of whom the enactment of the prescribed curriculum are solely in the hands of.

5.4.5 Implications for research methodology

The inclusion of descriptions of the individual participants' experiences was a step included in the analysis (as described in detail in Section 3.5.1) and reporting of the findings

(Section 4.2, 4.3 & 4.4) in this study. It appears that this step was not commonly employed in previous studies, although Ashworth and Lucas (2000) supported the production of individual profiles of the participants. The description of individual participants' experiences in the current study created an opportunity to persist a focus on the individual's experiences and utterances, serving to deepen the understandings of the particularities of each individual's experiences. In doing so, greater clarity and coherence in the interpretation of the teachers' utterances was made possible. This in turn aided the analysis of the rest of the data sources, the "pooling" of meanings and the construction of the themes. This step was pertinent because they allowed for an emergence of greater confidence that interpretations were taken in the context of what was being said. Equally important was that this reflected a step taken for the individual voices of the participants to be seriously and respectfully considered, even as they reflected authentic individual experience (Coulter, 1999). In the same way that Coulter felt it was important that the voices of people who have experienced repeating a grade was added to the voices of professional researchers (in order to better understand the retention of students in a grade), this current research similarly supports the adding of the voices and experiences of the teachers themselves as a way to better understand teacher learning and development. Thus, while the questions posed by Coulter (1999) – "Can researchers really tell someone else's story (or experiences)? How much of the context is absent?" are likewise applicable to this current study, the attempts in this study to account as accurately as possible the utterances of the participants strive to address these questions.

This study permits the inclusion of the step for describing individual participants' experiences in a phenomenographic analysis. Recognizing that it might only be feasible if the sample size is small, such a step might be a worthwhile effort in striving to establish coherence

(Sandberg, 2005). In addition, such a step also serves to increase the reliability of the study. In providing descriptions of individual participants and thus demonstrating how they lead to subsequent construction of themes (categories), it lays bare the researcher's interpretive process by "detailing" the steps in the form of descriptions. This is similar to Sandberg's (1997) "interpretative awareness" – a way to deal with our subjectivities throughout a research process. In doing so, it also allows the reader to make better evaluation of the constructed themes (Lincoln & Guba, 1985).

This section stresses the importance of interpreting the utterances and meanings of the participants as faithfully as possible. Along similar lines, the next section highlights how the interpretations of teaching practices, especially student-centered and teacher-centered approaches, could more accurately reflect the meanings teachers prescribed to them. The section argues that teachers' perspectives on these approaches warrant careful deliberations and even a re-envisioning of what good biology teaching could be. Extending the discussion further, such a re-envisioning might require the breaking down of prevalent "oppositional dichotomies", as was asserted by Clarke (2006).

5.4.6 Implications for teaching practice

This study has demonstrated how teachers have experienced student-centered pedagogy as more effectively utilizing students' conceptions and prior experiences to shape their lesson planning, lesson enactment and classroom discourses. In comparison, the teachers' previous attempts to employ student-centered approaches involved the struggle to decrease the typical "teacher-talk" or "lecture-style" approaches. The experiences in this study - of moving away from a mere coverage of stipulated content in a prescribed curriculum and a greater focus on

student learning served to reconstitute the teachers' understandings of student-centered approaches. Thus, these experiences serve to widen the meanings of "student-centered" approaches in a Singaporean classroom context. The results of this study thus beckons careful and further deliberations, and even a re-envisioning, of what good biology teaching could be in the context and constraints of a Singaporean classroom. It also urges for the probing of what "student-centered" approaches to curriculum would look like.

Such deliberations are also pertinent in light of the potential of learning study to address the challenges faced by the teachers, that is, the demands of a content-laden prescribed curriculum and the pressures of examination. According to the teachers themselves, these demands and pressures have resulted in the frequent adoption of more teacher-centered approaches. In contrast, their participation in the learning study have granted them opportunities to move away from these approaches, towards more student-centered ones. Considering the constraints and challenges that make up the terrain of the Singaporean educational context are also similarly shared elsewhere (Elliott, 1991; Hodson, 1993), the constant (re-)constitution of the meanings of "student-centered" and "teacher-centered" approaches also has its application beyond the context of Singapore.

This current study has brought about a realization that the notion of student-centered pedagogy in an Asian classroom may differ in meanings from those prescribed in literature. For example, although some of the participating teachers' conceptions of teaching and learning could be categorized in ways that were similar to those found in literature (Boulton-Lewis et al., 2001; Koballa et al., 2000; Prosser et al., 1994; Samuelowicz & Bain, 1992; Trigwell & Prosser, 1996, 2004; Wilson & Berne, 1999), the pedagogical strategies and classroom practices that the

participating teachers employed in correlation to a particular conception were not always consistent with those reported in literature. For instance, while there are similarities between this study and how Prosser et al. differentiated two of the reported conceptions of teaching, attributed to whether the teacher's focus was on the teaching activity or on student's focus, some other distinctions were less consistent with literature. In Samuelowicz and Bain's study, the correlation of the conception of supporting student learning as not wanting to, to a large degree, direct students' learning differs from this study. On one hand, the differences could be attributed to the differences in context, that is, Samuelowicz and Bain's study involved academic teachers in universities as compared to the high school teachers in this study (and thus supporting their assertion that conceptions of teaching may be context-dependent). On the other hand, what merits some comment is that student-centered pedagogy (or the conception of supporting student learning) in the context of this study does not necessarily mean less teacher-talk or less teacher-directedness. Rather, student-centered pedagogy was more evident in how teachers constantly focused on students' learning as opposed to their own teaching - this was likewise observed in Pang's study (2006) involving teachers from Hong Kong. Thus, the perception that teachers' pedagogies were tools rather than the central focus of teaching might more clearly demarcate student-centered approaches from teacher-centered ones.

The subtle differences in meanings are worthy of attention, especially since the perception of the teacher as the "authoritative" figure and the "master" of knowledge is prevalent in Singaporean classrooms. Such a perspective could be argued to be a cultural perspective. It has the potential to influence teachers' conceptions of their teaching and their teaching practices. Interestingly, these perceptions also seem to have created some sort of "dissonance" amongst the teachers (although not reported in detail in this thesis). The teachers

appear to have the initial impression that a student-centered pedagogy would necessarily mean that it was less teacher-directed. Given the differences in meanings between literature; teachers' initial perspectives; and the meanings that have emerged out of this study, what is urged for are deeper reflections into these very meanings within the contexts of an Asian classroom. This also warrants further research headed in this direction. Such an appeal draws support from other researchers, such as Clarke (2006), who stressed on how cultural context would shape the implementation as well as the interpretation of classroom practices. In citing Huang's (2002) study, Clarke illustrated how practices in Chinese classrooms could be misrepresented when the absolute dichotomy of teacher-centered and student-centered characteristics were prescribed.

Pursuing a similar line of thought, Clarke's (2006) contention of the prevalent oppositional dichotomies – such as teacher-centered or student-centered dichotomy; and “to tell” or “not to tell” dichotomy, serves to further enrich the discussion here. Clarke's concern was that such dichotomies might result in the tendency to ignore the connectedness of the dichotomous categories, and to privilege one category over another. An important point to be made here is that while such a dichotomy was used in this current study, since they were prescribed by the participating teachers themselves, the experiences of the participating teachers could also be interpreted in ways that were advocated by Clarke – that a teacher's communicative act could be addressed in terms of “function” rather than form (Clarke & Lobato, 2002; Lobato, Clarke & Ellis, 2005). For example, the participating teachers' uncovering of students' conceptions and prior knowledge mirrors the function of “eliciting”; and how the participating teachers introduction of new ideas and concepts could be seen to be similar to the function of “initiating”. Clarke's deconstruction of the teacher-centered/student centered dichotomy, and his advocacy call to focus on the distribution of responsibility for

knowledge generation instead, shed even more light on my prior appeal to “re-envision” what good biology teaching could be. It would hence extend beyond merely re-interpreting what a “student-centered” approach to curriculum would look like, to include an “integrative perspective” (Clarke, 2006). Such a perspective has the potential to allow teachers themselves to reflect on their pedagogies in ways that would encourage an appreciation of the connectedness of the dichotomous categories, rather than merely privileging one over the other and thus constraining themselves. In doing so, teachers might experience, examine and improve their own teaching practices in even more liberating, empowering and enriched ways.

5.4.7 Implications for future research direction

The results of this study have demonstrated how teachers have learnt professionally through their participation in the learning study. However, as previously mentioned (in Section 5.3), a limitation of the current study was that the influence of the learning study on teachers’ learning about their own pedagogy could not be captured over a longer period of time. To further improve the design of this study and as a possible future research direction, how the learning study can influence teachers’ professional growth could be studied over a prolonged period of time. In the context of this study, and as an extension of it, another set of teacher interviews could have been conducted at the end of the academic year (approximately six months later), and/or even in the next academic year. Such a study is worthy of consideration, especially in view of its contribution towards the development of learning study as an approach for teacher professional development. In revealing the aspects and conditions that are pertinent for long-term teacher learning, the learning study can be improved towards being a more “sustainable” and effective approach.

Along a similar vein, literature reviewed appears to suggest a gap in published studies that focused on the second round of implementation of the learning study. Akin to action research models that have a cyclical or spiral nature, if learning study is to be recommended as an approach that schools can consider in order to develop their teachers, the learning study could more appropriately be viewed to have a cyclical or spiral nature. Thus, a study that details the organization and implementation of a second round of learning study, coupled with the influences it would have had on teacher learning and professional development, is worthy of consideration. This could also have been an extension of this current research study.

The current study also points to another possible area of research related to the employment of a learning study. Although not reported in detail in this thesis, during the interviews, the participating teachers have expressed aspects of the learning study that they thought would facilitate or discourage participation. Several areas of considerations that were highlighted direct much attention to the organization of the schools, which would involve school administrators. These considerations also extend to policy makers and the Ministry of Education. For example, the perception of lesson observations in Singaporean classrooms were often synonymous to assessments of teachers, whereby it is common practice for assigned reporting officers and school administrators to observe the lessons and assign grades to the teachers. The participants in this study have in fact expressed their initial concern regarding the lesson observations to be conducted – concerns tied to their prior experiences of lesson observations, which were laden with the baggage of teacher assessment. While the organization of lesson observations in this learning study was exemplary in how this aspect of teachers' professional lives could be experienced differently, what it also points to was the potential obstacles that could have discouraged participation in the learning study. Thus, this warrants the

attention of both school leaders and policy makers who are committed to the professional development of teachers. In other words, understanding and promoting teacher learning and professional development in the learning study context urges attention to be paid to the factors beyond the mere organization of a learning study.

In addition, heeding the advice of Fullan (2001), we “should avoid thinking of sets of factors in isolation from each other. They form a system of variables that interact to determine success and failure” (p. 71). Hence, considering that “the school context can impinge on a teacher’s professional growth at every stage of the professional development process” (Clarke & Hollingsworth, 2002, p. 962), more research devoted to elucidating the complex relationships between teacher professional learning within the learning study and their specific “complexity of educational settings” (Trigwell, 1994) is worthwhile. Such an endeavor has the potential to shed light on the intricacies and the deliberations that have to take place when one considers employing the learning study in specific educational contexts.

5.5 Social science research experience

The multiple roles (Pedretti, 1996) that I have played in this study have often resulted in some tensions and need for negotiations. I have played the role of a change agent to help encourage teachers to develop new ways of teaching genetics and to interpret the biology curriculum. I have also played the role of a coordinator that organized the meetings; as a group recorder that summarized and provided notes of the meetings. During the meetings, I have also played the role as a facilitator of discussions, as well as the “teacher” introducing the learning study and theory of variation. I have also served as the resource person who has provided relevant research literature. In addition, I served as a critic that would also be involved in the

evaluation of teachers' research lessons. I have also assumed the role of a researcher who has helped to analyze the student data and conduct the student interviews. I also analyzed teachers' experiences in participating in the learning study. Due to the arrangements of this learning study that employed theory of variation to frame the study, I also played the role of a designer who deliberately created conditions whereby teachers may experience different aspects of their professional lives in more enriched ways.

A constant challenge faced in implementing this learning study is the finding of a delicate balance between providing some guidance in terms of the direction of the learning study, and being open to uncertainties and changes. That while there is, indeed, no "simple recipe for when and how to act", for how far to allow teachers to decide where the program will go (Hardy & Kirkwood, 1994, p. 243), all the more it was demanded of me as a facilitator-researcher to have the wisdom and commitment to create conditions that would widen the space of teacher learning. The challenges faced were in fact exacerbated by the multiple roles I had to play, in view of how they may create conflicts in terms of purposes, foci and conduct. Literature has highlighted such challenges related to the different goals and roles within and between researchers and teachers (Arbaugh, 2003; Richardson, 1992; Wilson & Berne, 1999; Wong, 1995). In this study, the different roles could be appreciated as a "complicated endeavor" that demanded a bifocal attention on creating meaningful professional development and doing rigorous research (Wilson & Berne, 1999); between attending to "teaching" and attending to research (Brown, 1992).

Through the course of negotiating the multiple roles played and overcoming the challenges, what I found particularly helpful were the availability of research literature that

helped me, as a young researcher, make sense of these tensions. The literature also served to guide my implementation of the learning study and the analysis of the results. For example, McLaughlin's (2003) foreground of the researcher's emotions - that the research process can be a deeply emotional process for researchers, helped me make sense and "legitimize" my own feelings both when I was implementing the study as well as during the analysis of the data. With respects to the latter, McLaughlin also warned against "the emotional temptation to distort the material that does not fit, and so ignore the data that counteracts hypotheses or challenges values" (p. 72). McLaughlin advised researchers to work through the analysis by accepting emotions as valid and even helpful in illuminating the data. My lived experiences as facilitator-researcher in this learning study amplified this deeply emotional process. Nonetheless, McLaughlin's advice to accept emotions of frustration, confusion, disappointments and excitement as valid propelled me to organize and implement the learning study, as well as to analyze and report the data in a way that would honor the rigor and integrity required in research. In doing so, it also helped to sensitize me to deeper issues of contention, challenges and considerations of implementing a learning study.

Similarly, I found myself facing the same challenges as highlighted in other research studies. For example, teachers constantly cite the problem of finding time to undertake the research (Elliott, 1991), or would complain that the study was too long. What resonated with me was James and Ebbutt's (1981) sympathetic stance of teachers considering school-based research experience as optional (although desirable), and how teachers' perspective of time as a constraint was realistic, given the patterns of organization of curriculum. These served as constant reminders of how I should be respectful of the teachers' time, and to efficiently maximize their opportunities to learn.

The brief description of some of my experiences here serves to highlight some of the challenges I have faced. The messiness in research is commonplace for those who endeavor in the research enterprise. Accounts of these less than neat and tidy aspects of research have been documented in action research (e.g. Cook, 1998) and elsewhere. These works have served as valuable signposts foregrounding the considerations to be deliberated upon, and have helped me to make sense of my own lived experiences. However, research literature seems to present a gap in terms of the potential messiness in employing the learning study. Considering the great potential learning study has to be employed as a professional development approach, and considering how participants in this learning study have expressed how pivotal a researcher-facilitator was to further encourage their learning, these compel the adding of another dimension to the pre-existing literature on the learning study. That is, to include detailed descriptions of how learning studies could be organized and implemented, but not to stop short in highlighting the messiness in implementing such an approach. In doing so, it might encourage those of us who plan and implement the learning study to refute naivety, to be open-minded and empathetic, and to consider carefully what we advocate and encourage – as advocated by Fullan (1999). In heeding Fullan's advice, it also compels us to resist the temptation to over plan and to get used to a certain degree of uncertainty, to allow the messiness of a learning study to point the way forward.

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APPENDICES

Appendix A: Genetics questionnaire

The questionnaire probed for (1) aspects of genetics that teachers felt were important to teach, (2) challenges they faced in teaching the old genetics curriculum, (3) students' common areas of confusion, (4) how students made sense of genetics, and (5) the teachers' aims for teaching genetics. The questions crafted drew in part from teachers' responses in the first set of interviews conducted, and in part from research literature (Boulton-Lewis, Smith, McCrindle, Burnett & Campbell, 2001; Koballa, Gräber, Coleman & Kemp, 2000; Prosser, Trigwell & Taylor, 1994; Samuelowicz & Bain, 1992; Trigwell & Prosser, 1996, 2004; Wilson & Berne, 1999). The questionnaire has been reformatted.

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Learning Study and the Theory of Variation – Impact on Teacher Learning and Professional Development

Genetics Teaching - Reflection

Part 1

Described below are some dimensions of teaching genetics. For each dimension, indicate which choice better represents your thinking about genetics/science teaching. Provide a brief explanation or comment for your choice if you deem it necessary to explain your choice of answer.

Dimension 1: Control of Science Content

The content of teaching/ learning genetics is controlled by

- a. the teacher
- b. the students
- c. the stipulated syllabus

Dimension 2: Directionality of Science Teaching

Teaching genetics in class is

- a. predominantly a one-way transmission of genetics content from teachers to students
- b. a two-way teaching/learning process actively involving teacher and students

Dimension 3: Classroom Instruction

When teaching

- a. student understandings are considered as the starting point of instruction
- b. it is assumed that students have no or very little useful understandings of the content to be taught
- c. the learning outcomes stipulated in the syllabus are considered as the starting point of instruction
- d. Others aspects are considered as the starting point of instruction.

Please specify: _____

Dimension 4: Expected Outcome of Teaching

The outcome of teaching genetics is expressed in terms of students knowing

- a. more content
- b. different content

Dimension 5: Knowledge Utilization

The knowledge addressed in science class reflects the subject matter that students learn and

- a. apply within the context of the class
- b. use to make sense of the world around them

(Appendix A: Genetics questionnaire)

Part 2

Rank the options, with “1” being the most frequent. If the option is not applicable to you, omit ranking it. Provide a brief explanation or comment for your choice if you deem it necessary to explain your choice of answer.

1. I use questions mainly to...

- a. check for students understanding of genetics
- b. draw out their understanding of genetics so that I can: _____ (please complete)
- c. help students establish links within and between the topics
- d. encourage students to establish links with real-life phenomenon that is related to genetics
- e. help students learn/understand genetics concepts with greater ease
- f. generate interest in biology and the learning of it
- g. help students to question their own ideas
- h. others. Please specify _____

2. When teaching genetics in class, I feel it is important to...

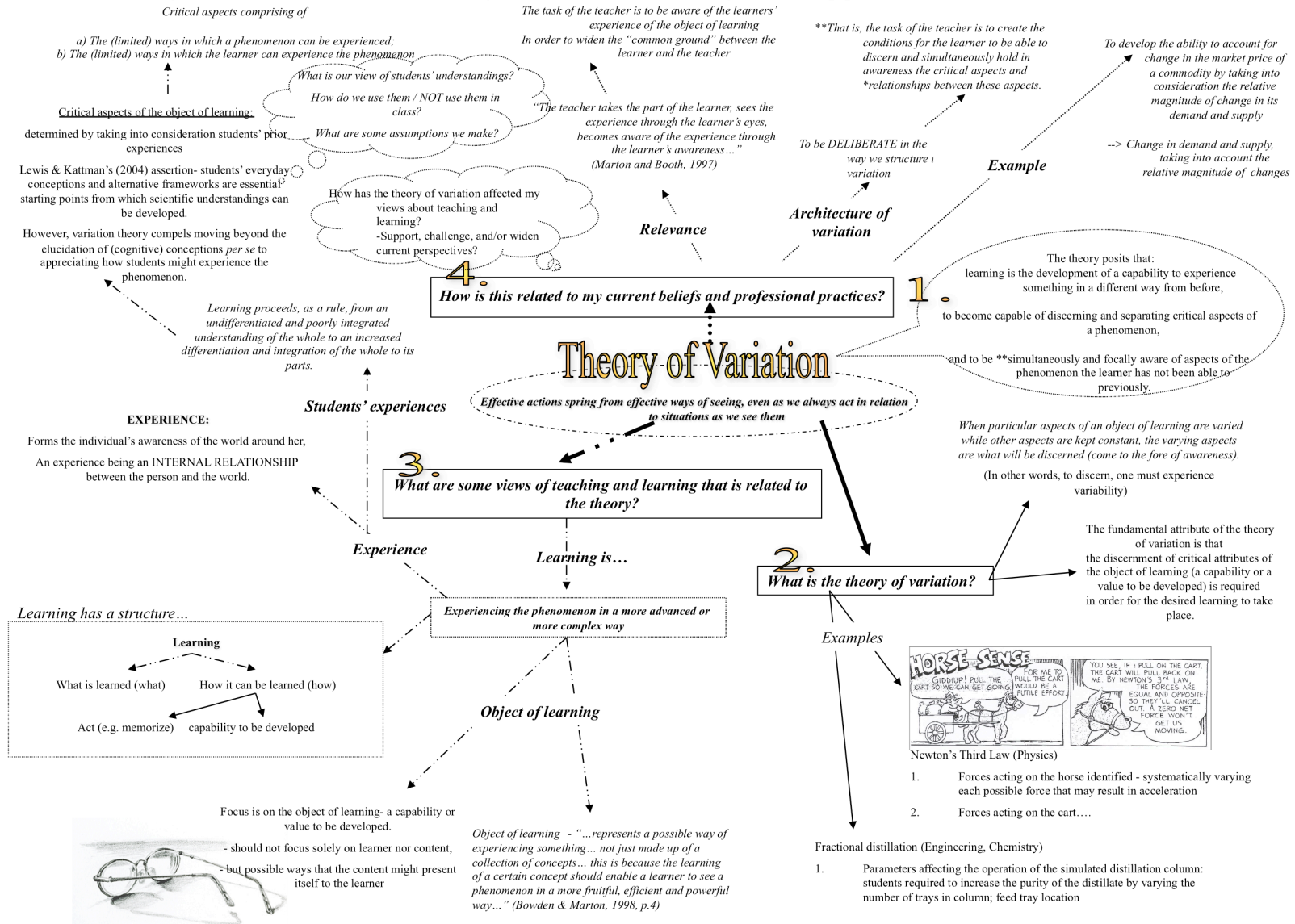
- a. present a lot of facts to students so that they know what they have to learn
- b. encourage students to restructure their existing knowledge in terms of the new way of thinking about the subject that they will develop
- c. structure the subject/content to help students to pass the formal assessment items
- d. know the answers to any questions that the students may put to me
- e. make available opportunities for student to discuss their changing understandings
- f. encourage students to generate their own notes rather than to always copy mine
- g. others. Please specify _____

3. The most important intended outcome of teaching genetics is ...

- a. to generate students' interest in genetics
- b. to help students develop the right terminology for describing and explaining genetics
- c. to allow students to see the relevance of genetics to their lives
- h. to enable students to explain genetics-related events in the world
- i. to help students understand and 'judge' reports of genetic-related issues made available through various media, such as the newspapers
- j. to enable students to be better prepared to answer the genetics questions in the exams
- k. to help students develop an understanding of the genetics content in the syllabus/textbooks
- l. to encourage students to want to learn more about genetics on their own
- m. to enable students to act in ways that are consistent with science
- n. to help students appreciate the beauty of life
- o. others: Please specify: _____

Appendix B: Introduction to theory of variation – Handout given to teachers

Increasing Students' Understanding of Genetics through the Application of the Theory of Variation



Appendix C: Handout highlighting students' understandings of genetics

Students' understandings of genetics, as revealed in research literature (e.g., Allchin, 2000; Lewis & Kattman, 2004; Lewis, Leach & Wood-Robinson, 2000a, b, c; Lewis & Wood-Robinson, 2000; Marbach-Ad, 2001, Nelkin & Lindee, 2004; Saka, Cerrah, Akdeniz & Ayas, 2006; Tsui & Treagust, 2004, Venville, Gribble & Donovan, 2005; Venville & Treagust, 1998, Wood, 1993), were highlighted. In this handout, most of the references were deliberately excluded, in view that the participating teachers have expressed some reservations towards large amounts of citations – a point raised in the pre-learning study meeting. The handout has been reformatted.



Learning Study and the Theory of Variation – Impact on Teacher Learning and Professional Development

Student perceptions and understandings of genetics as revealed in research journals and articles 2

Some key findings:

- Genetics has been widely identified as difficult to learn, especially:
 - (1) understanding phenomena involving small and often hidden entities
 - (2) the different levels of organizations, necessitating an understanding of mechanisms and interactions at the macro, micro and molecular levels
 - (3) the differences between the levels of genetic phenomena
- Some studies advocate the teaching of regulatory genes (gene switches), mutation, and polygenic, multifactorial traits with the intent to address possible gaps in understandings while approaching genetics in a more holistic way.
- A recurring theme that is consistent with literature is that students' understanding of genetics revolves around the notion of heredity, of traits (phenotype) and the structural aspects, rather than the functional aspects which would have brought to the fore gene expression and protein synthesis. While students may have some idea of the structure of chromosomes, DNA and genes, the structural relationships between the biophysical entities may not always be clear
- "... what is obvious to geneticists, but not to many of these students, is that both genes and DNA, essentially being the same thing, influence our genetic makeup..." (Venville, Gribble & Donovan, 2005, p. 625).
- The challenges are exacerbated by the poor organization of subtopics in genetics and related topics within the textbook; and the time gaps between the teaching of related topics which are important for the building of a coherent conceptual framework such that there is "little opportunity to bring the disparate pieces together to give a holistic overview or to make the relationship between topics explicit" (Lewis & Wood-Robinson, 2000, p. 190).

(Appendix C: Handout highlighting students' understandings of genetics)

Students' understanding of the structural aspects of genes, DNA and chromosomes

Question	Student perceptions and understandings
Rank the following in terms of their sizes: Cell, chromosome, gene, DNA, organism, nucleus	Genes are larger than chromosomes. Students showed an extensive lack of appreciation regarding the relative sizes of the structures (suggesting also a lack of understanding of the relationships between the structures).
Where are genes found?	Students might be unclear of the location of genes. Students had no recognition that genes had a specific location (concept of a gene locus) Few students were aware that DNA is found throughout the body.
Where, in your body, is DNA found?	
Where are chromosomes found?	
Are there chromosomes that do not contain genetic information?	This is the perception of some students.
What are genes made of?	The connection between genes and DNA with nucleotides was rarely made by students.
What is DNA made of?	Common alternative conception that DNA is made of proteins, since they consist of bases that codes for proteins. "Scientists used to believe that genetic material was made of proteins because its basic structure, consisting of 20 amino acids, could be arranged in different sequences." (Marbach-Ad, 2001, p. 186) Some students thought that DNA is made of chromosomes, or that DNA is a piece of gene.

Students' understanding of the functional and structural aspects of genes, DNA and chromosomes.

Question	Student perceptions and understandings
What do you understand by the term "genes"?	Students' conception of genes focused on the structural aspect of genes rather than the functional aspects. Some students viewed genes as particles (passive particle gene and/or active particle gene rather than sets of instructions that make proteins. (That is, an absence of association of gene with a product (protein) or with protein synthesis in students' conceptions.) Other studies suggested that there were a moderately high proportion of responses indicating an instructions view of genes. However, students did not think of genes as coding exclusively for proteins. Students' conception of gene as a physical trait/character. This is indicative that students failed to differentiate between a gene (micro level) and the trait it determines (macro level). Also, this hinders the development of the understanding that environment can influence they physical development of an organism. While students can comment that genes determine traits, they could not explain it coherently.

(Appendix C: Handout highlighting students' understandings of genetics)

Question	Student perceptions and understandings
Why are genes important?	<p>Attribution to determination of characteristics more common than to the transfer of information. However, there seems to be an unawareness as to how a gene might determine a characteristic, that is, there is a lack of appreciation that there is a product associated with a gene.</p> <p>View of genes as structure rather than information.</p> <p>Very few students held conceptions about gene affecting cell development.</p> <p>Lack of appreciation that two genes (a pair of gene) control each feature; and that some features are controlled by several pairs of genes.</p>
What is the difference between gene and gene expression?	<p>Students showed little understanding of the difference between gene (chemical sequence) and the effect of the gene (its expression as a characteristic or trait).</p>
What do you understand by the term "DNA"?	<p>DNA was more frequently connected to traits than to proteins. So erroneously thought that DNA is made of protein.</p> <p>Some students thought that DNA is made of chromosomes, or that DNA is a piece of gene.</p>
Why is DNA important?	<p>Students thought that the primary function of DNA is for identification.</p> <p>Few would mention the production of proteins.</p> <p>Students often failed to make connections between concepts such as DNA structure, the genetic code, and the characteristics or phenotype of an organism.</p>
What are chromosomes?	<p>Students' lack of understanding of chromosomes – what they are and what they do. There is also a tendency to focus on the structural aspects rather than functional ones.</p> <p>Some students did not recognize the relationship between genetic information and chromosomes.</p> <p>Some students erroneously think that chromosomes are segments of DNA.</p> <p>Chromosomes consisting of a single double-stranded DNA molecule are the kind of chromosomes that are present in haploid cells, and Chromosomes consisting of double –stranded DNA molecules or chromatids are the kind of chromosomes that are present in diploid cells.</p>
What is the relationship between DNA and genes?	<p>**Studies revealed that there were often no clear understanding between genes, DNA and chromosomes. Also, terms were often used interchangeably.</p> <p>Some students think of DNA and genes as different structures.</p>
Differentiate between genes, DNA and chromosomes.	<p>Lack of understanding that DNA and genes, "essentially being the same thing, influence our genetic makeup, and make organisms similar to, and different from, other organisms" (Venville et al., 2005, p. 625).</p>

(Appendix C: Handout highlighting students' understandings of genetics)

Students' understanding of genetics.

Question	Student perceptions and understandings
Which of the following are living things? Trees, Ferns, Mammals, Viruses, Fungi, Bacteria, Insects	Some students are unaware that genetic information is found in all living things.
Which of the following contains genetic information? Trees, Ferns, Mammals, Viruses, Fungi, Bacteria, Insects	
Explain if the following statements are true or false: There are male and female chromosomes. The male chromosomes are found in the sperms and the female ones in the eggs.	Some students have this perception.
How do genes get passed from parents to offspring?	Few students mentioned that genes are passed through sexual intercourse/reproduction.
Explain if the following statements are true or false: When cells reproduce, chromosomes are shared out.	Students believed that chromosomes and/or genetic information is shared out but not copied.
I have come to know more about genetics through the following sources: <ul style="list-style-type: none"> ○ Lessons in class ○ Science textbooks ○ Other books ○ Television programs ○ Movies ○ Conversations with friends, parents, etc. ○ Others 	Nelkin and Lindee (2004) termed some sources in which students draw notions of genetics from as "low culture" sources, in which canonical scientific understandings may not be represented.

Students' understanding of heredity.

Question	Student perceptions and understandings
Why do most people look like their parents?	Students' explanation of the heredity of traits involved the transfer of unchanged features (traits or genes) from one generation to the other. However, there is a lack of understanding that chance determines what genes/features the offspring will have
Why do you look different from your friends?	Some students are unable to link protein synthesis and an organism's phenotype. Students are unaware of sources of variation (genetic or environmental).
If you resemble your mother more than your father, did you get more genes from your mother? Explain.	Some students thought that the parental contributions of hereditary are unequal. Lack of appreciation that gametes carry one chromosome and one gene from each pair, that is, that the sperm and egg each carry one gene.
Explain why the following sentence is true or false: Within the body, different types of cells would contain different genes.	Students faced the difficulty of appreciating that each cell has a full complement of genetic material. A common view is that cells only contain the genetic information or chromosomes they need in order to perform their function.

(Appendix C: Handout highlighting students' understandings of genetics)

Gene concept: (in progressively more sophisticated models of genes)

Passive Particle Gene:

Gene as particle- like (image of genes as some kind of particle). Passive view of genes: what happens to the genes is more important than what genes do. E.g., "Genes are passed down from generation to generation".

Active Particle Gene:

Saw genes as controlling characteristics. The conception, however, still consider genes to be a particle of some kind.

Sequence of Instructions Gene:

Saw genes from being particle-like to being like a sequence of instructions. E.g., DNA or chromosomes store information; consist of a code for determining characteristics.

** However, the idea that a gene is a particle need not necessarily be discarded. Rather, that some students looked within the particle-like gene to see it as a sequence of instructions or a code or store of information.

Productive Sequence of Instructions Gene:

Connection between genes and protein synthesis, and protein synthesis and an organism's phenotype.

More conceptions related to gene expression:

"The students seemed to prefer a Mendelian explanation of how genes express themselves and neglected, ignored, or simply did not understand or know the microscopic, process-related idea that genes are a message coded in the DNA and expressed through protein synthesis" (Venville & Treagust, 1998, p. 1045)

"Mutation, for example, or genetic engineering is a fascinating and sensational topic for discussion; but what opportunity do students have for understanding the concepts involved if they do not understand what genes do, but only have an understanding of genes being particles?" (Venville & Treagust, 1998, p. 1053)

Using mutation to increase an understanding of gene expression:

"...students need to be encouraged to reconsider their perception that gene and trait are equivalent... Using sickle cell anaemia as an example, the key points would be as follows:

- There is a small change in the structure of one gene
- This results in the production of an unusual sort of haemoglobin.
- This unusual haemoglobin changes the shape of red blood cells, making them less efficient at carrying oxygen around the body.

Such an approach might also begin to shift the focus of students' thinking from phenotype to genotype.

Once students begin to understand that gene and trait are not equivalent... they will be in a better position to recognize the need for a mechanism by which genes can be expressed in the phenotype. They may then be more receptive to teaching about the concepts of transcription, translation and the chemical nature of genes and their products." (Lewis & Kattmann, 2004, p. 203)

Dominance and recessiveness as the presence or absence of a trait, protein or gene product, that is, the phenotype can be switched on or off. (See "Mending Mendelism")

From the students' perspectives:

Students are attracted to answers at a level of generality that is most familiar to them, i.e., answers which require the fewest mental steps to verify. This may explain why students are more familiar with structural and compositional relationships than with coding relationships, which require more cognitive steps.

The teaching of genetics in schools emphasizes the genotype whilst the child builds her concepts around the phenotype.

Appendix D: Student pre-lesson test

The student pre-lesson test drew primarily from a sample pre-test (used for a pilot study by the researcher), as well as handouts given to the teachers showing sample questions. The questions used in the pilot study drew from research literature (Duncan & Reiser, 2007; Lewis & Kattmann, 2004; Lewis, Leach & Wood-Robinson, 2000a, b; Lewis & Wood-Robinson, 2000; Marbach-Ad, 2001; Martins & Ogborn, 1997; Nelkin & Lindee, 2004; Saka, Cerrah, Akdeniz & Ayas, 2006; Tsui & Treagust, 2004; Venville, Gribble & Donovan, 2005; Venville & Treagust, 1998; Wood, 1993). The test has been reformatted.

Students' Understandings of Genetics

This activity serves as a way for biology teachers to better understand how you experience the topic of genetics.

*Please note that this is **NOT a test**. This activity has no consequence on the marks you will obtain in your formal assessments.*

*Please **do NOT refer** to the textbook, internet or other resources for your responses. The main objective is to uncover what you understand, and we are by no means merely looking for correct answers.*

Thank you very much.

Genes

I have never heard of genes ☐

I have heard of genes but don't really know what genes are ☐

I have heard of genes and could say something about genes ☐

Now if you can, please answer the following questions. If you can't answer a question, please put a cross beside it.

1. What do you understand by the term "genes"?
2. Why are genes important?
3. What is the connection between proteins and genes?
4. Where, in your body, are genes found?

DNA

I have never heard of DNA ☐

I have heard of DNA but don't really know what DNA are ☐

I have heard of DNA and could say something about DNA ☐

Now if you can, please answer the following questions. If you can't answer a question, please put a cross beside it.

5. What do you understand by the term "DNA"?
6. Why is DNA important?
7. Where, in your body, is DNA found?

(Appendix D: Student pre-lesson test)

Chromosomes

I have never heard of chromosomes ☐

I have heard of chromosomes but don't really know what chromosomes are ☐

I have heard of chromosomes and could say something about chromosomes ☐

Now if you can, please answer the following questions. If you can't answer a question, please put a cross beside it.

8. What do you understand by the term "chromosomes"?

9. Why are chromosomes important?

10. Are there chromosomes that do not contain genetic information? Explain.

11. Where, in your body, are chromosomes found?

Genes, DNA and Chromosomes

Now if you can, please answer the following questions. If you can't answer a question, please put a cross beside it.

12. Rank the following in terms of their sizes: cell, chromosome, DNA, gene, nucleus, organism
Largest Smallest

13. What is the relationship between genes, DNA and chromosomes? (Include, also, the differences between them.) ***Please provide details if possible.***

14. If you were reduced down to a very small size and you could walk around your genes, what do you think you would see? ***Please provide details if possible.***

Gene expression, transcription and translation

I have never heard of gene expression ☐

I have heard of gene expression but don't really know what gene expression is ☐

I have heard of gene expression and could say something about gene expression ☐

I have never heard of transcription ☐

I have heard of transcription but don't really know what transcription is ☐

I have heard of transcription and could say something about transcription ☐

I have never heard of translation ☐

I have heard of translation but don't really know what translation is ☐

I have heard of translation and could say something about translation ☐

(Appendix D: Student pre-lesson test)

A Case Study

Most bacterial cells can sense and respond to substances in their surroundings. For example, if you put bacteria near food substances (sugar) they will sense the food and move towards the food; if you put them near poisonous substances they will sense the poison and move farther away from it. *The ability for bacteria to sense and respond to substances is traced back to a special gene found in the bacteria.*

In some bacteria, this special gene is changed and the bacteria can no longer sense substances in their environment. These bacteria therefore are more likely to die from starvation or poisoning.

*Now if you can, please answer the following question. If you can't answer the question, please put a cross beside it. **Please provide details if possible.***

15. Using your knowledge of genetics, suggest how/why the change in the special gene can cause the bacteria to die. Provide details to your explanation.

Appendix E: Handout summarizing key results of students' pre-lesson test and interviews

(The handout has been reformatted.)

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Learning Study and the Theory of Variation – Impact on Teacher Learning and Professional Development

Main Points emerging from Students' Pre-lesson Test and Interview

Gene Conception

1. P (from pre-test), I (from interview): Popular conception: Genes are important for the a. *determination of characteristics* or b. *to pass on/inherit parent's traits (theory of kinship)*, although students lack an appreciation for the processes (transcription, translation) involved.
 - a. Students often *fail to differentiate traits as phenotype from the behavior/character* of a person (what the person likes, etc.).
Few are able to draw on ideas that some characteristics are also attributed to non-genetic factors like the *environment*.
 - b. Some students appreciate that genes need to be passed on for the “survival of the species”, that is, from an *evolutionary perspective*.
2. I: When students are probed for their understanding of how genes essentially result in the traits, some students displayed their ideas about *dominance; alleles* (although term was not mentioned at all), although not always accurate.

**I: What is also noteworthy is that while some students are able to describe transcription and/or translation, they are often unable to apply it into the context of determination of traits, determination of gender, mutation or even to the case study, that is, to genetic phenomenon.
3. P: Most students view genes as *active particles determining characteristics*, while some of them view genes as passive particles that is trait-bearing, or as sequence of instructions that determine the characteristics. Very few are able to appreciate that these sequence of instructions results in proteins being formed (genes as productive sequence forming proteins).

I: It has been observed that while students hold a particular conception of genes, not all of them were able to apply them to different contexts. Hence, the ‘knowing’ of a particular conception does not necessarily mean that students are able to apply it to a particular question.

DNA Conception

1. P: Popular conception: Appreciation that DNA contains *genetic information*, although few are able to associate this information with nucleotide sequences.

I: While students may mention that biophysical entities like DNA may contain genetic information, the interview reveals that *not all of them have an idea of the nature of the genetic information*. Hence, while they may still hold the conception that gene is a trait-bearing particle despite being able to mention that DNA contains/is information, without making the connection that it is essentially the information that determines the traits.

(Appendix E: Handout summarizing key results of students' pre-lesson test and interviews)

I: Of interest is a student who defines genetic information from a functional aspect rather than solely from the structural aspect. This student defines genetic information as the part of the DNA that codes for something useful, separating it from “junk DNA” which “doesn’t seem to serve any function”. – “Genetic information will be useful for doing something”.

- Consideration to include the notion of “junk DNA”? – that there are parts of the DNA which does not code for proteins. What might be helpful is to help students appreciate that these parts also contain nucleotides as well, which seems to be a missing conception.

2. P: Popular conception: DNA is important for the *determination of characteristics* but, again, students lack the appreciation for the processes (transcription, translation) involved.
3. P: Students’ understanding of DNA tends to revolve around “macro” processes and genetic phenomena, and its structure (double-helix) rather than its function at the molecular levels.
4. I: Students’ view of DNA might be affected by *movies*, etc. Hence, the close association of DNA with fingerprints and the function of identification or to make one unique. This may be problematic as students tend to separate the function of DNA from the rest of the biophysical entities.
5. I: Common *confusion* between DNA replication and transcription.
6. I: One student mentioned about DNA being *damaged by UV rays*, that “DNA has these caps at the end that can like unravel...”.
7. I: Students seem to be less sure that *plants* contain DNA. One student mentioned that *viruses* do not contain DNA but RNA as it is not exactly living.

Chromosomes

1. P, I: Popular conception: Chromosomes involved in the *determination of gender; determination of characteristics; number of chromosomes* found in human beings
2. I: Some students appreciate that chromosomes are important for cell *division/meiosis/mitosis*, although the interviews revealed that there is a lack of differentiation between sexual reproduction and meiosis.
3. P, I: Increased mention of chromosomal *mutation*, although there is little evidence of the differentiation between gene mutation and chromosomal mutation. Students seldom relate mutations to molecular processes, although few of them were able to explain about the changes in sequences in gene mutation.

I: Some students revealed *confusion* between mutation and “genetic modification” whereby foreign genes may be deliberately inserted into an organism.
4. I: Chromosomes-related genetic phenomena like determination of gender and mutation – students seem to have *difficulty explaining these phenomena using the gene or DNA level*.
5. P: While student often mention that chromosomes contain genetic information, few have explained what this genetic information is, or have linked it to DNA and genes.

(Appendix E: Handout summarizing key results of students' pre-lesson test and interviews)

Relationship between Genes, DNA and Chromosomes

1. P: The focus is often on the *structural relationships* (which contains another), although only 28% were able to give the correct sequence in terms on the relative sizes of cell, chromosome, gene, DNA, organism and nucleus.
2. P: While some students mentioned that they are hereditary material, the extension of the relationships to functional aspects was very rare.
3. I: Some students indicated their confusion. Some attributed it to the “loose” *terminology*, while others to the fact that the concepts exist as *disparate pieces of information*.

Transcription and Translation

1. I: Some students, when probed, reveals their ideas about transcription and translation, although there might be confusion between transcription and DNA replication.
2. I: The interviews also revealed that while students indicated that they have heard of transcription and translation, they may have erroneously regarded other processes as such, and that their understandings are often incomplete.
3. I: Some students think that proteins are formed not as a result of gene expression, but that one of the many possible actions resulting from genes being coded is the formation of proteins. Several others could not adequately describe what the proteins are for, hence falling back on the idea that our body is made up of proteins.
4. I: The inaccurate/incomplete conceptions of the molecular processes might have hindered a more holistic understanding of the relationships between traits and genes/DNA.
5. I: Another point of consideration is that some students revealed ideas about gene *regulation*, while others seem to think that different cells contain different genes. Should the ideas of gene regulation, then, be introduced?

A Case Study

1. P: Essentially, 84% of the students could not answer the question
2. P: 13% of the students' ideas revolve around the notion of information, that the change in the gene would *hinder the transmission of some form of information/signals*. Almost none of the students related this to transcription or translation.
3. P: 3 of the students mentioned about “quorum sensing”, but were not able to link it to gene expression.

I: One out of these three students were able to explain the case study using ideas of transcription and translation. When asked why they were not included in the pre-test, the student indicated that *she didn't think, then, that the processes were relevant.*

****Does this support the importance of allowing students to discuss and articulate their understandings during lessons, which help them to clarify and to draw relevant pieces of information to form a more coherent whole of genetic phenomenon studied?**

Appendix F: Example of post-lesson conference meeting notes

Key points discussed during the post-lesson conferences were noted. The teachers were given a handout jotting these key points after every meeting. The handout has been reformatted. The actual names of the participating teachers are substituted with pseudonyms.



Meeting 3: Evaluation of Amy's Lesson 2 (Transcription, Translation and Mutation)

- Chris: Using of the video animation to understand the process of transcription and translation. The first time when the animation was played, it allowed students to recall what they know or have learnt previously. (**Principle of "common ground"*) The second and third time round, students were granted opportunities to fill in the gaps and to make linkages.

Amy: **Intended and Enacted learning:*

1st time round: removal of sound to enable students to not be bogged down by the terms, but rather, for them to appreciate what is going on (the changes that were taking place).

2nd time round: Layering of details to the basic ideas that they would have as to what was going on, including the recognition and application of terms.

3rd time round: To consolidate learning, and to check for misinterpretations.

(**Architecture of Variation, Establishing whole-parts relationships*)

Researcher: What Amy has done is also another way to use variation theory (similar to the case study in the handout whereby the teacher also used a video to help students pay attention to different aspects).

Amy and Researcher, as elaborated by Chris:

**Comparing the intended and enacted object of learning with students' lived experiences:*

1st time round: Students already trying to use the terms to make sense of the animation.

2nd time round: Checking and layering of details.

3rd time round: To consolidate learning, and to check for misinterpretations.

Researcher:

The slight differences in what the students were attending to the first time round leads us to consider how we can, right from the start, enable students to use the terms they know more effectively. (**Teacher and students directed to the same critical aspects? Principle of "common ground".*)

Another point, which was raised by Chris' students, was that animations were an effective way to help them visualize the processes. However, it was important that they knew what to look at, and what the objects were, which, if erroneously identified, could lead to further confusion.

Hence, we might want to consider pointing to some of the objects concurrently when the animation was played (as observed in Pam's class). One could also freeze the frames to highlight the key ideas, as Chris did in his class. (**Teacher and students directed to the same critical aspects; Principle of "common ground".*)

(Appendix F: Example of post-lesson conference meeting notes)

- Researcher: Do students know where transcription ends and translation starts? Could that be more apparent in the video, or when explaining the process on the board subsequent to watching the animation?

Amy: Was even considering doing the reverse: explaining the key concepts on the board before screening the video. In this case, she could comfortably use the terms transcription and translation when screening the video.

Researcher: How about putting this explanation segment before the third screening of the animation instead?

Kate: Reiterated the need to extend the idea of proteins formed to how they eventually lead to the determination of traits. The challenge, however, is the constraints of time. Hence, it is dependent on what the focus of the lesson for that day was.

Researcher: Ultimately, we want to help them deepen their understanding on gene expression, and address the inadequate conception that proteins = traits.

Pam: When teaching about mutation (sickle cell anemia), Amy used an excellent slide showing the changes that occur at the gene level, cellular level, leading up to the “traits” level. (**Variation in the levels in which mutation can be understood*)

That could help students to link the proteins formed to traits. (And Pam intends to use it.)

Everyone agreed.

- Researcher: Introduction of Down Syndrome focused on chromosomal level and macroscopic level (traits) rather than how the extra chromosomes affect the molecular processes related to gene expression. (**Architecture of Variation*)



3.3. Meeting 3 – 13th April 2009: Evaluation of Pam’s Lesson 2 (Transcription)

- Pam: Wanted students to know what proteins do (from genes to polypeptides), to introduce the complexity.
- Pam: Use of video: first time round for students to just “look at it” (holistic manner), and to layer it with the details later on. (**Architecture of Variation*) However, because the sound wasn’t working, she explained the details the first time round, which wasn’t her preference. She also wanted to address some of the questions that students have, leading to her adding more details than is needed.

Researcher: What might be effective is to give them the key points first. And then layer it with the details later. This was what Pam has done when she mapped out the key concepts on the board prior to showing the video. This just might encourage the kinds of learning we are targeting at. (**Architecture of Variation*)

- Pam: In the next lesson, looking into completing transcription and translation before introducing mutation. Will focus on helping students understand how genes code for proteins (focusing on the importance of gene sequences). When teaching mutation as a way to vary the code, Down syndrome will not be used as an example. Will focus on changes in the nucleotide sequences and varying that instead. She intends to employ a “Name” game, which is similar to the “Scrabble” game that Chris has used.

(Appendix F: Example of post-lesson conference meeting notes)

- Chris: Students were presenting analogies to show the relationships between genes, DNA, chromosomes, nucleus and cells at the beginning of the lesson. Chris noticed that the students were focusing on the physical (structural) aspects, and have seemingly omitted the functional aspects. (**Architecture of Variation*)

Researcher: Agrees with Chris that the functional aspect could have been weaved more powerfully into the exercise, especially since analogies have been used widely in the teaching of genetics, and proven to be effective (as reported in research findings). Pam's constraints for time, however, has indeed posed a challenge.

Chris: Because the analogies were varied, Pam could have given them an analogy to work on, to further establish the functional relationships between the entities. So they have a similar analogy to discuss about.

Pam: Students were supposed to work on the analogy of the book to show the functional aspects. And come up with an analogy of their own as well. However, due to the shortage of time, she focused the presentations on their own analogies, as a way to check their analogies. (**Architecture of Variation: Using varied analogies helps students explore the various ways in which they experience the structural relationships between the entities. This, in fact, is another way in which variation can be employed- as expanded on in the paper given showcasing the learning of Mathematics using students' answers – "Postman Route".*)

Pam brought in the analogy of the book – to show the coding and non-coding sequence. Some of the ideas were borrowed and modified from Chris' slide.

Chris: The book analogy could be extended to the library.

Researcher: Quite sure that the coding and non-coding concept was well grasped. However, as the pace of the lesson was a little fast, she's not sure if students fully grasped the functional relationships through the book analogy. (**Comparing the intended and enacted object of learning with students' lived experiences*)

Pam mentioned some of the difficulties students faced, as illustrated in some of the analogies students came up with, which didn't even exemplify the structural relationships Pam highlighted some of these problematic analogies (from other classes) to the class.

Researcher: Brilliant that Pam showed the students where the analogies broke down. (This in fact is also 'variation'.) (**Architecture of Variation*)

The post-lesson test had identical key questions to the pre-lesson test, with the questions arranged in a slightly different order. There was also an inclusion of an additional question that probed for students' understanding of the relationship between the structural and functional aspects of genes (under "Students' Understandings of Genetics (2)"). The post-lesson test has been reformatted.

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(Appendix G: Student post-lesson test)

Chromosomes

*Now if you can, please answer the following questions. Whenever possible, **please provide detailed answers** to demonstrate what you understand. If you can't answer a question, please put a cross beside it.*

5. What do you understand by the term “chromosomes”?
6. Why are chromosomes important?
7. Are there chromosomes that do not contain genetic information? Explain.
8. Where, in your body, are chromosomes found?

DNA

*Now if you can, please answer the following questions. Whenever possible, **please provide detailed answers** to demonstrate what you understand. If you can't answer a question, please put a cross beside it.*

9. What do you understand by the term “DNA”?
10. Why is DNA important?
11. Where, in your body, is DNA found?

Genes

*Now if you can, please answer the following questions. Whenever possible, **please provide detailed answers** to demonstrate what you understand. If you can't answer a question, please put a cross beside it.*

12. What do you understand by the term “genes”?
13. Why are genes important?
14. What is the connection between proteins and genes?
15. Where, in your body, are genes found?

(Appendix G: Student post-lesson test)

Students' Understandings of Genetics (2)

This activity serves as a way for biology teachers to better understand how you experience the topic of genetics.

Please note that this is NOT a test. This activity has no consequence on the marks you will obtain in your formal assessments.

Please do NOT refer to the textbook, internet or other resources for your responses. The main objective is to uncover what you understand, and we are by no means merely looking for correct answers.

Thank you very much.

Now if you can, please answer the following question. If you can't answer the question, please put a cross beside it.

1. What is the relationship between traits, genes, transcription and translation? ***Please provide details if possible.***

Appendix H: Documentation of good practices – handout given to teachers



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Learning Study and the Theory of Variation – Impact on Teacher Learning and Professional Development

DOCUMENTATION OF EFFECTIVE ORGANIZATION (PLANNING) AND IMPLEMENTATION OF STUDENT LEARNING EXPERIENCES

Object of learning: To develop the capability to understand key ideas around gene expression, and to be able to apply them in various genetic phenomenon

No.	Strategies / Practices (How was variation theory used?)	Evidence supporting the degree of effectiveness of practice; Suggestions to make practice even more effective (anecdotal, pre- and post-test results, student interviews) (How did the focus on various critical aspects through deliberate foregrounding of them help students learn? What could possibly be learnt?)	Other comments
E.g.	<p>Chris' Class:</p> <p>Aim: To help students to apply concepts of transcription and translation into the context of mutation, in order to help them reinforce the key ideas in gene expression, while helping them to develop the capability to apply the concepts in the context of mutation</p> <p>Strategy: Using the scrabble game to help students develop the appreciation that changes in nucleotide sequences can result in changes in traits (mutation)</p> <ul style="list-style-type: none"> - Students were asked to form words using letters they picked, as they would in a scrabble game. Aspect focused on: Sequence of 	<p>Supporting Evidence:</p> <ol style="list-style-type: none"> 1. From the interviews, students commented that the game was effective in helping them understand the importance of nucleotide sequences in forming genes, and how changes in them are important as they can lead to mutation 2. From the post-test (mutation case study): decreased number of students using a macromolecular view to explain the changes in bacteria. Also, more students are able to explain how the gene changes – changes to gene copies or nucleotide sequences (26%), and/or appreciate that an incorrect amino acid sequence or protein is 	

(Appendix H: Documentation of good practices – handout given to teachers)

	<p>letters, like nucleotides, are important in forming words, equivalent to nucleotides sequences forming genes that can be coded.</p> <ul style="list-style-type: none"> - Students were then asked to replace letters to disrupt the words (See appendix for details). Aspect focused on: Changes in letters, like changes in the nucleotide sequences, results in non-sensible words, just as the latter leads to mutation. - Subsequently, case studies were used to further strengthen students' understanding that changes in nucleotide sequences and or gene copies can eventually result in changes in traits. 	<p>produced (48%).</p> <p>How could this be improved:</p> <ol style="list-style-type: none"> 1. During the powerpoint presentation, although the changes in mRNA and proteins were mentioned, they could have been highlighted even more, especially since these are the critical aspects of the object of learning as well. The lack of explicit mention of changes in transcription and translation may explain why some of the other students (some amongst 74%) did not include how the gene in the bacteria could have changed. 	
No.	Strategies / Practices (How was variation theory used?)	Evidence supporting the degree of effectiveness of practice; Suggestions to make practice even more effective (anecdotal, pre- and post-test results, student interviews) (How did the focus on various critical aspects through deliberate foregrounding of them help students learn? What could possibly be learnt?)	Other comments

(Appendix H: Documentation of good practices – handout given to teachers)

Other points to note:

Evaluation of Curriculum Flow:

Review of the Critical Aspects of the Object of Learning:

Appendix I: Overall reflection– handout given to teachers

(The handout has been reformatted.)

My experiences in the learning study...

How did my experiences in this learning study affect the learning about my own pedagogy?

-So what did I learn? How has the learning study impacted my teaching? How have I been professionally developed?

-How did I experience my own learning as professional development?

-How was my pedagogy affected by my experiences in this learning study?

- What does it mean to learn as a teacher?
- What is professional development to you?

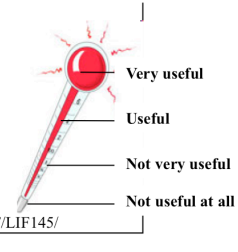
1 My beliefs about teaching and learning biology...

Opportunity to articulate and reflect on your beliefs about teaching biology, and students learning biology.

Were there new insights that emerged from the opportunity to share your beliefs? What were they?

How useful was the opportunity given to articulate and reflect on your beliefs about learning and teaching biology?

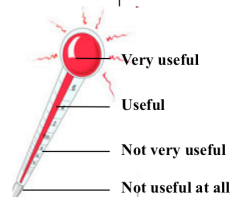
How else did the experience allow you to learn, or impacted your professional development?



<http://www.fotosearch.com/bthumb/LIF/LIF145/PDB07011.jpg>

http://www.dnamnd.med.usyd.edu.au/DNA_logo.jpg

2 Introduction to the Theory of Variation...

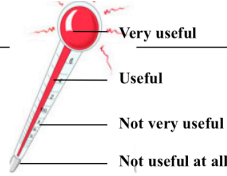


How did the introduction of the theory support, widen, or challenge your beliefs about teaching biology?

How did the introduction of the theory support or challenge some of your teaching practices?

(Appendix I: Overall reflection– handout given to teachers)

▪Emphasis on a specific capability rather than the syllabus to be taught.

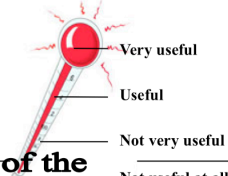


The pre-lesson tests and interviews were used to help elucidate students' pre-ideas. The results helped to support some of the challenges we thought students might have faced learning the topic, while ascertaining some of their pre-conceptions that we might want to address.

How did this aspect of the learning study impact your teaching or beliefs about teaching the topic?

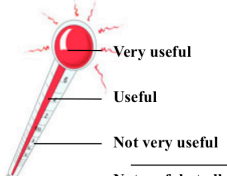
What were your experiences in this part of the learning study that allowed you to learn, or impacted your professional development? What did you learn?

3 Determination of the object of learning...



5 Analysis of pre-lesson tests and interviews

4 Determination of the curricular flow...



The curriculum flow in genetics in part helped us to map out the different subtopics and the relationships between the subtopics. It also helped us to get a big picture of what we were going to teach in the whole topic of genetics.

In doing so, we were also able to derive what we thought were the key concepts students required in order to learn the individual subtopics effectively, while being able to establish links to help them experience genetics in a more holistic way.

What were your experiences in this part of the learning study that allowed you to learn, or impact your professional development? What did you learn?

How did your experiences in this part of the learning study impact your pedagogy?

How helpful was it to determine the curriculum flow collectively?

How helpful was it to be able to derive the fundamental concepts and hence capability that we wanted students to acquire through the process?

(Appendix I: Overall reflection– handout given to teachers)

Although the critical aspects and pattern of variation were collaboratively planned, it was agreed upon that teachers will be given the flexibility as to how they want to organize and implement the lessons. As a result, as we have previously discussed, all three teachers actually taught pretty different lessons, while drawing on common key aspects that were collaboratively agreed upon.

How did the opportunity for you to plan and implement a lesson based on the theory of variation, and what has been agreed upon collaboratively impact your classroom in terms of 1. your teaching? And 2. your students' learning?

How helpful was it to apply a theory into the planning and implementation of your lessons?
What did it cause you to do differently from your previous lessons on genetics?

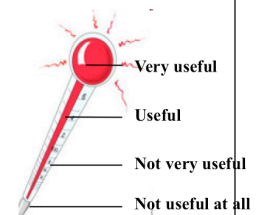
What were you paying attention to when you were preparing for the lessons – e.g., the activity? General aims? Content? What students might be focusing on? How can the content be delivered? How can I address students' inaccurate/incomplete conceptions?

What were you paying attention to when you were teaching the classes? *How different was this from the previous time you taught genetics / or from your previous experiences teaching other topics if you have not taught this topic before?

Did this opportunity allow you to think about what could possibly be learnt or acquired by students, beyond that of the syllabus?

How differently were you teaching this topic when compared to your previous experiences?

What were your experiences in this part of the learning study that allowed you to learn, or impacted your professional development? What did you learn?



7 Organization of lessons, and Implementation of lessons



6 Collaborative planning of lessons using the theory of variation

Collaborative planning of the lessons using theory of variation as the framework

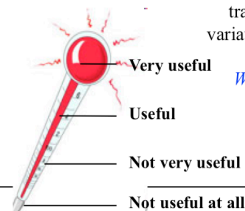
Using the pre-lesson tests and interview results, we ascertained that there was indeed a need to help students develop the capability to understand the key ideas around the molecular processes involved in gene expression, and to be able to apply these key ideas to genetic phenomena like expression of traits, and in mutation (- the object of learning).

Using the theory of variation, the critical aspects around our intended object of learning were determined – namely, 1. structure of genetic materials (and the importance of nucleotide sequences – a precursor to help students to move beyond the structural aspects of genetic materials and to start appreciating the functional aspects of genetic materials); 2. Transcription and 3. Translation process. How do we help students to pay attention to these critical aspects?

It was collectively decided that we vary these aspects, starting with the variation of the sequences of nucleotides – sickle cell anemia (as a way to vary the structure of genetic materials), as this will lead to a variation in the products of the processes of transcription and translation (the 2nd and 3rd critical aspects). Later on, it was also decided that we extend the variation of the first aspect to include variation in the number of gene copies- Down Syndrome.

What were your experiences in this part of the learning study that allowed you to learn, or impacted your professional development? What did you learn?

How did your experiences in this part of the learning study impact your pedagogy?

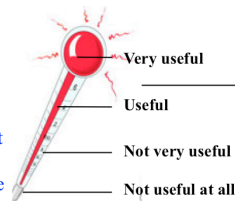


(Appendix I: Overall reflection– handout given to teachers)

The post-lesson meetings allowed us to highlight the both the effective parts of the lessons as well as aspects that could be better.

What were your experiences in this part of the learning study that allowed you to learn, or impacted your professional development? What did you learn?

How helpful were the comments made in the planning and/or the implementation of your own lessons?
How helpful were the comments made in the planning and/or the implementation of your lessons in future?



9 Post-lesson meetings

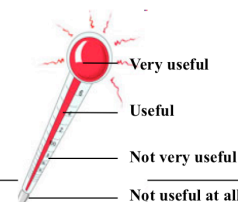
8 Observation of Colleagues' Lessons

The learning study has afforded opportunities to observe one another's lessons. While the observation provides us with opportunities to critically evaluate one another's lessons, it also allows us to learn from one another.

Was the theory of variation useful in helping you to observe your colleague's classes, and how so?

What were your experiences in this part of the learning study that allowed you to learn, or impacted your professional development? What did you learn?

How helpful was the observation of your colleague's class in the planning and/or the implementation of your own lesson?



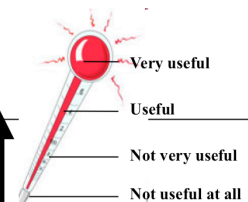
10 Analysis of Post-lesson tests and interviews

This aspect of the learning study allows us to conduct **research** in our own classrooms, even as we use the data collected to ascertain the effectiveness of the use of theory of variation to achieve the object of learning – if the critical aspects determined and the pattern of variation allowed for a widened space of learning.

It also helps support the aspects of our pedagogy that we feel were effective - moving beyond the use of our own personal experiences towards a more systematic use of 'research data'.

How was the data collected useful, and to what degree was it helpful?

What were your experiences in this part of the learning study that allowed you to learn, or impacted your professional development? What did you learn?



(Appendix I: Overall reflection– handout given to teachers)

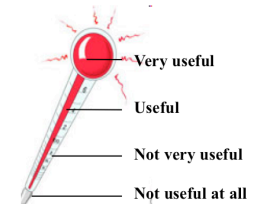
Pg. 5

A large part of the learning study was used to explore students' conceptions- through discussions of the incomplete / inaccurate conceptions that they have; through ascertaining their pre-ideas before the planning of lessons, etc.

How useful were students' conceptions to you? How did you make use of them?

Did you use students' conceptions in way that you formerly did not?

How did this aspect of the learning study impact your professional development?



Although not compulsory, readings were given from time to time. These include journal articles that introduced the learning study and/or the theory of variation; articles and summarized handouts focusing on students' conceptions in genetics and some of the areas that one should pay attention to when teaching genetics; case studies related to recent issues in genetics.

How useful were the readings to you? How did you make use of them?

Did the use of the readings enable you to teach differently from before?

How did this aspect of the learning study impact your professional development?

A A focus on students' conceptions

B The use of a theory

The theory of variation was used in this learning study to guide the planning, implementation and the evaluation of the lessons.

The teaching and learning views that the theory posit may also support, challenge or widen one's views on the teaching and learning of biology / genetics.

How did this aspect of the learning study impact your learning or professional development?

How did this aspect impact your pedagogy? (How useful was it to you?)

D Readings

C Teacher Collaboration

What were your experiences in this part of the learning study that allowed you to learn, or impacted your professional development? What did you learn?

Which aspects of collaboration were useful for you, and how were they useful?

What could have been done to increase the degree of 'effective' collaboration amongst the team?

(Appendix I: Overall reflection– handout given to teachers)

? So how did my experiences in this learning study affect the learning about my own pedagogy?

-So what did I learn? How has the learning study impacted my teaching? How have I been professionally developed?

-How did I experience my own learning as professional development?

-How was my pedagogy affected by my experiences in this learning study?



? So how has the experience of the learning study impacted (support, challenge, or widen) your perspectives of your own learning as a teacher, and what professional development means to you?