FOCUSING ON THE OBJECT OF LEARNING AND THE CRITICAL ASPECTS: A CASE STUDY OF TEACHER CANDIDATES APPLYING VARIATION THEORY

by

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ABSTRACT

In an attempt to bridge the theory and practice gap in teacher education, this study employed a learning study approach as a platform for teacher candidates to learn about variation theory. This study investigated teacher candidates’ experiences in applying variation theory in lesson planning and explored how teacher candidates identify the object of learning and the critical aspects. In groups of four to five, 27 teacher candidates participated in a learning study and worked collaboratively to plan science lessons either on the topic of genetics and cell division (biology) or rate of reaction (chemistry). The lesson planning was framed using variation theory. Guided by a descriptive case study approach, variation theory was employed as the theoretical framework and phenomenography was the methodological approach. Data sources included the teacher candidates’ lesson plans, the researcher’s field notes, and participant interviews. Data analysis included the construction of individual profiles of the teacher candidates, followed by a construction of three categories of description that build on each other. Arranged in increasing complexity, the categories included: (1) Analysing content knowledge in order to develop a coherent learning plan; (2) Reflecting on personal experiences and beliefs about teaching and learning; and (3) Developing knowledge about students and their prior knowledge as informed by external resources. These categories captured the different ways the teacher candidates identified the object of learning and the critical aspects during their lesson planning. The findings revealed the complex nature of this critical stage of planning a lesson based on variation theory.
LAY SUMMARY

In an attempt to bridge the theory and practice gap in teacher education, a teacher professional development approach, namely, a learning study, was implemented. Framed using a learning theory, the variation theory, 27 science teacher candidates planned lessons focusing on the topic of genetics and cell division (biology) and rate of reaction (chemistry). The study investigated different approaches the teacher candidates used to identify their lessons’ objects of learning and corresponding critical aspects. The variation in the teacher candidates’ approaches were captured through the construction of three categories of description, which were arranged in hierarchical order of complexity.
PREFACE

This research study obtained the approval of the UBC Research Ethics Board (Behavioural Research Ethics Board; UBC BREB Number: H17-02596).
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DEDICATION

To my mother
for your unconditional love and for calling me at the right moment

To my father
for your hard work and for believing in me

To my sisters and my brother
for supporting me and cheering me up
CHAPTER ONE: INTRODUCTION TO THE STUDY

This chapter presents an introduction to the study and the problem statement. The research questions guiding this study are also presented. A brief description of the researcher background is also included. This chapter concludes with an overview of the thesis.

1.1. Introduction to the Study

The theory–practice problem in education constitutes the failure to apply theory into practice and a lack of relationship between theory, developed by researchers, and the practice knowledge possessed by teachers (Elliot, 2014). An absence of instruction based on theoretical understanding can lead to teachers focusing on the teaching methods rather than on content and conceptual knowledge when planning their lesson (Brante, Holmqvist, Holmqvist, & Palla, 2015). Consequently, focusing only on the teaching methods often distracts teachers from the actual content knowledge they want to teach (Gustavsson, 2008).

Similarly, the theory–practice gap issue can also be found in teacher education. Teacher candidates often criticise that teacher education courses are insufficient in connecting theory to practice (McGarr, O’Grady, & Guilfoyle, 2017). Seeing little connection between the theories informing their coursework and classroom practice, teacher candidates may be unable to decide on suitable opportunities for the enactment of their knowledge learned in teacher education (Darling-Hammond, 2006). Therefore, teacher candidates may find it difficult to develop the connection between theory and practice as they are unable to find a relevant theory that explains their practice (Lunenberg & Korthagen, 2009). In this study, I introduced a learning theory, variation theory (Marton & Booth, 1997), to guide teacher candidates as they planned their science lessons as a way to bridge the theory and practice gap in teacher education.
Brante et al. (2015) stressed the importance of explicitly linking the learning theories to classroom instruction in teacher education. Some efforts have been made to educate teacher candidates in a way that would bridge theory and practice gap. Fernandez and Robinson (2007) invited teacher candidates to participate in a microteaching lesson study which provided an opportunity to apply their theoretical knowledge in a practice context. Recently, there has been a number of studies to integrate learning study approach in teacher education to help teacher candidates to connect theory to practice (e.g. Brante et al., 2015; Wood, 2013). In my study, learning study was employed as an approach to allow teacher candidates at a University in Western Canada to plan a lesson with variation theory as a guide.

Learning study is an approach with an explicit theoretical framework that enhances teachers’ professional competence in teaching (Cheng & Lo, 2013). There are two important features of a learning study (Cheng et al., 2013). First, learning study focuses on an object of learning which refers to what is to be learned and is generally a capability or a concept that teachers find difficult to teach and/or students find difficult to learn. Teachers collaborate to design and integrate the object of learning in their lessons as a part of classroom research. Therefore, the focus of learning study is on how the selected object of learning can be taught so that students can see the object of learning in ways intended by the teacher.

The second feature of a learning study is the explicit theoretical framework to guide the teachers’ learning study discourse, and variation theory (Marton et al., 1997) is typically employed. Developed from the phenomenographic research approach (Marton, 1981), variation theory posits that learning is a function of discernment, and discernment is a function of variation (Marton et al., 1997). To discern the object of learning in the intended way, students must focus
on the critical aspects. The critical aspects are introduced through crafted patterns of variation and invariance where the critical aspect is varied while other aspects are kept invariant.

Learning study helps teacher candidates improve their teaching skills and enhance student learning (Cheng, 2014; Lai & Lo-fu, 2013). Cheng (2014) conducted a learning study with teacher candidates in Hong Kong which included tutorials, consultation and a research practicum for the purposes of nurturing their instructional design and developing their theoretical lens. Similarly, Lai et al. (2013) incorporated learning study to enhance teacher candidates’ mathematical content knowledge and pedagogical content knowledge which allowed the teacher candidates to design theory-based classroom instruction that better facilitated learning. These learning studies conducted in teacher education programs provided a platform for teacher candidates to integrate variation theory as a guide in their lesson plan to be enacted during their practicum.

There are challenges in implementing learning study with variation theory in teacher education. Davies and Dunhill (2008) argued that the challenge is that significant amount of time is needed to help teacher candidates understand variation theory. Moreover, identifying a worthwhile object of learning, the critical aspects and patterns of variation, is not a simple process as teacher candidates may not have enough teaching experience to inform them in choosing a worthwhile topic (Ko, 2011). Consequently, when planning a lesson, teacher candidates focus less on the object of learning (Wood, 2013). Despite of all the challenges, Calgren (2012) emphasised that teacher candidates must be actively involved in integrating variation theory in lesson planning.

As Calgren (2012) recommends the integration of variation theory into lesson planning, my goal is to adopt variation theory as the theoretical framework for my learning study approach
in an attempt to address the theory and practice gap in teacher education. Specifically, the purpose of this study is to investigate how teacher candidates plan a lesson using variation theory. This study is designed to bring teacher candidates’ focus towards the object of learning and the critical aspects. Specifically, this study focuses on the different ways teacher candidates identify an appropriate object of learning and the critical aspects in their lesson planning.

1.2. Problem Statement

In an attempt to bridge the theory and practice in teacher education, I employed learning study framed with variation theory in my study. One of the essential stages of a learning study is planning a lesson guided by variation theory which includes identifying an object of learning and the critical aspects. This is often a challenging task for teacher candidates due to their lack of teaching experiences (Ko, 2011). To address this problem, I explored teacher candidates’ approaches to identifying the object of learning and the critical aspects.

1.3. Research Questions

The purpose of this study is to investigate teacher candidates’ process when planning a lesson using variation theory. I focused on the three core features of variation theory: (1) the object of learning; (2) the critical aspects; and (3) the pattern of variation (Cheng et al., 2013). Therefore, the following research questions guided this study:

1. What is the object of learning as the point of departure and defining it in terms of the critical aspects in the teacher candidates’ lesson plans?

2. How are the critical aspects introduced in the form of patterns of variation in the teacher candidates’ lesson plans?
3. What are some of the ways the teacher candidates approach the object of learning and the critical aspects?

1.4. Brief Researcher Background

I attended school in Indonesia for my K-12 education and moved to Singapore to pursue my undergraduate degree in Chemistry. Subsequently, I worked as a tutor in Singapore teaching Grades 11 and 12 Chemistry in the International Baccalaureate (IB) curriculum. Before pursuing my graduate studies in education at the University of British Columbia (UBC), I focused my teaching on delivering content knowledge with limited teaching methods or pedagogical strategies. I believe my approach to teaching was still lacking and there was a need for teacher professional development which led me to pursue my graduate studies in education.

I was introduced to teacher professional development through action research in the forms of lesson study and learning study in my first graduate course. I believe that teacher professional development is important to empower teachers to teach virtuously by providing the opportunity to reflect on their teaching practice. I am particularly interested in learning study due to the strong emphasis on the need for a theoretical framework to frame teaching instruction and its focus on the object of learning. This approach is suitable to my context as my career focus is on students’ learning and supporting teachers to understand their own teaching practice.

While enrolled in chemistry and biology teaching method courses at UBC, I observed that teacher candidates often focused on pedagogy found from online sources. They tended to apply these strategies in their teaching with little reflection on the correlation between the content and the selected teaching method. Few of my peers took into account the student perspectives when planning a lesson. My experiences both as a teacher and student as well as my
classroom observations of my peers during chemistry and biology methods classes motivated me to conduct a study of variation theory with learning study approach with teacher candidates.

1.5. **Organization of the Thesis**

This thesis is organised into five chapters. Chapter 1 introduces the study which includes the problem statement, research questions, and a brief background about the researcher. Chapter 2 begins with a literature review of variation theory as this study’s theoretical framework. The literature review presents and discusses the learning study approach and learning study research conducted in teacher education. A brief overview of the biology and chemistry topics in this study is also provided. Chapter 3 outlines the study context as well as case study as the investigational approach and phenomenography as the research methodology. The methods employed to collect and analyse data in order to answer the research questions are also presented. Chapter 4 describes the teacher candidates’ profiles which illustrate their lesson plan as well as their identifying of the object of learning and corresponding critical aspects. Chapter 5 presents the analysis of the teacher candidates’ lesson plans as well as the categories of description that reveals the complex nature of the process of identifying the object of learning and the critical aspects. The answers to the research questions, the significances of the study as well as the challenges and limitations of the study are also presented. This thesis concludes with the implications of the study and suggestions of areas for further research as well as the researcher’s reflection.
CHAPTER TWO: THEORETICAL FRAMEWORK and LITERATURE REVIEW

This chapter begins with a detailed description of this study’s theoretical framework, variation theory, and how it is employed in educational settings. Then, learning study and the extension of learning study to the context of teacher education are outlined. This chapter concludes with an overview about the chemistry and biology topics selected for this study.

2.1. Variation Theory as a Theoretical Framework

2.1.1. Phenomenography Perspective

*The qualitatively different ways of experiencing the same phenomenon*

This review serves to explain variation theory with the view that it is an extension of phenomenographic perspectives (Marton et al., 1997). This section focuses on phenomenography and the relationship to variation theory. Phenomenography explores the qualitatively different ways in which people potentially experience certain phenomena and captures them in qualitatively distinct categories (Marton et al., 1997). Qualitatively different ways of experiencing a phenomenon are the results of differences in the structure of awareness at a particular moment. The foreground of our awareness is assumed to have certain structure, which means that we can only focus on a few things at one time (Lam, 2013). Our awareness changes as different things become the focus of our attention.

The development of phenomenography further reveals that variation in the ways of experiencing a phenomenon can be divided into two types of variation, termed “faces of variation” (Pang, 2003). The first face of variation refers to various ways a particular phenomenon appears to different people. In the first face of variation, phenomenography is descriptive and categorises how people experience a phenomenon. The second face of variation
refers to nature of the differences, which concerns how different ways of experiencing something can be captured to correspond with the critical aspects of a phenomenon. Based on these two faces of variation, there is a shift from description of different ways of experiencing to understanding a way of experiencing a phenomenon and the differences between two ways of experiencing a phenomenon.

The differences in the ways of experiencing are the results of discernment of different aspects of a phenomenon (Marton et al., 1997). One way of experiencing a phenomenon reflects different combinations of the aspects that we are aware of at a particular time. Runesson (2006) closely analysed the different aspects of the phenomenon and believed that in experiencing a phenomenon there could be a shift in what aspects are in the forefront and background which resulted in the different ways of experiencing a phenomenon. Hence, the aspects that differentiate the different ways of experiencing a phenomenon are the critical aspects of the phenomenon (Marton et al., 1997).

Every phenomenon has limited number of critical aspects that distinguish it from other phenomena. The differences in the way the critical aspects are discerned correspond to the differences in experiencing the phenomenon. Marton et al. (1997) argued that experiencing a phenomenon has structural aspects and referential aspects. The structural aspect refers to the internal horizon of a phenomenon which includes the parts of the phenomenon and the relationship between the parts. The referential aspect refers to the external horizon of a phenomenon which surrounds the phenomenon and gives meaning to the phenomenon. These two aspects are intertwined and occur simultaneously when we experience the phenomenon.
Discernment, Simultaneity, and Variation

According to Marton et al. (1997), variation theory is premised on the dynamic structure of awareness that is related to discernment, variation, and simultaneity. In variation theory, learning is appreciated as a change in discernment of a phenomenon and to be able to discern something, the aspects the phenomenon must be discerned; for example, learning a square shape requires the discernment of its shape, angle, and number of sides. The qualitatively different ways of experiencing a phenomenon can be understood as the discernment of critical aspects of that phenomenon (Lo, 2012).

Variation theory also claims that aspects must be considered simultaneously as aspects can be related in different ways, either as parts or as a whole (Holmqvist, Tullgren, & Brante, 2011). There are two different types of simultaneity which are diachronic simultaneity and synchronic simultaneity (Marton & Tsui, 2004). Diachronic simultaneity is defined as the necessity to recall earlier experiences of a dimension of aspects at the same time for example to discern the square as a shape, we simultaneously discern other shapes that we have seen before (e.g. triangle, rectangle). Wallerstedt (2013) writes that it is essential for learners to simultaneously experience the aspects learned at different points in time. On the other hand, synchronic simultaneity is defined as necessity to be able to discern different co-existing aspects of the same thing at the same time for example to discern a small green cube, we simultaneously discern the aspects of colour, size and shape.

Variation theory places an emphasis on variation as a necessary condition for discernment of meanings as learners can never discern anything without experiencing variation (Marton et al., 1997). For instance, experiencing square as a shape does not mean anything unless we experience variation in shapes such as triangle or circle. If there is no variation in
shape, it is impossible to discern the aspect of shape. To discern square, we need to discern other shapes apart from square. If a critical aspect is varied against an invariant background, it is more likely that learners will discern the critical aspect.

2.1.2. Variation Theory in Educational Contexts

Qualitatively different ways of experiencing a phenomenon may account for why some people learn better than others (Marton et al., 1997) as the consequence of qualitative differences in ways of understanding various topic or subjects. Variation theory explicates learning as a result of changes in the way we experience the object of learning and discerning new aspects of the object of learning. The aspects attended or discerned are of significance for how we understand the object of learning (Kullberg, Martensson, & Runesson, 2016). If students are to see the object of learning in the way teachers do, they must focus on the same aspects.

As a learning theory, variation theory focusses on what is critical to the understanding of the object of learning (Runesson, 2013). Variation theory posits that necessary conditions for learning include focusing on the object of learning, identifying the critical aspects, and exposing learners to the critical aspects through appropriate patterns of variation (Cheng et al., 2013). In order to bring about effective learning, teachers must choose a worthwhile object of learning and carefully study it in order to identify the critical aspects students need to discern to see the object of learning in the intended way (Lo, 2006). The next step would be designing systematic patterns of variation and invariance to help students to discern the intended critical aspects. A teacher must be good at creating such conditions that are necessary to bring about intended learning (Marton et al., 2004).
Three Types of Variation as a Guiding Principle

Through learning study, teachers experience three types of variation related to their teaching instruction (Lo, 2012; Pang et al., 2012). The first variation (V1) is the variation in the students’ understanding of the object of learning. The investigation of V1 helps teachers to identify students’ learning gap and possible conceptions and difficulties they may have and these can be revealed through students’ responses, interview, or a diagnostic test (Cheng et al., 2013).

The second variation (V2) is the variation in the teachers’ understanding of the object of learning and their ways of dealing with the object of learning. The first form of teachers’ variation is teachers’ own understanding and conceptualisation of the topic (Lai et al., 2013). Gustavsson (2008) showed that teachers do not commonly reflect on the different ways of understanding the content. Learning study provides a space for teachers’ own understanding of the topic to be analysed and open for scrutiny. The second form of teachers’ variation relates to their previous experience of teaching the same or a similar topic (Lai et al., 2013). Teachers vary considerably in the way they teach a lesson and employ different pedagogical strategies. This allows teacher to reflect on their own short-comings in dealing with the topic.

The third variation (V3) is variation as a guiding principle of pedagogical design. To give learners the opportunity to discern the critical aspects, teachers structure the lesson in terms of the patterns of variation and invariance. What is varied and what remains invariant is intended to bring about students’ discernment of the critical aspects. In planning a lesson, it is crucial that the use of variation is controlled and systematic.
Object of learning as the point of departure

Variation theory assumes that there is no learning without something being learned, which is known as the object of learning and the object of learning refers to what the students need to learn. The object of learning is divided into direct and indirect object of learning (Holmqvist et al., 2011). The direct object of learning usually refers to the content knowledge, whereas the indirect object of learning refers to what the learners are supposed to be capable to do after they develop the content knowledge.

An educational learning objective, that is the expected learning outcome, is related to an object of learning. The object of learning is the gap that must be considered before teachers decide on teaching methods and assessment to achieve the desired learning objectives (Lo & Pong, 2005). Finding out the gap and understanding how to fill the gap require teachers’ deeper reflection and analysis of the learning objectives (Kullberg et al., 2016). Therefore, it is necessary to consider what is to be learned to achieve the educational learning objective.

Kullberg et al. (2016) demonstrated that the inquiry of the object of learning is a process of delimitation which defines the boundaries of the object of learning. In a learning study, the first meeting is dedicated to identifying a topic that would prompt meaningful learning and simultaneously match the curriculum (Cheng et al., 2013). Having decided a topic, teachers collaboratively discuss on selecting an object of learning. Due to time constraints in the class, teachers are encouraged to carefully select a worthwhile object of learning to maximise students’ learning (Lo et al., 2005). When considering an object of learning, the context in which the object of learning exists must also be considered as the object of learning cannot be separated from the system it exists in (Lo, 2012). This context may influence students’ overall understanding of the object.
Identifying an object of learning is a challenging task for many teachers and requires deeper reflection (Kullberg et al., 2016). Lo, Chik, and Pang (2005) illustrated several learning studies with different approaches to identifying a worthwhile object of learning. For instance, an object of learning can be identified through understanding content knowledge and identifying a new focus of the content knowledge that may develop more powerful ways of seeing. In this case, an object of learning may aim for a higher level of understanding of a particular topic. Another way could be through carefully examining past teaching experiences and research literature to identify what is worth learning or difficult to learn about a particular topic.

An object of learning should not be simply selected based on the prescribed learning objectives in the curriculum (Runesson, 2013). Instead, its relation to students, relatedness to other topics, students’ difficulties, skills and concept to be acquired need to be considered. The rationale for choosing the object of learning must centre around the learners and the object of learning. To help students learn the object of learning, teachers must first be able to understand why the object of learning presents difficulties to students (Bjorkholm, 2015). This can be done by referencing to related research papers from which students’ conceptions of a particular topic can be derived. Research papers provide some ideas on the object of learning that students frequently find challenging.

According to Holmqvist et al. (2011), teachers should focus on the connection between the learner and the object of learning. Variation theory states that the relationship between the object of learning and the learner can be shown as a description of how the object of learning is experienced by the learners. Exploring what students need to know to understand the object of learning can be done through unpacking the object of learning in terms of the critical aspects to
generate more detailed knowledge that can help teachers in designing the teaching (Bjorkholm, 2015).

Defining and Identifying Critical Aspects

According to variation theory, an object of learning is defined in terms of the critical aspects. A critical aspect is defined as an aspect that is critical to learners’ understanding of an object of learning and are not yet discerned by the learners (Lo, 2012). Critical aspects emerge not from the content alone, but through careful examination of students’ understanding (Pang & Ki, 2016; Runesson, 2013). Therefore, a critical aspect is relational to both object of learning and students.

Certain aspects are critical for a specific way of seeing. Depending on the aspects being discerned, one would have different understanding of the phenomenon. Decisions made by a teacher regarding the structural aspects and referential aspects of an object of learning may affect what the students discern in the lesson. Through defining the structural and referential aspects, the dynamic character of the object of learning can be captured (Marton et al., 2004).

In order to bring about an intended way of understanding of the object of learning, teachers must focus on the critical aspects. Analysing how the critical aspects of an object of learning is identified and understood through different phases of learning study, Bjorkholm (2015) found that the meaning of the object of learning can be slowly refined through the critical aspects. Bjorkholm (2015) argued that this process is a process of exploration that concludes with specification of an object of learning.

Apart from discerning the critical aspects of an object of learning, a learner must be able to discern how the different aspects are related to each other and how each aspect makes up the
whole object of learning (Chik & Lo, 2004). To experience an object of learning in a powerful way, students must be aware of the part-whole relationships and part-part relationships between the aspects (Lam et al., 2013). Olteanu and Olteanu (2013) categorised the relation between aspects of an object of learning in six general categories: (1) the whole; (2) the parts that form the whole; (3) the relation between the parts; (4) the transformation between the parts; (5) the relation parts-whole; and (6) the relation between different wholes. By making sense of these general categories, teachers constituted a complete object of learning which critical aspects could be identified to enhance students’ learning.

Critical aspects can be derived from a phenomenographic study of the object of learning. From knowledge of V1 and V2, teachers attempt to identify the critical aspects. Generally, this is based on their previous teaching experiences and a pre-test the teachers administered, which was specifically designed to reveal learners’ difficulties and prior knowledge (Runesson, 2013). The pre-test may be used to identify or to confirm the critical aspects by analysing how the task/question is interpreted and solved by students. For example, Herbert and Pierce (2012) conducted a phenomenographic study to reveal the students’ conceptions about the concept of rate. From these conceptions, they identify the critical aspects which may guide teachers in extending students’ understanding of the concept of rate.

A few studies have demonstrated that critical aspects can be derived through other approaches. For instance, Fredlund, Linder, and Airey (2015) illustrated that a social semiotic approach can be used to identify the critical aspects. They examined texts and diagrams in a physics textbook and proposed that this approach as an underexplored method to identify the critical aspects of an object of learning. Similarly, Tang and Leung (2012) conducted a learning study where the objects of learning and the critical features were designed by researchers through
adopting teaching materials such as textbook series rather than in collaboration with teachers. However, Runesson (2013) argued that critical aspects of an object of learning are relational to the learners and thus cannot be found solely from the subject or the discipline alone. Critical aspects are related to the qualitatively different ways learners experience an object of learning (Pang et al., 2016). Although, the derivation of “critical aspect” may be different on those cases (Fredlund et al., 2015; Tang et al., 2012), the approaches seem to have potential in identifying critical aspects.

Identifying the critical aspects of an object of learning is not always a straightforward task (Wood, 2013). Some critical aspects can be readily identified through the use of pre-test or literature. In other cases, critical aspects can only be revealed through a few cycles of research lesson through unpacking the object of learning (Bjorkholm, 2015). The usual procedures of identification of the critical aspects of an object of learning include brainstorming, reading research, or carrying out empirical research (Fredlund et al., 2015). A deep and thorough subject matter knowledge and knowledge about common misconceptions and difficulties among students are necessary prerequisites to find the critical aspects of an object of learning (Rovio-Johansson & Ingerman, 2016).

Identifying a critical aspect of an object of learning can be challenging for teachers. One of the reason is that teachers often do not find these aspects difficult to discern and take them for granted (Lo et al., 2005). These taken-for-granted aspects are often not highlighted in the teaching which may create a learning gap and cannot be found unless teachers suspend their natural attitude and attempt to analyse the object of learning carefully (Lo, 2012). Fredlund, Linder, Airey, and Linder (2014) pointed out that some degree of unpacking of the object of learning is needed for analysis aiming to identify critical aspects.
Moreover, being more sensitive to how students learn and to what constitutes their difficulties may allow teachers to identify the critical aspects more efficiently. In identifying a critical aspect, students’ possible preconceptions and alternative conceptions can be a great tool. Through collaboration such as that in learning study, the difficulties can be minimised (Msonde & Msonde, 2017). In different cycles of a learning study, more information about students’ various alternative conceptions may be drawn and tackled.

*Pattern of Variation and Invariance*

To discern an aspect of a phenomenon, one must experience variation in the aspect. Variation theory emphasises that variation is a necessary condition for discernment of a new aspect of an object of learning. Variation must be experienced against the background of what is invariant (Marton et al., 2004). Systematically varying one aspect and keeping other aspects invariant may help learners discern the varied aspect. Teachers employing pattern of variation and invariance in their teaching does not guarantee learning. Nonetheless, explicit variation in a certain aspect suggests a higher degree of probability that the aspect will be discerned by the students.

Simply pointing out a critical aspect may not make a learner discern the critical aspect. In the first cycle of learning study that Pang et al. (2012) conducted with rate of reaction as the object of learning, the students failed to discern the critical aspects (the effect of concentration and volume of the reactant) as the aspects were only presented at the end of the class. The result from this study emphasise on the significance of the students explicitly engaging in activities that provide the experience of the pattern of variation and invariance to promote their discernment of the critical aspects.
Four different functions that pattern of variation can serve include contrast, generalisation, separation, and fusion; the functions are dependent on what is focused in the lesson (Marton et al., 2004) and are described as:

- **Contrast** – contrast is the awareness brought about by experiencing the differences between two values of an aspect. To experience what something is, a learner also needs to experience what something is not.

- **Separation** – separation occurs when one aspect of a phenomenon is brought to awareness while keeping other aspects as invariant background. When the learner becomes aware of a value by contrasting it with other value, the value is separated from the object and the aspect is opened up.

- **Generalisation** – generalisation occurs when previous discernment is applied to other contexts for further understanding of a phenomenon. Some other aspects vary while one aspect does not and it is the invariant aspect that is discerned (Lam, 2013).

- **Fusion** – simultaneous variation of several critical aspects is necessary to understand a phenomenon as a whole. The simultaneous discernment of two critical aspects can be experienced with experiencing the variation in the two aspects simultaneously (Marton & Pang, 2006).

Different patterns of variation can be created in different combinations and structures to bring about different desired learning outcomes. As different patterns of variation promote different learning opportunities, some patterns have been found to be more effective than others (Holmqvist, 2011). For instance, Ljung-Djarf (2013) found that, after teaching with different patterns of variation, a conscious use of simultaneity and contrast of identified critical aspects could stimulate students’ learning better in her study. Lam (2013) argued that in addition to
contrast, generalisation also has the potential to develop learning through invariance to complement the existing variation. These examples suggest that the patterns of variation and invariance as well as the sequence of the patterns need to be carefully planned.

Marton et al. (2004) suggested that teachers pay attention to the pattern of variation in order to understand what is and is not possible to learn through the pattern of variation. The use of pattern of variation and invariance in the instruction needs to focus on which aspects of the object of learning are varied and kept invariant at different stages of the lesson. Marton (2015) found that for the same content if variations are organised differently, the learning effects can markedly differ. This shows that, apart from the pattern of variation and invariance, the order and the organisation of the patterns play an important role in the learning.

2.2. Learning Study

Developed by a group of researchers in Hong Kong, learning study is a theory-framed collaborative approach to improve the professional competence of teachers (Cheng et al., 2013). Learning study involves a group of teachers, with the help of a researcher, who meet regularly to work on the design, implementation, testing, and improvement of one or more lessons. Pang and Lo (2012) stated that the main purpose of the learning study is to answer questions e.g. how can the object of learning be taught so that students can see the object of learning in the intended way? Teachers and researchers collaborate to investigate effective ways to teaching a specific object of learning.

Although a learning study typically progresses 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, Chik, & Pang, 2006). The cycle of a learning study comprises the following steps:

1. Choosing an appropriate object of learning, primarily chosen on the basis on teachers’ experiences of something that is difficult for teachers to teach and for students to learn.

2. Developing and conducting a pre-test to find out the extent to which the students have understood the object of learning.

3. Designing a lesson aimed at teaching the object of learning taking into account the students’ pre-test results, teachers’ previous approaches to teaching the selected object of learning, and the research literature.

4. Teaching the lesson where one teacher carries out the lesson and other teachers observe to note down the strengths and weaknesses of the lesson.

5. Evaluating the lesson and reflecting on its effect for possible improvement.

6. Revising the lesson and teaching the revised lesson in another class by another teacher.

7. Sharing the overall results in the form of a seminar or presentation.

One of the features of a learning study approach is the presence of a theoretical framework, namely variation theory (Marton et al., 1997). The point of departure for learning study is the object of learning, a capability that the students are expected to develop (Cheng et al., 2013). Combining variation theory with learning study leads to systematic development of teaching specific object of learning (Holmqvist, 2011). This may solve the issue identified by Gustavsson (2008) who found teachers directed their attention primarily on different methods without making connection to the content. Therefore, using variation theory to frame lesson
planning, teachers’ attention can be directed towards the object of learning and how to approach the object of learning in teaching.

It has been suggested that a learning theory will likely contribute to more efficient learning (Nuthall, 2004). Teachers participating in a learning study can discuss how to handle the object of learning in terms of variation theory (Gustavsson, 2008) as it can provide a framework to understand how teaching affect students’ learning (Runesson, 2013). Tan (2014) argued that the presence of variation theory adds value to learning study by promoting a more student-centred pedagogy and developing a theoretical lens to teachers’ approach to teaching. As teachers may have difficulties implementing a new learning study due to time constraints, teachers may use variation theory when planning instruction individually (Holmqvist, 2011).

2.3. Learning Study in Teacher Education

One aim of teacher education is for teachers to base their teaching practices on theoretical perspectives (Brante et al., 2015) and to establish an enquiry lens in terms of connecting theory and practice. Theoretical understanding of the conditions for learning is considered as important as pedagogical skills, and is necessary for developing understandings of effective teaching and learning (Gustavsson, 2008; Holmqvist, 2011).

Numerous researchers have examined the theory and practice gap issues in teacher education. Darling-Hammond (2006) found that teacher candidates saw little connection between their coursework (teaching method courses) designed with a theoretical basis and their fieldwork. Jaworski (2006) states that the disconnection between theory and practice in teacher education may lead to failure in preparing teacher candidates for their teaching practice. Brante and Holmqvist (forthcoming) found that teacher candidates choose certain features of various
learning theories and transform them in new ways that diverge from the actual intentions of the original theories and indicates that teacher candidates face difficulties in translating theory into practice. Lunenberg et al. (2009) noted teacher candidates found it challenging to identify a relevant theory that conceptualised their teaching practice. This finding shows that teacher candidates often lack a complete understanding of a learning theory and the application, leading to weak reflection on practice (Agbenyega, 2012).

The effectiveness of learning study and how teachers are better equipped to tackle the process of designing student learning through paying attention to the object of learning has been explored. Learning study provides a platform for teacher candidates to learn about learning theory and then apply it to lesson planning (Cheng, 2014). In addition to the opportunity to develop a theoretical lens, learning study is a productive framework for teacher candidates to engage in activities such as analysing student difficulties and conceptions and planning lessons that meet both curriculum requirements and students’ needs (Koirala, Davis, & Johnson, 2008).

The challenges teacher candidates faced in participating in learning study are also explored. Brante et al. (2015) found that many teacher candidates were unable to understand the core concept of variation theory which are critical aspects and pattern of variation. Davies et al. (2008) found a substantial problem in helping teacher candidates to identify variation in students’ conceptions. Another challenge found was the substantial amount of time needed by teacher candidates to identify the object of learning and the critical aspects (Wood, 2013).

The challenges in the implementation of learning study seem to lean towards the process of the lesson planning framed with variation theory. Lai et al. (2013) found that in designing variation theory-based classroom instruction, teacher candidates participating in a learning study believed that content knowledge and pedagogical content knowledge were significant
components of a lesson plan. However, Lai and colleagues (2013) did not further elaborate on how these components are incorporated into the lesson plan. Based on my review of the literature for this thesis, little research has been done to closely examine the process of lesson planning. Therefore, I found a gap in literature I reviewed examining how teacher candidates identify the object of learning and the critical aspects which is the essential part in variation theory-framed lesson planning. Consequently, this study is designed to identify the different ways teacher candidates approach the object of learning and the critical aspects.

2.4. Overview of the Science Topic Selected

An object of learning refers to what is worthwhile for students to learn in the context of teaching and learning in the classroom (Cheng et al., 2013). Ko (2011) argued that selecting a common learning topic with a broad theme may reduce the amount of time individual groups spent on choosing the topic and simultaneously retaining the freedom of the group to narrow it down to a specific object of learning. Therefore, for this study, I selected the topic of rate of reaction for chemistry teacher candidates and genetics and cell division to be the topic for biology teacher candidates. The topics are selected due to the significance to the respective subject (Justi, 2002; Tsui & Treagust, 2004). The topics can be found in the British Columbia (BC) Curriculum (2016) which is the curriculum that teacher candidates are associated with in their teacher education program. Table 1 presents a brief description of the topics, and the associated terminologies which are presented in the following subsections.
Table 1

Topics and associated terminologies featured in this study.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biology</strong></td>
<td></td>
</tr>
<tr>
<td>Genetics</td>
<td>Gene: a unit of heredity in DNA that contains genetic information in the form of sequenced nucleotides</td>
</tr>
<tr>
<td>biophysical entities</td>
<td>Chromosome: a condensed structure formed by DNA coiling around proteins</td>
</tr>
<tr>
<td>Mutation</td>
<td>Change in the sequence of nucleotides which resulted in the change in the genetic information in the gene</td>
</tr>
<tr>
<td>Mitosis</td>
<td>The process of cell duplication</td>
</tr>
<tr>
<td>Meiosis</td>
<td>The process of splitting of a cell and its genetic materials (chromosomes)</td>
</tr>
<tr>
<td>Inheritance</td>
<td>Passing of traits and characteristics from parents to offspring</td>
</tr>
<tr>
<td>Genotype</td>
<td>A set of genes that determines the expression of a particular characteristic or trait</td>
</tr>
<tr>
<td>Phenotype</td>
<td>Observable characters of an individual</td>
</tr>
<tr>
<td><strong>Chemistry</strong></td>
<td></td>
</tr>
<tr>
<td>Rate of reaction</td>
<td>The change in the concentration of a reactant or a product over a period of time</td>
</tr>
</tbody>
</table>

*Note.* Data for chemistry topic from Wright (2004) and for biology topic from Tan & Caleon (2016).

2.4.1. Genetics and Cell Division

Genetics and cell division are topics covered in biology in the British Columbia Science Curriculum (2016) and both are regarded as challenging biology school topics for students and teachers (Bahar, Johnstone, & Hansell, 1999; Lewis & Wood-Robinson, 2000; Marbach-Ad & Stavy, 2000). Genetics and cell division have become pivotal in biology as both topics are greatly related to human affairs such as mutation, genetically modified species, and cloning (Tsui et al., 2004). The overarching concepts of genetics include biophysical entities, protein synthesis processes, inheritance, the nature of mutations, and their effect. Genetics is also related to cell division (the process of meiosis and mitosis) (Williams, Debarger, Montgomery, Zhou, & Tate, 2011). A good background knowledge in genetics can be applied to understand many important
political, social, and ethical issues in the society regarding genetic research and technologies (Duncan, Freidenreich, Chinn, & Bausch, 2009).

Research indicates that students share similar difficulties in learning genetics and cell division. These shared difficulties include: (1) inability to understand phenomena involving small genetic biophysical entities (Osman, BouJaoude, & Hamdan, 2017); (2) inability to understand the interaction and distinctions between the different levels of organisations (macro, micro, and molecular) which are the fundamentals of understanding of mechanism of processes (Duncan & Reiser, 2007; Verhoeff, 2003); and (3) inability to understand and relate specific vocabulary and terminology (Knippels, 2002; Riemeier & Gropengiesser, 2008).

Many students are unaware of the nature of genetic information present in different types of biophysical entities (e.g. a gene, a chromosome, and a cell) (Chattopadhyay, 2005). One conception is that different cells contain different genes which further develop into a misconception regarding traits. Moreover, students are not able to capture the relationship between biophysical entities and relate them to other genetics concepts such as gene expression, cell division, and mutation. Tsui et al. (2004) found that only a small number of students held the conception that genes affect cell development and contains information, which are two conceptions closely related to the ontological category of processes (see Tsui et al. (2004) for more details).

Learning processes in genetics and cell division involve students developing complex understanding of the topic. This includes approaching the genetic phenomena through multiples organisational levels such as gene, protein, and cells (Gericke & Wahlberg, 2013). Moreover, mastering genetics entails understanding the mechanism and interactions at the molecular level and microlevel that bring about effects at the macrolevel (Duncan et al., 2007). Duncan et al.
(2007) proposed that the ontological distinction between the levels of genetic phenomena is an important factor contributing to students’ difficulties. One ontological distinct is physical level including the existed biophysical entities (e.g. proteins, cells, tissues, etc.) and another ontological distinct is information level including the genetic information (genes). Relating these ontological distinct levels can be brought about by understanding the interactions between informational entities and biophysical entities and how genetic information brings about the physical effects.

Within genetics curricula worldwide, there is considerable variation in how biological terminologies are used to explain concepts of genetics, with little clarification on the differences in meanings between the different terms (Gericke & Hagberg, 2010). Due to the accumulated terminology to explain concepts in genetics, it is difficult to transform the knowledge into a form that is easily grasped by students (Duncan, 2007). Similarly, some terminologies (e.g. division, multiplication) used to describe cell division may not necessarily reflect the same meaning in our everyday experiences (Riemeier et al., 2008). Students often bring in their conceptions from daily-life context and these conceptions are often resistant to change (Kruger, Fleige, & Riemeier, 2006).

Textbooks often present the abovementioned contents separately with little focus on their relation between various contents/concepts and teachers often did not explicitly link the structure and function of the biophysical entities (Tsui et al., 2004). Moreover, students have difficulties in understanding various related concepts, for example the connections between cell division and genetic inheritance (Williams et al., 2011). Therefore, there is a need to bring this fragmented content knowledge together in order to put across the concepts in a coherent way and explicitly show the connection between various concepts (Lewis & Kattmann, 2004).
Previously, a learning study has been conducted in this topic with “the genetic processes of transcription and translation” as the object of learning (Tan, 2014). The aim of the learning study was to develop students’ capability to understand and apply principles of transcription and translation to real-life genetic phenomena such as mutation. The critical aspects of the object of learning were the structural and functional relationships between genetic entities (genes, DNA, and chromosomes). The pattern of variation was designed where the genetic code was varied resulted in the changes in the mRNA formed during transcription and followed by the changes in the protein formed in the translation process. This pattern of variation highlights how variation of one critical aspect may result in variation in other critical aspect.

2.4.2. Rate of Reaction

Chemical kinetics is a fundamental topic in chemistry and is an essential prerequisite for the understanding of additional chemistry concepts such as equilibrium and thermodynamics (Justi, 2002). Chemical kinetics provides a detailed study into the nature of chemical reactions and presents chemical reaction in three ways: macroscopically; microscopically; and mathematical model (Taber, 2013; Talanquer, 2011). It is also highly relevant to chemical processes in industrial, medical, and environmental areas. Due to the complexity and importance of chemical kinetics, effective teaching and in-depth student understanding of the topic are crucial (Bain & Towns, 2016).

Chemical kinetics covers rate of reaction, defined as the change in the amount (concentration) of a substance (product or reactant) divided by the reaction time. In addition to the concept of rate of reaction, chemical kinetics can be expanded to collision theory, factors affecting rate of reaction (temperature, concentration, surface area, catalyst), quantitative
measurement of rate of reaction (rate constant, rate expression, and order of reaction), energy (enthalpy and activation energy) and the catalyst (Wright, 2004).

Both teachers and students consider chemical kinetics to be one of the most difficult topics to master (Chairam & Klahan, 2015). Conceptual understanding of chemical kinetics is found to be low among secondary school and undergraduate students (Cakmakci, 2010). Kaya and Geban (2012) conducted a concept test and found some common student conceptions included: (1) Rate of reaction is constant throughout the reaction; (2) rate of reaction can be increased through mechanical processes such as stirring; and (3) rate of reaction is the time required for the reaction to end. Moreover, Calik, Kolomuc, and Karagolge (2010) also identified students’ difficulties in learning chemical kinetics which include: (1) inability to define the rate of reaction and distinguish rate of reaction and reaction time; (2) inability to understand the relationship between rate of reaction and the factors such as temperature, surface area, catalyst; and (3) inability to understand the dynamic nature of chemical reactions.

Many students are unable to properly define “rate of reaction”, and they often use a range of definitions inappropriately (Bektasli & Cakmakci, 2011; Cakmakci, 2010; Yalcinkaya, Tastan-Kirik, Boz, & Yildiran, 2012 For instance, rate of reaction is the period of time taken for a reaction to occur (reaction time) (Yalcinkaya et al., 2012) or the amount of time that turns into product per unit time (Bektasli et al., 2011). Terms such as “the instantaneous rate”, “the initial rate”, and “the average rate” are often overlooked and thus, not distinguished (Cakmakci, 2010). This has caused students’ difficulties in understanding the context in which the different concepts of rate of reaction are applied. As these different types of reaction rate have contextual meaning, differentiating these terminologies is necessary to create a coherence conceptual understanding of rate of reaction.
When relating rate of reaction with the factors affecting it, students have difficulties in explaining the relationship. For example, students maintain the idea that a catalyst would increase reaction yield and would not change the mechanism of the reaction (Turanyi & Toth, 2013). One of the most commonly held conception is that “volume is a factor affecting the rate of reaction” (Pang et al., 2012). Students believe that stirring may be able to increase the rate of reaction (Kaya et al., 2012). This could be due to students’ tendency to use “macroscopic” modelling rather than “particulate” or “mathematical” model to explain the chemical reactions (Cakmakci, Leach, & Donnelly, 2006).

Students have difficulties providing explanations about the dynamic nature of the reaction system as they have little conceptual understanding of changes in the reaction rate as the reaction progress towards the end (Calik et al., 2010). This could be due to their perceptions of everyday phenomenon which rate increases e.g. a wood fire burns faster after a certain period of time (Cakmakci, 2010). Textbooks often present rate of reaction as the initial and final state of a reaction. The reaction mechanism is often neglected or fragmented from the concept of rate of reaction. Cakmakci et al. (2006) argued that more attention should be given to explain the processes that occur between the initial and final state of a reaction.

Previously, a learning study was conducted on this topic with “factors affecting the rate of a chemical reaction” as the object of learning (Pang et al., 2012). In this study, two critical aspects were identified: (1) the concentration of the reactants will affect the rate of a chemical reaction and; (2) the volume of the reactant will not affect the rate of the chemical reaction. When the critical aspect (1) was varied, critical aspect (2) remained invariant. Similarly, when the critical aspect (2) was varied, critical aspect (1) remained invariant. Such patterns of variation allowed students to see the change in the rate of reaction caused by changing the variables.
2.5. Summary

As a learning theory, variation theory posits that the qualitatively different ways of understanding the object of learning may account for different learning experiences (Marton et al., 1997). The necessary conditions for learning is to expose learners to the critical aspects of the object of learning through patterns of variation. Variation theory typically frames learning study approach to enhance teachers’ professional teaching competence (Cheng et al., 2013; Lo, 2012). Learning study in teacher education programs has been shown to develop teacher candidates’ instructional design skills as well as nurturing their teaching competency (Ko, 2012; Lai et al., 2013). Although studies indicate that teacher candidates have positive experience engaging in learning study, they can struggle with the process of lesson planning framed with variation theory, particularly with identifying the appropriate object of learning and the critical aspects. Therefore, this study aims to address this problem by exploring some of the ways teacher candidates identify the object of learning and the critical aspects.

In the next chapter of this thesis, Chapter 3, I will provide the context of the study and the participants. The study’s investigation approach, methodology, and methods used to collect and analyse the data will be elaborated.
CHAPTER THREE: INVESTIGATION APPROACH, METHODOLOGY, and METHODS

This study examines the different ways teacher candidates identify the object of learning and the critical aspects when planning a lesson using variation theory. In this chapter, I present the context of the study as well as the participants’ educational background. I also discuss the investigation approach, the methodology, and details of the methods I used to collect and analyse the data to answer the research questions.

3.1. Context of the Study

The study was conducted with teacher candidates enrolled in a Teacher Education Program at a University in Western Canada and in a required course focusing on teacher inquiry for 3 hours a week over 13 weeks. The course was designed to develop teacher candidates’ ability to engage in research to understand curriculum, teaching, and learning. At the end of the course, teacher candidates were to be able to critically examine their practice, address issues from various perspectives, consider alternative inquiries and evaluate the outcomes. In summary, teacher candidates may continue to develop the abilities to question, reflect, and act on their practice.

There were 27 teacher candidates who participated in the study. Among those, 22 were biology teacher candidates, four were chemistry teacher candidates, and one was an earth science teacher candidate. The teacher candidates held undergraduate degrees in biology, chemistry and geology respectively. They self-selected a group of 4 – 5 based on their subject expertise (chemistry or biology), and the earth science teacher candidate joined the chemistry group. Subsequently, the researcher presented variation theory to the teacher candidates, and the teacher candidates planned a lesson together for the topic of genetics and cell division or rate of reaction.
for biology and chemistry respectively. Among the 27 participants, five teacher candidates self-selected based on their availability to participate in the interview.

3.2. **Investigation Approach: Case Study**

In this study, case study was employed as an investigational approach (Yin, 2002). Case study is employed as an in-depth and descriptive study of a bounded system such as social groups, events, and programs (Stake, 1995). A case study accounts for a real-life context within an actual setting and circumstances, and thus does not occur in artificial environments (Yin, 2015). The contextual conditions of the system add value to the accurate understanding of the case and create clear boundaries in which the case can be examined (Stake, 1995). I viewed this study as a bounded system due to the boundaries of the teacher education program, the course on inquiry, and the high school science curriculum.

Due to the “in-depth” nature of case studies, each study may include a large number of observations on different aspects of the case (Bennet, 2015). A case study involves an intensive data collection effort to obtain a thick description of a case (Yin, 2002). Multiple data collection methods are usually employed concurrently such as direct observation, interview, and various kinds of documents and archives. This is also to ensure triangulation of data to produce more trustworthy and accurate results (Patton, 1990). Therefore, data sources for this study include teacher candidate one-on-one semi-structured interviews, graphic organisers constructed by the teachers, and the researcher’s fieldnotes.

Stake (1995) divides case study into either intrinsic or instrumental. Intrinsic case study focuses on the case itself and is conducted to enhance the researcher’s understanding of a particular case. Instrumental case study highlights how the case may contribute to other similar cases. Findings from a case study can be related to (Bassey, 1999), transferred to (Guba &
Lincoln, 1982), or recontextualised (Morse, 1991) to other similar contexts. In intrinsic case study, the case itself is dominant. In instrumental case study, the issue underpinning the study is dominant. I regard my study as an instrumental case study. The dominant issue underpinning the study is the teacher candidates’ understanding of the core concepts of variation theory.

Based on the study’s purpose, case study research can be categorised into exploratory case study, descriptive case study, and explanatory case study (Yin, 1994). The exploratory case study is an intuitive investigation done prior to determining a research question. In an exploratory case study, data is collected first and hypothesis may be dropped or added based on the data collected. A descriptive case study is a thorough description of a phenomenon in its context. A descriptive theory serves as a foundation to the study to describe a phenomenon in the real-life context. For this study, I employed a descriptive case study to seek to describe how teacher candidates determine the object of learning and the critical aspects.

3.3. Research Methodology: Phenomenography

Phenomenography was selected as the appropriate methodology for this study to complement that case study investigation approach. The methodology was chosen as it aims to map the different ways individuals experience the same phenomenon (Marton et al., 1997). A phenomenographic approach has been used in research that is directed towards describing, analysing, and understanding experiences of a phenomenon as seen from the individual perspective (Marton, 1981). Phenomenography has also been employed as a methodology for case studies focusing on teachers’ learning experiences within a teacher development context (Tan & Nashon, 2013). Therefore, phenomenography adopts a second-order perspective to describing individual experiences, and phenomenography is suitable for this case study which aims to
capture the variation in the teacher candidates’ approaches to object of learning and the critical aspects.

A way of experiencing a phenomenon can be described through the learner’s awareness, that is what a learner focuses on and could consist of both a structural aspect and a referential aspect (Marton et al., 1997). Structural aspect refers to the relationship between the different aspects of a phenomenon that are focused on by the subjects. Referential aspect refers to particular meaning of a conception of a phenomenon. Structural aspects and referential aspects are intertwined and mutually contribute to each other in the act of experiencing the phenomenon (Pang, 2003). Structural and referential aspects were likewise included in the analysis of this study to examine the critical aspects identified by the teacher candidates.

3.4. Data Collection

3.4.1. Intervention

Similar to many other learning studies implemented in teacher education program (e.g. Brante et al., 2015; Tan, 2018; Tan, Amiel, & Cheng, 2017; Wood, 2013), I embraced learning study approach with some deviations and modifications to fit into my context. Due to the time constraint imposed by the course structure, I presented variation theory to the teacher candidates through one 3-hour session. Hence, I modified the learning study approach to focus only on the three core concepts of variation theory, which are the object of learning, critical aspects, and patterns of variation and invariance (Lo, 2012). This is similar to the modified learning study that was conducted in teacher education by Brante et al. (2015) where they conducted three sessions to study the effect of three different instructions to introduce the three concepts of variation theory.
To compliment my presentation on variation theory, I prepared a handout for use in the session (appendix A). I developed based on a literature review on various learning studies on science topics (e.g. Lo, 2012; Lo et al., 2005; Tan et al., 2015; Vikstrom, 2013, 2014). This handout included an elaboration on the three core concepts of variation theory as well as some examples on a few learning studies of various science topics. The teacher candidates may refer to this handout at any time while engaging in the activity.

Working collaboratively in a group of 4 – 5, teacher candidates planned a lesson based on the variation theory on a given graphic organiser (Appendix B). The lesson planning activity was divided into two sections: (1) determining the object of learning, 20 mins; (2) identifying the critical aspect and designing the pattern of variation, 40 mins. The activity was implemented in ways that were similar to the learning study approach (Cheng et al., 2013): the teacher candidates determined the object of learning at the early stage of learning study (step 1) and then they subsequently planned the research lesson that included the critical aspects and the patterns of variation and invariance (step 3).

Due to the inaccessibility to the classroom teaching and time constraint, deviations from a conventional learning study approach were noted. First, there was no opportunity for the teacher candidates to design and conduct a pre-test. This may limit the variation in the approaches of identifying the object of learning and the critical aspects. The pre-test was substituted by the pre-test from external resource and research literatures that included students’ conceptions and difficulties (Appendix C – G). Second, there was no opportunity for the enactment of the lesson and thus, there is no opportunity for reflection and revision of the lesson. However, this limitation might have little effect on the results as this study focuses on the process of lesson planning, the absence of the enactment of the lesson has little effect to the results of the study.
3.4.2. Hawthorne Effect

All teacher candidates were invited to participate in the interview and the participants were selected from these volunteers. This approach of selecting interviewees may have introduced bias due to the possibility that the teacher candidates’ interest in the study and thus may not represent the overall study sample. Furthermore, they may have answered the interview questions in a way they believed the researcher expected them to in their roles as study participants. This effect is known as the Hawthorne Effect (Chiesa and Hobbs, 2008) which refers to how participants’ behaviours might alter as a result of their engagement in a research study. In an attempt to minimize the Hawthorne Effect, triangulation was employed. According to Bryman (2008) the use of more than one approach to data collection may overcome the problems associated with the Hawthorne Effect and may overcome problems with the single method approach (Holden, 2001). The Hawthorne Effect is minimal in this study as I did not intrude obtrusively while participants were planning the lesson and during the interview to allow the teacher candidates to feel relaxed and unthreatened. Moreover, during the interview, participants’ responses were not paraphrased in order to avoid asking leading follow-up questions.

3.4.3. Triangulation

Multiple data sources were collected in this study to enhance the richness of the data. A justification for the approach of multiple data sources can be called triangulation. Guba (1981) described triangulation as “collecting data from a variety of perspectives, using a variety of methods” (p. 87). Triangulation involves the use of multiple data collection tools (Denzin, 1989).
Researchers are encouraged to triangulate between methods such as interviews, participant observations and document analysis because within-method triangulation may leave varying error (Brewer & Hunter, 1989).

In my study, I applied triangulation (Mathison, 1988) of multiple data sources to establish the credibility and validity of the results. The purpose of triangulation is to seek a convergence and corroboration in the investigation outcome from the use of multiple methods (Leech & Onwuegbuzie, 2007; Ma & Norwich, 2006). Guba et al. (1982) believed that triangulation can develop the most persuasive evidence. Triangulation enriches our understanding of the same phenomenon by allowing deeper dimensions of the phenomenon to emerge (Jick, 1979). Guba (1981) indicated that the strength of triangulation comes in a way that the weakness of one method is compensated by the strengths of another method and it is certain that if similar results are found using different methods, the stability of the data is reinforced. Triangulation yields a more accurate and valid estimate of a result when the results obtained from various methods converge on the same outcome (Mark & Shotland, 1987). In this study, I triangulate the multiple data sources that I collected such as the interview excerpts, the lesson plan in the form of graphic organiser as well as my field notes in order to fully exploit different but complimentary data on the same phenomenon (Morse, 1991).

### 3.4.4. Documents

I collected the lesson plans in the form of a graphic organiser (Appendix B). I based the design of the graphic organizer on Lo and colleagues’ (2015) model of lesson plan in their learning studies. The graphic organisers provided me with “unobtrusive data” which is recommended by Hatch (2002) as a measure to reduce the researcher’s influence or control over the data. From the graphic organiser, I obtained information about their object of learning.
critical aspects, and patterns of variation as well as brief description of their approach to identify the object of learning and the critical aspect. The graphic organiser also served to stimulate recall for the teacher candidates to describe their lesson plan during the interview.

Another document I created were my field notes which were comprised of both descriptive information and reflective information. The researcher’s field notes recorded information about perceptions of what was happening from the researcher’s insights, values and interests (Lincoln & Guba, 1985). My field notes consisted of my personal observation of the activities and teacher candidates’ behaviours and conversations that were unable to be captured in the interview and the graphic organiser. My field notes also consisted of my reflection on both my presentation of variation theory to the teacher candidates and my observation of teacher candidates when they were planning the lesson in the classroom.

3.4.5. Interview

One set of semi-structured interviews were conducted the following week after the graphic organizers were completed. The interview is a common method for data collection in phenomenographic studies (Booth, 1997; Sandberg, 1997) and is usually semi-structured and open-ended (Booth, 1997; Sandberg, 1997) to allow the participants to respond to aspects of the questions that appeared relevant to them and to capture the variation in the participants’ ways of experiencing of a phenomenon. I conducted one-on-one semi-structured interviews (Appendix H), and each interview lasted approximately 45 minutes. The purpose of the interview was to probe for teacher candidates’ experiences in designing a lesson plan which included the approaches they used to identify the object of learning and critical aspects based on the lesson plan provided.
The interview also served as a platform for reflection as Bogdan and Biklen (1982) described an interview as a “purposeful conversation” and the interview may be the dominant method of data collection in conjunction with other methods. Bogdan et al. (1982) argued that the purpose of interview is to gather descriptive data in participants’ own words in order to develop insights into how participants interpret a phenomenon. According to Borg and Gall (1983) semi-structured interview permits a more thorough understanding of the participants’ perspectives than the document or questionnaire would possibly show. In this study, teacher candidates drew upon their graphic organiser, the lesson planning activity as well as their understanding of variation theory to provide deep description of their experiences of lesson planning.

In this research study, a set of semi-structured, open-ended questions (Appendix H) guided the interview. I recorded the keywords that emerged during the interview and used the keywords to frame the subsequent questions. However, participants’ responses were not paraphrased to avoid premature interpretations of participants’ comments. This practice was implemented due to the concern about the use of leading prompts that might lead to self-fulfilling prophecies through mechanism of behaviour confirmation (Francis, 1993). I also implemented the interview according to Bowden’s (1994) suggestion of using a limited set of planned questions is to be used to guide the interview, with all other follow-up questions focusing on encouraging the interviewees to elaborate on their ideas; the interviewer needs to construct the follow-up questions within the theme rather than the interviewer’s prior knowledge.

3.4.6. Ethics and Confidentiality

To ensure appropriate ethical guidelines are followed, I successfully applied to the UBC Behavioural Ethics Review (BREB) board for approval to conduct the study. An email inviting
the teacher candidates to participate in my study was sent by the course instructor. The email contained my contact information which the prospective teacher candidates responded to if they were interested to participate. All participants received a consent letter outlining the conditions for participating in and withdrawal from the study. To ensure anonymity and confidentiality, pseudonyms were used for all participants and the data was stored on an encrypted, password-protected computer and written documents were locked in a filing cabinet in one of my faculty advisors’ office.

3.5. Phenomenography Data Analysis

I employed phenomenographic data analysis (Marton et al., 1997) after collecting the data. In phenomenography, the researcher searches for the most distinct characteristics appearing in the data which classify descriptions of a phenomenon structurally to define how a particular phenomenon is experienced by individuals (Marton et al., 1997). The results of phenomenographic analysis are categories of description depicting distinct aspects of how a phenomenon is experienced. Phenomenography suits the purpose of this study which is to explore the variation in the teacher candidates’ approaches in identifying the object of learning and the critical aspects. Therefore, in this study, the categories of description show the complexity of the different ways that teacher candidates experience their phenomenon of identifying the object of learning and the critical aspects.

Profile development

Employing phenomenography, describing how a phenomenon or aspect of a phenomenon appears to an individual requires a second-order perspective (Marton et al., 1997). This implies that the phenomenon is described through the individual’s experiences as opposed to the
researcher’s interpretations of the phenomenon. Similar to the data analysis method employed by Tan et al. (2013), I created an individual profile for each teacher candidate. According to the authors, profile development creates an opportunity to focus on the particularities of the individual’s experiences and serves to provide greater clarity in the interpretation of the individual’s experiences. In my study, individual teacher candidates’ profile was developed to describe their experience of planning a lesson using variation theory and to provide an opportunity to focus on the individual’s experience. Individual teacher candidates’ profiles were developed through the construction of narrative description of teachers’ experiences which were supported by excerpts from the interview transcripts (Tan et al., 2013).

Analysis of teacher candidates’ experiences to construct categories

During data analysis, I constructed the qualitatively different categories (Marton et al., 1997) that described the ways teacher candidates identified the object of learning and the critical aspects. In this study, the transcripts for the interview (transcribed verbatim) were viewed alongside with the reviewing of other data sources, such as the researcher’s field notes and the graphic organisers. This was done multiple times to ensure I was familiar with the data collected. Then, the excerpts that were related to the phenomenon of interest were selected to be analysed to form the categories of description.

After selecting the data, I began organising the data and search for recurring words and phrases (Lincoln et al., 1985). I studied the data in attempt to search for significant meanings describing the phenomenon of interest and descriptions with similar meanings were then grouped. This part of the analysis required reading through the entire data set to identify the data items or sorting the different meanings that may form the categories of description (Marton,
The themes and patterns that cut across the entire data were developed into initial categories of description that describe the variation in teacher candidates’ experiences of the phenomenon.

By re-examining the selected interview excerpts, these groups were then further refined to form categories of description that describe the core meanings of the groups. The categories of description constructed were tested to ensure accuracy in the interpretation against all sources of data. I adjusted, retested, and adjusted multiple times the categories in order to ensure that they are stable (Marton, 1986). The categories were further validated by two faculty members who served as my critical friends (Lincoln et al., 1985).

The hierarchical relationship of categories of description

According to Marton et al. (1997), a way of experiencing a phenomenon consists of a combination of various aspects of the phenomenon coming into our awareness simultaneously. Consequently, the categories of description that are formed through phenomenography develop a relationship which could be arranged in hierarchical order where some ways of experiencing a phenomenon are deemed to be more complex than others (Marton, 1981). A less complex way of experiencing of a phenomenon may consist of fewer aspects of the phenomenon of interest, whereas the more complex one may constitute of more aspects of the phenomenon of interest.

In this study, the categories of description were mapped in hierarchical order. The hierarchical order is essential because it indicates the complexity nature of identifying the object of learning and the critical aspects (Lo et al., 2005; Wood, 2013). The categories of description were arranged from less complex to more complex where the lower-ordered categories are typically subsumed into the higher-ordered ones (Marton et al., 1997).
3.6. Summary

In conclusion, I employed an instrumental descriptive case study in combination with phenomenographic methodology in my study. In this case study, phenomenography was employed to investigate the different ways teacher candidates identify the object of learning and the critical aspects. The data was collected in the form of teacher one-to-one semi-structured interviews, graphic organisers the teachers constructed, and researcher’s field notes. These data were subjected to phenomenographic analysis resulting in categories of description that captured the different ways teacher candidates approached the object of learning and the critical aspects. The complex nature of the phenomenon is further demonstrated through the hierarchical ordering of the categories of description (Marton et al., 1997).

The next chapter will outline the study findings. The individual teacher candidates’ profiles discussing their lesson plan and their approaches to identifying the object of learning and corresponding critical aspects will also be presented.
CHAPTER FOUR: DATA and DISCUSSION

In this chapter, the data from the participants will be presented and discussed. The participants’ individual profiles were developed to describe their experiences in planning the lesson using variation theory. The profiles are organised by the description of the object of learning and its corresponding critical aspects as well as the participants’ approaches to identifying the object of learning and related critical aspects. The descriptions of participant experiences are presented in the subsections below and outlined in the following order:

1. Identification of the object of learning and corresponding critical aspects
2. Introduction of the critical aspects
3. Presentation of the participants’ approaches to the object of learning and the critical aspects

4.1. Mary’s Experience of the Lesson Planning

4.1.1. Identification of Object of Learning and Corresponding Critical Aspects

Mary selected phases of mitosis as the focus of the lesson. The object of learning was to develop systematic understanding of mitosis as a process. It was aimed at allowing students to see mitosis as a process involved in the physical developmental of human life. In other words, the emphasis was on the significance of mitosis as a process that sustains life. In the graphic organiser, Mary highlighted important keypoints for developing a systematic understanding of mitosis. These included understanding cell cycle and division as processes, each different phases of mitosis, and the outcomes of mitosis.

Mary stated that the critical aspect for the lesson focused on the phases and purpose of mitosis. The critical aspect identified was how the different phases constituting the mitosis
process are interconnected and leads to the overall purpose of forming identical daughter cells. Mary further argued that the purpose of mitosis reinforced the significance of the different phases in mitosis whereas presenting mitosis as a continuous process served to provide the conceptual learning as it allows students to understand the link between these phases. Altogether, the critical aspect provided a more contextualised and conceptualised form of learning as they allowed the students to see mitosis as a continuous process with a purpose.

4.1.2. Introduction of the Critical Aspects

With the critical aspects of the object of learning identified, Mary designed a pattern of variation to introduce the critical aspect. In the variation, she would use errors (e.g. cells not fully dividing) in a cell during each phase of mitosis; she would keep all the biophysical entities (e.g. spindle, chromosome, etc.) invariant. Mary claimed in her interview:

This is when we want to compare what actually happen, what would happen if an error is in the cell… That was our variation. We would show this is a good stage of interphase.

But then if this happens at interphase this is the consequence. So, it was a comparative. As seen in excerpt above, her idea was to provide the students an opportunity to contrast the phases with error and the phases without error. When Mary was asked to elaborate on how the pattern of variation may help students understand the critical aspect, she responded: “When we were explaining the stages, if something went wrong in that stages, what happen? It kind of gives you an idea of why the stages are so important and how the stages work.”

The students would be asked to model how a change in a particular phase affects the overall process of mitosis (Tan et al., 2017). Mary would add an error in each phase to emphasize the
importance of that particular phase in a mitosis process, the differences in each phase, and how they are interconnected.

To allow the students to experience the variation, Mary used a poster drawing activity where the students were given a particular cell error to be incorporated into their poster. The students were to show the disruption occurring at the phase and the outcome of the process in the presence of the cell error. Through this activity, Mary did not just point out the process and the purpose, but she would also allow the students to discover the differences between the process with and without the errors in the cell.

4.1.3. Presentation of Mary’s Approaches to the Object of Learning and the Critical Aspects

In her interview, Mary stated that the “phases of mitosis” was the basic concept that may build students’ understanding of development and growth in human. Mary was concerned about building a strong foundation of knowledge to enable students to tackle challenging biology concepts. This was evident in her emphasis on covering “the first building block” as her object of learning, which she clearly stated in her interview:

Kind of the most basic understanding, fundamental understanding, the basic of how this process works. […] So, it’s like your base knowledge revolve around mitosis and then from mitosis you build up to development and growth and human. It’s kind of the first building block.

Mary believed that a critical aspect is the most pivotal component that build understanding of the object of learning. For her critical aspect, she argued that it was critical for the students to be able to relate the purpose and process of mitosis to provide a context for
understanding the significance of mitosis in the developmental of life. Mary argued that the aspect of purpose of mitosis provided a clear understanding of how each phase affects the others, how they are interconnected and subsequently, how the whole process is important to sustain life. In the critical aspect, it can be implied that she would point out the differences in the different phases by emphasizing the purpose of each phase. This is evident in her interview where she stated:

- We kind of thought it’s kind of critical that they get the systematic knowledge and some kind of connection. So, the purpose and the process. After identifying the different aspects, we kind of thought coming together it makes perfect sense. […] I guess after talking about process, you would discuss mitosis actually involve in the developmental of life. It’s just the “why is it important?” What could go wrong in each stage and how it affects us, how it affects different microorganism, what mitosis contributes.

Mary believed that understanding how the different phases are interrelated to contribute to the purpose of mitosis may provide other contexts for learning of mitosis, which, in this case, is the context of human development and then another context such as reproductive method. She claimed that:

- I think our thinking was that it gave more context to why study mitosis. I think we thought more of a different perspective. […] but our idea was to kind of shed a different light on mitosis, looking at it from human development and now we’ll be looking at it as a reproductive method.

The locating of the process of mitosis in the biological phenomena of development and reproduction may allow teachers to identify the critical aspects and make the content more comprehensible and relevant to students.
Mary was one of the teacher candidates with educational experience in the form of tutoring. Apart from her content knowledge, her educational experience also shaped her critical aspects. She drew from these tutoring experiences to help her anticipate students’ difficulties and learning gaps. When Mary was asked to elaborate how her teaching experience was incorporated into the lesson planning, she said, “I think honestly that’s (teaching experience) the most helpful in students’ difficulties and the learning gap, understanding where the students tend to go wrong and where they’re kind of tripped up, and the language that you have to use.” Mary identified one of the students’ learning difficulties in mitosis as their inadequate understanding of terminology and its application to mitosis. Mary further elaborated:

Because we talked a little bit about defining the keywords and like confusing things might be a problem and see the alternative conception that mitosis and meiosis as the same. A lot of it is about being able to really identify vocabulary in this section is really important.

Mary stated that because of this difficulty, it is important that mitosis was taught in a more process-based manner and by giving context to the process (Gilbert et al., 2011). Incorporating the purpose allowed the students to see the big picture of the mitosis process prior to reinforcing terminologies in biology.

It can be implied that in identifying both the object of learning and the critical aspects, Mary focused her teaching on promoting students’ understanding of the content. She appeared to be well aware of how to organize the content in a way that would develop a systematic understanding of the topic and thus, the relationships between the aspects of the object of learning were clear. Her critical aspects clearly portrayed her desire to develop students’ understanding of mitosis in a process way and to highlight the significance of mitosis.
Furthermore, she was able to identify students’ difficulty from her teaching experiences and relate it back to the content and then present it as the critical aspects.

4.2. Jim’s Experience of the Lesson Planning

4.2.1. Identification of Object of Learning and Corresponding Critical Aspects

Jim focused on the idea of inheritance and cell cycle (mitosis and meiosis), and his object of learning was to build students’ conceptual understanding of inheritance through in-depth analysis of the cell cycle. Jim claimed that through the process of meiosis, inheritance can be understood at the cellular level. In other words, inheritance is the topic in which cell cycle is the content that makes up the understanding of inheritance. He intended to show the concept of inheritance at the cellular level, such as what is inherited and how it is inherited, and subsequently relate them to the effects on an individual. Consequently, these became his focus for the critical aspects.

Jim identified the critical aspect as “traits are determined by the expression of genes” and he explained his critical aspect as:

Whether that is some kind of mix or whatever, the way that we look is going to be expressed kind of in one way. That’s what we kind of called our traits. We’re having blue eyes, blonde hair, two different genes perhaps, maybe two of the same genes or very similar genes. When those genes are expressed, that’s how we look. We’re talking about phenotype and genotype here. That’s kind of the underlying idea behind this. Our phenotype is how our gene is expressed. Those are our traits.

In his critical aspect, Jim would emphasise on how our traits, which determine how we look, are the results of the expression of the genes, prior to genes from the parents being passed down to
offspring through the process of sexual reproduction. This involves biological processes such as meiosis, that is, the division of chromosomal material and the formation of cells carrying genetic materials from the parents. To relate the cell cycle (including meiosis) to the biological phenomenon of inheritance, it is critical for students to understand that genes found on chromosomes are expressed, resulting in the formation of proteins that determines the traits of an individual. By learning the critical aspects, students should be able to understand that inheritance is a process of passing on genes, where the transcription and translation of genes occurring at the cellular level (genetic processes of copying genetic information and producing proteins respectively) result in cascading biological reactions culminating in observable traits.

4.2.2. Introduction of the Critical Aspects

To introduce the critical aspect of the object of learning, Jim intended to use computer simulations in his lesson plan to vary the genes of a particular trait and thus the phenotypic expression of the traits (dominant or recessive). Jim demonstrated that the simulation was able to generate patterns with many different traits and variables to choose from. He further elaborated on the simulation in his interview:

[…] simulation could vary like the dominant or recessive traits or something like that, we would get an outcome of different individuals. We could vary some of those traits. You can add a gene and you can make a dominant or recessive… and you can start to see the outcome of the different organism coming up. We could use that simulation or one that is similar to it or we could switch the genes that is being introduced to the population. In this case, it was fur color. We could switch it from white being dominant to recessive versus the brown color. Just to kind of let the students see the outcome of that.
By varying the dominant and recessive traits observed in the parents, Jim wanted to show that the traits of the offspring are not directly inherited from the parents (Tsui et al., 2004). Rather, the expression of the genes determines the traits in the offspring. It can be seen that Jim varied one critical aspect at a time. Based on variation theory principle, by focusing on one aspect, which in this case is the expression of dominant and recessive traits, Jim would be able to bring to his students’ awareness the relationship of genes and traits by allowing the students to experience the variation in the genes expressed and the traits observed.

4.2.3. Presentation of Jim’s Approaches to the Object of Learning and the Critical Aspects

Upon thinking about the object of learning, Jim saw the link between meiosis, gene expression and inheritance. He elaborated how this link could be made obvious:

[…] Through meiosis [and sexual reproduction], you got one parent’s genetic material joining another parent’s genetic material. When that happens, there is a lot of genetic materials that kind of come together. Some genes will be expressed one way or another. Depending on how the genes are expressed, those are the traits that you inherit from your parents. You’re still getting the genes from your parents. They have different genetic materials. There is a lot of it is the same, some materials are a little bit different. When all that materials come together, the combination of that materials which genes is being expressed in this new organism that is what you’re inheriting. You’re inheriting some materials from one parent, some materials from another parent. Then it is that combination of the genetic materials that kind of makes you unique.

Jim’s words reveal that he aimed to develop students’ understanding of inheritance at the cellular level, that is, through the process of meiosis and expression of genes. By understanding the
process of meiosis and gene expression, students would be able to approach the topic of inheritance by focusing on biological processes rather than merely on the transfer of traits from one generation to another and to understand the outcomes of the genetic materials inherited. The object of learning clearly pointed out the significance of the process of meiosis in understanding the idea of inheritance.

In planning this lesson, Jim argued that the students need to be able to develop a network of interrelated concepts and to connect the concepts through a wider biology topic, which in his case was inheritance, and he claimed:

So, I think the object of learning was to try to tie the concept which is in this case the cell cycle to something that is a bigger topic. That’s the way I would think of it because we would tie it to the idea of inheritance. We are trying to get them to understand what inheritance is, that’s what we have written as the object of learning. […] But we want to build their conceptual understanding of inheritance. To me, inheritance is kind of like a big concept and so we’re using the cell cycle as our content or concept to do that.

This was projected in his object of learning where he wanted the students to connect the concept of cell cycle with inheritance. Furthermore, he stated that creating this network was similar to painting a bigger picture that helped students to extend their understanding to other related concepts.

In his interview, Jim mentioned that, “So, once they understand something like meiosis, we can talk about inheritance, we can talk about their own reproduction, we can talk about evolution. We can talk about other concepts and we have this kind of building block of understanding.” It can be implied that Jim aimed to connect concepts that would help students to grasp a more conceptual understanding of the biological phenomenon of inheritance. Jim also
argued that by building this network of concepts, students would be able to add more links and categories that form more interconnected understandings.

Jim argued that students were interested in their traits, thus it would be easy to relate the select biological concepts to real-life phenomenon. When Jim was asked how traits can be related to the real-life, he responded that:

I think we picked traits being determined by the expression of genes as our critical aspect because when students think of inheritance, they think of how they look. It is something that they can relate to. We’re always judging and looking at people, particularly for this age, they’re always thinking, “this is how I look”. Why do I look this way? […] This is a good anchor for the students to kind of talk about all these concepts and we always kind of come back to this is why I look this way. Students have interest in that. It’s the way for them to kind of relate to the information. I think that’s why we picked that.

Moreover, Jim also believed that through covering the critical aspect, the students may be able to clear some of their common alternative conceptions. Drawing on resources such as academic literature, he identified students’ common alternative conceptions. One of the common alternative conceptions he focused on was “height is inherited from one parent” (see appendix C for the list of students’ conceptions). In his interview, Jim elaborated on the specific alternative conception:

[…] I would guess that there might be some genes that kind of, “oh, you’re gonna be roughly this height.” But the new organisms, the child, is the product of combination of parents’ genes. […] You’re the combination of your parents’ genetic materials, not just one. You’re not just getting this one thing.
According to Jim, by covering cell cycle (mitosis and meiosis) and relating it to sexual reproduction, the alternative conceptions about how genetic materials are passed down from both parents could be cleared.

Jim also shared his aim in science education which involves developing science literacy among his students. He argued that students need to be able to get across their scientific ideas and to think critically about scientific phenomena. Jim saw the importance of understanding science in society, and being able to “have a conversation about science”. He claimed:

Personally, my interest in science is to try to create a more scientific literate population. There is a lot of really great science out there, […] It’s about just trying to kind of set people on the right path so they understand what’s actually happening so that they understand the science behind something and actually understand how it works. […] Ultimately, all these things, scientific literacy leads people being able to have conversation about science. […] Let’s at least get our students to the point where they can have conversation and tie some of these things together and understand how they relate to each other and how they are connected so that they can conversation. But they can at least explain “this is why I look this way, this is how genetic information is passed from one generation to another or this is ultimately how animal adapt in the population over time”.

It is clear from the object of learning and critical aspect Jim selected that he intended for students to develop a conceptual understanding of inheritance, connecting the cellular and genetic levels to observable characteristics. What shaped the way he determined the object of learning and critical aspects included his personal beliefs about science education, his intentions to address students’ interest and alternative conceptions, and his goal of helping students to
develop a network of related concepts. Jim was also able to incorporate the literature research to assist him in identifying his object of learning and corresponding critical aspect.

4.3. Stacy’s Experience of the Lesson Planning

4.3.1. Identification of Object of Learning and Corresponding Critical Aspects

Stacy started with the idea of diversity of living things at the genetic level as the big picture she wanted to focus in a lesson. Her object of learning was for students to develop an understanding of how mutation may contribute to the diversity of living things in various ways as she claimed:

I think that this is the key aspect to understanding the big idea about gene and diversity. You can understand gene but you also need to understand there is a different observed characteristic, there is also non-observable characteristics. Because it is not enough to say the genes are changing or there is a mutation. You need to take that further. I think that’s where we were going.

Stacy interpreted the critical aspects to include concepts that students should grasp and remember for a long period of time. Consequently, she identified the critical aspects to be the relationship between genotype and phenotype. Furthermore, she argued that it is critical for students to understand the relationship of genotype and phenotype to be able to link mutation to diversity. In her interview, she elaborated her critical aspects as:

So, when you’re teaching neutral mutation, if I understand what a genotype is but then if I saw a change in genotype, but I see no change in phenotype, I would be really lost. [...] Just because you change one nucleotide doesn’t mean that you change the whole code,
right? You are still coding for the same genotype. There was a change there but nothing happens. That’s why we have that kind of phenotype.

4.3.2. Introduction of the Critical Aspects

With the genotype and phenotype as the critical aspects, Stacy preferred to introduce genotype and phenotype at the beginning of the lesson prior to the variation, where she would point out the meanings of genotype and phenotype as well as the relationship between the two terms. Then, Stacy would introduce the pattern of variation through select examples. When she was asked about her pattern of variation, she explained:

We were thinking we could have examples. We have the genotype, it leads to this phenotype, observable characteristics. Now, let’s change the genotype, what’s gonna happen to the phenotype? We could show how changing the genotype can change to the phenotype. We also want to show that changing the genotype doesn’t always mean that the phenotype is going to change. So, highlighting that mutation can be neutral.

By allowing the students to experience the variation in genotype (e.g., changes in gene sequence) while keeping the phenotype invariant, Stacy would be able to show that change in the genotype is not necessarily followed by the change in phenotype (observable characteristic). This particular pattern of variation corresponds to the phenomenon of silent mutation.

Similarly, by keeping genotype invariant and varying the phenotype, Stacy would demonstrate that variations in the phenotype may not necessarily be due to variations in the genotype. In other words, the observable characteristic is not directly attributed to the biological process of inheritance but could be attributed to other factors such as environmental ones. To add
to her earlier statement on the first pattern of variation, Stacy elaborated upon her second pattern of variation:

We were thinking also about for example someone has an observable characteristic that changes and that’s phenotype, it does not always mean that genotype change. It is common misconception I think is that about someone goes to the gym and they have a lot of muscle. Just because their observable characteristic has changed, nothing has happened to the genotype. The children are going to inherit the genotype, they are not going to inherit the phenotype. Even though we are changing the phenotype does not mean that that is changing.

It can be seen that Stacy focused on one aspect at a time in her patterns of variation. Consistent with variation theory, she would be able to clearly and systematically explore the complex relationship between genotype and phenotype.

4.3.3. Presentation of Stacy’s Approaches to the Object of Learning and the Critical Aspects

Stacy argued that it is essential for students to understand diversity at the genetic level where genes are the foundation for the diversity of living things. Unpacking the big idea of diversity at the genetic level, Stacy believed that students need to know that mutation is one of the causes for genetic diversity and claimed:

So we picked mutations for our object of learning because when we thought of diversity, we thought of mutation because that’s what contribute to diversity. There is no mutation, we just going to have the same thing over and over again. Everyone is going to be the clone of each other. What are the different types of mutation? There are positive one,
negative and there is also neutral. I think a lot times people think mutation has to change something, but that’s not necessarily true. We just thought that’s the type of mutation that we want to focus on.

Stacy concluded that students’ incomplete understandings of the phenomenon of mutation could be attributed to them not fully comprehending the effects of mutations, that is, that they could be positive, negative or neutral. Drawing upon her knowledge of diversity and mutation, Stacy was able to identify this learning gap in the biology topics of genetics. Through her object of learning, she addressed the issue of partial understanding of mutation.

Stacy clearly pointed out the partial understanding of mutation that the students might have and elaborated:

I think the reason why I say students might not know because I did not know. [...] a lot prior knowledge was assumed. I do not think it is right to assume. I feel like you have to either get a background knowledge of your student or you have to just kind of cover as most of your basic. [...] I also know it from past experience. A lot of things I don’t know until someone told me you don’t know that.

Stacy’s reflection on her own experiences learning about diversity contributed to the way she conceptualised students’ the partial understandings of the biological phenomenon of mutation. Her past experiences informed her understanding of what is essential to cover and the assumptions she held about students’ prior knowledge. She declared that based on her past learning experiences, the relation between genotype and phenotype was important but it was not explicitly covered because it was assumed to be part of students’ prior knowledge. This constituted the learning gap she wanted to address in her lesson design.
Apart from her own learning experience, Stacy believed that the partial understanding of what mutation resulted from pop culture inferences of mutation, that is, the influence of popular media and claimed:

I think it is just the pop culture references that are out there like a lot of people think mutations are just kind of negative thing. I think that has to do with what they have seen in the media like teenage mutant, ninja turtle. […] Mutant sounds like something weird. Even neutral, some people would say if you’re changing something, something is going to change. Not necessarily. Because the genotype changes, that doesn’t mean the phenotype change.

Stacy argued that students were aware of the negative impacts of mutation due to the way that mutation was presented through media. On the other hand, the positive and the neutral impacts of mutation seem to be taken-for-granted. Stacy addressed this partial understanding through the critical aspects, which were the genotype and phenotype.

Stacy argued that the different types of mutation could be understood through the concepts of genotype and phenotype. She claimed that, “All of the different mutation we describe before, it kind of comes back to these two things, the critical aspects (genotype and phenotype).” Stacy stated that genotype and phenotype are the key aspects to understanding the big idea about genetic diversity. In her interview, she explained:

We think one of the big things to understand about genetics, the critical aspect, is genotype versus phenotype because genotype is at the genetic level, the DNA code is what the genes are. But the phenotype is the observable characteristic. I think students can get those mixed up. Not understand how they are related, sometimes they are not related.
As pointed out in the excerpts above, Stacy concluded that it was intuitive for students to think that variations in the phenotype is always attributed to genotypic variations. That is, differences in physical appearances is always due to variations in genes; the understanding thus negates considerations of environmental and other extrinsic factors that could have altered the phenotype of the organism. Because this conception was considered to contribute to students’ partial understandings of genotype and phenotype, Stacy noted it was critical for the students to experience the variation in genotype and phenotype separately in order to understand the relationship between the two.

Combining her understanding of the concept of mutation as well as the students’ conceptions that revolves around mutation, Stacy was able to identify the learning gap she wanted to address in her lesson. By introducing the critical aspects, she tackled students’ alternate conceptions and closed the learning gap. She also drew from her own experiences and difficulties in learning the topic, which helped shape the way she determined the object of learning and the critical aspect.

4.4. Nina’s experience of the lesson planning

4.4.1. Identification of Object of Learning and Corresponding Critical Aspects

Through the object of learning, Nina wanted the students to develop conceptual understandings of growth at the cellular level through the process of mitosis. She stated:

Cell cycle and cell division are basically the big ideas of understanding how cells go through phases that lead to cell division which leads to growth. There is a specific thing that needs to happen in metaphase, anaphase, telophase to lead to growth.
It can be seen from the excerpt above that Nina emphasised the relationship between the different phases of mitosis to the biological phenomenon of growth of an organism. She further elaborated:

We were just trying to narrow it down a little bit instead of trying to cover everything. We wanted them to learn the phases of mitosis for understanding what’s happening inside each cell in each phase and how each function is important for the end product and how all of those lead to final product.

In her interpretation of critical aspects, Nina believed that a critical aspect was what the students needed to learn to understand the object of learning. She identified the critical aspect to be the different phases in mitosis are significant to contribute to the final outcome of mitosis which is the production of two genetically identical daughter cells. Nina wanted to emphasize what occurs at each phase of mitosis and its significance to the overall process of cell duplication. Nina argued that relating the phases to the purpose of mitosis created an understanding of mitosis in a process-oriented way.

4.4.2. Introduction of the Critical Aspects

To introduce the critical aspects, Nina would point out the importance of each phase to the overall process of mitosis by highlighting the effects of the error in each phase of the mitotic process. That is, when one error was introduced in one mitotic phase, the rest of the phases remained invariant. Nina concluded that through this variation, students would be able to understand that the process of mitosis leads to growth and that different errors, for example, a dysfunctional mitotic spindle, or cytokinesis (division of cytoplasm in a cell to form two
daughter cells) not occurring properly, can prevent or disrupt growth. In her interview, she elaborated her pattern of variation:

[…] it is just absence from the cell or the function is disrupted or something is overactive or underactive as well. For example, if we are varying the functionality of mitotic spindle, number of chromosome and aspect of the cell cycle are constant. That’s one example. I would go with another one when the cytokinesis didn’t happen, what would you have…? You would have double DNA. They will be at the pole. It will still be one cell. Then you will continue. This cell tries to divide, what happens then? Just varying mostly what happen if you don’t have a phase.

To introduce the variation, students would use play-doh® to model of the process of mitosis. However, given a particular error in a specific phase, the students would need to figure out how the process would continue with the error. Through this hands-on experimental activity, students would be able to experience the contrast between the actual process and the disturbed process. Nina stated that by introducing errors and allowing the students to experience the disturbed process, it provided contextualised learning where the significance of the phases to the overall process was emphasised through its purpose. She further explained the activity:

For example, if we are varying the functionality of mitotic spindle, number of chromosome and aspect of the cell cycle are constant. That’s one example. I would go with another one when the cytokinesis didn’t happen, what would you have? You would have double DNA. They will be at the pole. It will still be one cell. Then you will continue. This cell tries to divide, what happens then? Just varying mostly what happen if you don’t have a phase, what happens if you don’t have structure. So varying phases and structure, I would say.
4.4.3. Presentation of Nina’s Approaches to the Object of Learning and the Critical Aspects

The big picture Nina wanted her students to see was that mitosis is a process fundamental for growth of living things; when the process of mitosis is disturbed, growth may be hindered. She claimed, “We thought that mitosis is a fundamental concept for understanding growth and for understanding cell biology. […] It is fundamental concept for growth. It allows organism to grow. It is helpful for teaching meiosis, if you’re talking reproduction as well.” Therefore, students were expected to build up an understanding of how growth occurred by learning the process of mitosis. Nina proposed that knowing the specific events in each different phases of mitosis, and relating back to the overall process of mitosis may develop an in-depth understanding of how mitosis may lead to growth.

Nina aimed to develop a conceptual understanding of mitosis. According to Nina, it is essential for the students to develop an understanding of mitosis as a whole process. She argued that this form of conceptual learning allowed students to think critically about mitosis instead of just merely memorizing the content details that might lead to fragmented learning. She elaborated that, “[…] it (object of learning) would engage them in conceptual learning. If we extend the object of learning to mitosis and how phases of mitosis lead to growth, that would be a better conceptual understanding reflected in our object of learning.”

Nina identified the critical aspect to be the different phases in mitosis. These phases are significant and contribute to the final outcome of mitosis which is the production of two genetically identical daughter cells. She explained that, “I think we were thinking about how to make sure that learning of the phases was contextualized with the purpose. Combining purpose
and process is conceptual understanding.” As can be concluded from her excerpt, Nina argued that relating the process of mitosis and the purpose of each different phases in mitosis would create a picture of a whole process of mitosis. It also provided a more contextualised way of understanding of the process of mitosis. In this regard, Nina emphasised that the critical aspects should tackle the issue of fragmented learning, where students learn knowledge pieces by pieces without relating them. When Nina was asked how combining purpose and process lead to conceptual learning, she responded:

I think instead of like having them as snapshot, “oh, this is what it looks like in this phase” you get kind of a more dynamic picture of what’s happening. Instead of memorizing, you understand what the structures are doing. So, you understand the process a little more than just like this happens or this is what’s going on. You understand that the spindle fibres are pulling and this is necessary because you need to have the different pole so that cell can split. I think the process kind of lead to the purpose in some ways. It’s kind of like all tie together.

Nina proposed that simply pointing out the structures of the cells and the mitosis process may not result in conceptual learning for the students. Instead it may lead to fragmented learning and students’ partially understanding each phase of mitosis in isolation. Nina emphasised the importance of connecting otherwise fragmented pieces of knowledge (e.g. keywords, terminology, and structure) in order to develop a clear picture of how the phases of mitosis work together to lead to growth. When she was asked why this conceptual understanding was important, she responded that “[…] Cell biology is so small, it’s hard to do that unless you teach it in like process oriented way that has a direction and purpose. But just like showing pictures and be able to name this structure, it’s not conceptual.”
Nina also brought in her own experiences of learning biology to her design of the object of learning and critical aspects. In the interview, she shared her learning experiences:

Kind of thinking back to how I learned and how it is fragmented a lot of the time, how I left high school feeling like a dictionary more than actually really understanding. In university, I gained a lot more on bigger picture, because I was taking a lot of biology courses. It was pretty easy to remember what was confusing with the vocab [vocabulary] because with all the chromosome all of those words were kind of similar and confusing. We were all discussing what we had trouble with and then I guess remembering our test, which one is meiosis, which one is mitosis.

She believed that her own learning of biology lacked clarity of the big picture of biological processes. She emphasised on how it was like puzzle pieces that were not put together. Eventually, she had trouble with terminologies which led to confusion in learning the overarching concept. Due to this, she crafted her critical aspects with the intention of promoting contextualised learning, which in this case, referred to the student understanding the overall mitotic process and how it relates to the biological phenomenon of growth. This allowed her to embed the biology terminology within select biological phenomenon (context).

Through her object of learning and critical aspects, Nina aimed to develop students’ conceptual understanding of mitosis by relating mitosis to the idea of growth at the cellular level. Nina’s personal learning experiences such as her own learning difficulties and her partial understanding of the topic as a student also shaped her object of learning and the critical aspects. She believed that promoting conceptual learning could help tackle rote memorisation that is commonly found in biology education as well as the fragmented learning she faced when learning biology as a student.
4.5. **Bree’s Experience of the Lesson Planning**

4.5.1. **Identification of Object of Learning and Corresponding Critical Aspects**

Bree worked on the Chemistry topic of rate of reaction, and focused on the factors affecting the rate of reaction. The object of learning was for students to identify the factors affecting the rate of reaction, and to manipulate the conditions for the chemical reactions. The object of learning focused on the experimental variables for a chemical reaction. In other words, the object of learning aimed to develop students’ understanding of chemical reaction both theoretically and experimentally. Students may apply their understanding of the variables to their experiments as described by Bree:

> If they understand what they are able to change, they could play with that, trying to get the reaction to occur after a certain time period like the clock reaction. We talked about this in our chemistry class to get them to explore this thing like challenge them to get the reaction to occur at exactly 30 seconds and they have to figure out different manipulation to get to there. Maybe they are changing the temperature, maybe they’re changing the concentration.

According to Bree, there are two independent critical aspects, the effects of catalyst on reaction rate and the effects of temperature on reaction rate. From these critical aspects, students would be able to understand: (1) increasing temperature may increase the rate of reaction; (2) a catalyst may change the rate of reaction, but catalyst does not influence the reaction yield. What Bree wanted to highlight for the students was the cause and effect of these two variables to enable students to manipulate these variables experimentally to obtain the desired result in a chemical reaction.
4.5.2. Introduction of the Critical Aspects

As there are many other factors influencing the rate of reaction (e.g. concentration of reactants, pressure, etc.), Bree would vary the temperature and keep other factors constant as her first pattern of variation and stated:

We kind of thought this is like a chemical experiment. So, in this situation, we wouldn’t change any of the factors that affect the reaction rate. So, we wouldn’t add any catalyst, the reaction would be the same, the concentration, surface area and volume will be the same and we would just talk about the temperature and how altering that would give you a different result.

In the second pattern of variation, Bree shifted the focus to the critical aspect of the effect of catalyst. She would keep other factors constant in order to allow her students to experience an experiment in the presence and in the absence of a catalyst in order for the students to note the difference in the rate of reaction. Bree explained that, “For catalyst, we thought of a chemical reaction. So, we keep everything else constant, we show a reaction in the presence of a catalyst and the absence of a catalyst.” This models the patterns of variation termed as “separation” where the aspect of catalyst was brought to the students’ attention and thus separated from the other aspects (concentration of the reactants, temperature of the chemical reaction, and the volume of the solution) that were kept invariant.

With the help of chemical reaction demonstrations, Bree would introduce the variation, one aspect at a time. To introduce the aspect of temperature, three same chemical reactions would occur at three different temperatures (high, room, and low temperature) and the rate of reaction would then be compared. Similarly, for the catalyst, there would two same reactions
occurring, one in the presence of a catalyst and the other in the absence of a catalyst. Bree argued that it is essential that the two critical aspects be separately introduced to ensure that the students understand both aspects clearly.

4.5.3. Presentation of Bree’s Approaches to the Object of Learning and the Critical Aspects

Bree focused on the various factors influencing the rate of reaction. She believed that this is a good place for students to start developing an understanding of the concept of rate of reaction. She claimed that:

We kind of just focused on the first section because we thought it was kind of the baseline for all of the rest of unit. You really need to understand all of this in order to understand everything else. We chose the factors influencing the rate of reaction. Bree argued that this was a worthwhile object of learning because it forms the “baseline” (excerpt above) where other concepts can build upon. The selected object of learning serves as the introduction to various topics that will be subsequently covered in depth, such as the rate equation and changing experimental conditions. Therefore, the object of learning may form a good foundation for understanding kinetic chemistry.

Taking into account that most students were already aware of the spontaneity of chemical reactions, she would use this as a chance to extend her students’ knowledge by introducing how to manipulate chemical reactions. In the interview, she claimed:

I think we picked that more because I guess starting the unit, you probably don’t really think of the different things that affect the rate of reaction. It’s like it happens when you
add these two together, or it did not happen. There is not a lot of thought to whether you can increase the rate or slow it down.

As seen from the excerpt, Bree found that the object of learning allowed students to expand their idea of a chemical reaction experimentally in laboratory-based activities. It is evident that Bree planned the lesson with the goals of maximising students’ learning. Similarly, teachers in a learning study were reported to have pitched their students’ learning at a higher level of difficulty (Lo et al., 2005). This further emphasised how variation theory can be used to cater for individual differences.

According to Bree, the critical aspect was the main point she wanted to get across in the lesson. The two independent factors affecting rates of reaction, temperature and the presence of a catalyst, are among a few other factors to be covered in the curriculum. Bree stated that it is essential to be detailed in covering the select critical aspects. This allowed students to explore the critical aspects more in-depth as she claimed, “[…] I think it’s kind of important to go into the background of catalyst and explain it a little bit further so that they understand what it does.” She further added that, “We want them to understand how temperature affects the reaction rate. If you increase the temperature, you increase the reaction rate. Then also specifically the exothermic and endothermic reaction.”

Drawing from the pre-test designed implemented by external researchers (see appendix G for the pre-test and pre-test results) and reported science education literature (see appendix E for students’ common conceptions on rate of reaction), Bree was able to identify some alternative conceptions and further support her choice of the critical aspects. She explained how she incorporated the literature research in her lesson plan:
We chose those (critical aspects) because we looked at the misconceptions that you gave to us (literature researches). We found that they were the ones with the most misconceptions and also reflecting on our own learning that is the trickier one. Especially in high school where you heard the word “catalyst”. You maybe have seen one, but you do not really know what it is or how it works. And then temperature can be kind of confusing as well especially for endothermic and exothermic. We kind of looked at the one where the students may have difficulties with, shown to have the most difficulties.

Bree argued that alternative conceptions were commonly found to include the factors that she focused on: students might not have a complete understanding of what a catalyst is and the cause and effect of temperature to different types of reactions (exothermic and endothermic reactions). Bree also argued that students had a tendency to extrapolate information from their prior knowledge that may not always be consistent with canonical science. Therefore, Bree saw the importance of addressing the alternative conceptions students might have through the critical aspects.

In addition to addressing alternative conceptions, Bree also highlighted that students may have issues with terminology. Reflecting on her own experiences, Bree argued that terminology such as catalyst was new to students and students may need to grasp the meaning of the terminology. In her interview, she shared:

From my own experience, from the time we start looking at the curriculum, you do not talk a lot about catalyst until you get to reaction rate and equilibrium that sort of thing. Again, a new vocabulary that they haven’t heard before. So, especially the first time you hear thing, it’s hard to wrap your head around it.
When identifying the object of learning and the critical aspects, Bree brought with her the knowledge of the content and referred to the research literature as resources for students’ alternative conceptions and difficulties. Bree was able to see what students’ prior knowledge was (the feasibility of chemical reaction), what students needed to know (in depth understanding of the effect of catalyst and temperature to rate of reaction), and what students have not yet learned (the terminology). Bree was able to focus on the content and further extended it to the aspects that are sensitive to students’ understanding.

4.6. Summary

The individual teacher candidates’ profiles describe their lesson plan in detail. The teacher candidates’ lesson plans were examined, focusing on the objects of learning, critical aspects and patterns of variation. Working with large science curricular topics such as genetics and cell division as well as rate of reaction, the teacher candidates focused their lessons on subtopics such as mitosis, meiosis, inheritance, mutation, and factors influencing rate of reaction. Moreover, the teacher candidates’ approaches to crafting the objects of learning and critical aspects were identified and described. The phenomenographic analysis of the teacher candidates’ approaches to identifying the object of learning and the critical aspects will be presented in the next chapter. Categories of description that capture the variation in the approaches the teacher candidates used will be presented.
CHAPTER FIVE: DATA ANALYSIS and CONCLUSIONS

This chapter presents the analysis of the lesson plan and the categories of descriptions that describe the different ways the teacher candidates identify the objects of learning and the critical aspects. Following the analysis, I will summarise the study and answer my research questions. I will also discuss the significances as well as challenges and limitations of this study. I will conclude with the implications of this study and suggestions for future research as well as the researcher’s reflection.

5.1. Analysis of the lesson plan

This study reveals that the teacher candidates reflected on what it takes for students to learn the object of learning and designed patterns of variation and invariance to introduce the critical aspects. I analysed the object of learning in terms of its structural and referential aspects (Pang, 2003); the structural aspect refers to the focus of the critical aspect, whereas the referential aspect refers to the meaning ascribe to the critical aspect. The teachers identified an object of learning as students developing understanding of the process of mitosis through systematic variation of the individual phases in the process. Understanding mitosis can be challenging for students (Lewis et al., 2000; Marbach-Ad et al., 2000). The structural aspect was the different phases of mitosis and their functional relationships, while the referential aspect was how the different phases of mitosis are interrelated and contribute to the overall purpose of mitosis.

Another object of learning which the teachers identified was to build students’ understanding of inheritance at the cellular level. Linking inheritance with cell division has been found to be important for students to learn the topic of inheritance, where students were reported
to face difficulties in making the connections between cell division and genetic information (Williams et al., 2011). The lesson the teachers designed focused on the recessive and dominant traits as the structural aspects, and the referential aspect was how the visible traits can be categorised as dominant or recessive, depending on the genes expressed for that particular trait.

Another object of learning the teachers identified was for students to develop an understanding of how mutation contribute to the diversity of living things. The different effects of mutation (positive, negative, and neutral), and the relationship between the genotype and phenotype were the structural aspects. The referential aspects included how mutation is one of many processes that could contribute to the diversity in living things. However, alterations of genotype do not always result in phenotypic changes (silent mutation). Similarly, variations in phenotypes could be due to extrinsic factors and are not always solely accounted for by genotypic changes.

The teachers also identified the students’ object of learning as developing conceptual understanding of how growth occurs at the cellular level. By understanding the process of mitosis, students may be able to foster their understanding of the link between growth and cell division (Kruger et al., 2006). The structural aspect was the different phases of mitosis, while the referential aspect was that the different phases of mitosis contribute to the formation of two genetically identical daughter cells.

Another object of learning the teachers identified was for students to develop the skill of manipulating the factors affecting the chemical reaction. The object of learning allows students to design their own experimental set-ups to maximise the rate of reaction. The students would learn the effect of temperature and the presence of a catalyst on the rate of reaction (the structural aspect). The referential aspect was that the temperature of a chemical reaction can be
manipulated to obtain the desire rate of reaction, and the catalyst can be added to speed up the rate of reaction.

Marton (2009) asserts that solely focusing on similarities may not be sufficient to promote learning; experiencing differences are also pertinent to understanding the object of learning. According to Marton and colleagues (2004), the use of variation can serve four instructional functions including contrast, generalisation, separation, and fusion. In this study, the teacher candidates utilized patterns of variation to create contrast between two critical aspects and/or to separate the critical aspects from other aspects of the object of learning.

An example of contrast included comparing the normal process of mitosis and errors within the different phases of mitosis. According to Tan et al. (2017), variation in the phases would help students to understand the importance of that particular phase in relation to the overall purpose of mitosis. Another contrast in the critical aspects the teacher candidates employed pertained to students experiencing the dominant and recessive traits as the results of gene expression. The dominant traits were contrasted with the recessive traits. By contrasting the different types of traits and linking it to gene expression, students would be able to discern the relationship between the traits and the gene expression. This pattern of variation allows students to experience the part-part relationship of the object of learning (Lam et al., 2013; Olteanu et al., 2013).

To discern a critical aspect, the critical aspect must be separated from the whole, that is through keeping other aspects invariant. When the critical aspect of genotype is varied while the aspect of phenotype is kept invariant, genotype is separated from phenotype. The students would then be able to discern phenotype and genotype separately. Similarly, when the temperature of
the chemical reaction was varied, while keeping other factors influencing rate of reaction constant, the effect of temperature was separated from other factors influencing rate of reaction.

5.2. Categories of Description of the Variation in the Participants’ Experiences

In this study, I am exploring the variation in the ways the participants approached the objects of learning and the critical aspects. The phenomenographic analysis of the data presented in Chapter 4 revealed three qualitatively different categories of description which cut across the entire data set:

1. Analysing content knowledge in order to develop a coherent learning plan
2. Reflecting on personal experiences and beliefs about teaching and learning
3. Developing knowledge about students and their prior knowledge as informed by external resources

Category 1 describes how the teachers focus on the content knowledge, with no or little consideration of the students’ prior knowledge. Category 2 describes how the teachers drew from their own experiences of learning the topic as students themselves and their own perceptions of the difficulties students face in learning the select topics. Category 3 focuses on how the teachers would develop and draw on knowledge about their students and their prior knowledge, in addition to focusing on biology or chemistry content and their own experiences, to construct the object of learning and critical aspects.

The categories are ordered (Marton, 1981) to capture the increasingly complexity in how the teachers approach the process of identifying the object of learning and critical aspects, where categories deemed more complex include aspects of the less complex categories. In other words, more facets of teaching instruction and planning are considered in the process as we progress.
through the categories. For example, Category 1 describes the teacher candidates’ overt focus on curricular content to shape the object of learning and critical aspects. In contrast, in category 2, the teachers were able to extend their approach by drawing on their own personal experiences that have shaped their beliefs about teaching and learning the topic. This allowed for gaps in students’ knowledge to come to the fore of their attention and were subsequently addressed in how they crafted the object of learning and critical aspects. Category 3 would imply that the teachers are able to draw from their own personal learning experiences, beliefs about teaching and learning, and examination for curricular content to influence their choice of the objects of learning and critical aspects. However, the process is further informed by external resources, such as research literature, that teachers could utilize to refine their approach. Their approach further illustrates the teachers’ attempts to connect students’ prior knowledge, academic research and stipulated curricular content. This suggest their increasing sensitivity towards students and the learning process (e.g. Lo, 2012). The categories are discussed in the sections that follow.

Category 1: Analysing content knowledge in order to develop a coherent learning plan

As captured in the earlier descriptions of each teacher candidates’ approach to identifying the object of learning and critical aspects, three key points were highlighted by the teacher candidates in relation to the content knowledge: (1) the teacher candidates believed that a critical aspect should cover a fundamental concept related to the topic; (2) the teacher candidates presented the critical aspects in a conceptual and contextualised manner; and (3) the teacher candidates identified how a concept is positioned within a bigger topic. This suggests that the participants had a good conceptual understanding of the content selected, which is essential in
teaching for understanding (Thompson, Carlson, & Silverman, 2007) and to design an effective lesson plan (Lui & Bonner, 2016).

The teacher candidates perceived there was the need to focus on concepts fundamental to learning a topic. In other words, mastering the object of learning and the critical aspects may help students develop a good foundation for the topic; students lacking understandings of basic scientific concepts have been previously reported (Klymkowsky, 2007). The teacher candidates knew what students could learn in order to facilitate subsequent learning of more challenging concepts or demonstration of skills, for example, factors influencing the rate of reaction is a fundamental concept to conducting experiments.

Teachers also presented the objects of learning and the critical aspects in a conceptual and contextualised manner. The idea of conceptual learning was to tackle the fragmented learning that is common in science teaching (Lewis et al., 2004; Tsui et al., 2004). One of the ways that the teacher candidates supported conceptual learning was through combining different critical aspects (e.g. a combination of the phases in mitosis and the overall purpose of the process). Furthermore, Van Breukelen, Van Meel, and De Vries (2017) stated that to develop deep conceptual understandings requires contextualisation of the concept. The teacher candidates clearly put an emphasis on the context in the teaching and ensured that students would be able to see the object of learning from various perspectives (e.g. learning mitosis from human development context). This may lead to a more comprehensive understanding of the object of learning.

Similarly, related to the content knowledge, the teachers explored the relationship between the targeted concept and other concepts. The teacher candidates developed a network of related concepts under a big topic in order to identify the relatedness and differences between
concepts. This approach is consistent with literature that asserts that deepening conceptual understanding requires significant relationships between various related concepts to be clear (Van Breukelen et al., 2017). For instance, Jim explored how learning cell division may be related to the idea of inheritance; these curricular topics are often separated in textbooks and other curricular resources. Additionally, variation theory posits that it is essential that teachers provide examples and explanations that focus on both differences and similarities between concepts rather than the concept alone (Nilsson & Vikstrom, 2015). This can be seen in Stacy’s lesson plan where she highlighted the differences between genotype and phenotype as well as how they are related. Moreover, Taylor and Rohrer (2000) suggested that contrasting various concepts and providing instructions with intermixed examples promote better learning outcomes.

The teacher candidates’ identification of the object of learning and critical aspects drew from the content/concepts that the students need to learn from the science curricula. Their approach has similarities with the social semiotic approach Fredlund et al. (2015) employed to analyse textbooks, which served as an approach to identifying the critical aspects of the object of learning. Fredlund found that unpacking the object of learning to its constituent parts was necessary. This finding is also evident in this category of description as teacher candidates did not merely cover curriculum, but rather, they studied the curriculum and related various concepts to create a coherent lesson. The study of curriculum, text books, and other teaching resources is indeed one of the essential elements in lesson planning (Runesson, 2015). However, the power of these resources in identifying appropriate critical aspect is still underexplored. In this study, this is considered to be a viable approach to guide the teacher candidates in identifying the object of learning and critical aspects.
In determining the object of learning, the teacher candidates unpacked big curricular topics to order to identify overarching concepts of the topic of interest. The participants also intended to develop students’ conceptual understanding of the content rather than merely delivering the facts and reinforce memorisation of content. This category further emphasised the findings in the research literature. For example, Ko (2012) noticed that teacher candidates focused their teaching to cover the content as they tended to overlook the complexity of the object of learning and the critical aspects, because they might not have understood the content deeply. Through planning a lesson based on variation theory, the teacher candidates became more aware of the dynamic nature of the object of learning. This indicates that variation theory may play a significant role in building teacher candidates’ content knowledge (Lai, et al., 2013).

This category of description also highlights persistent issues in teacher education regarding developing science teacher candidates’ understandings about scientific concepts (Mantyla & Nousiainen, 2014; Parker & Heywood, 2000; Wheeldon, 2017). The concern revolves around how teacher candidates should not merely acquire or possess content knowledge, but that teacher candidates need to increase their capacity to discriminate knowing from understanding of content by focusing on the coherency, conceptualisation, and causal explanation in scientific knowledge. It has been shown in this category that the teacher candidates were able to recognise some basic content and have a clear direction of progress of content knowledge, as well as clarity about how various concepts/contents are related (Brante et al., 2015). Lui et al. (2016) suggested that teacher training should develop teachers’ conceptual knowledge that is required to plan teaching in ways that help students learn concepts as well as skills. This shall remain to be the focus of teacher education (Kind, 2014), as is alluded by the teacher candidates’ experiences captured in this category.
Category 2: Reflecting on personal experiences and beliefs about teaching and learning

Research literature highlights the value of reflection for teacher candidates in preparing them for the challenges and realities of teaching practice (e.g. Griffiths, 2000; Lamb & Aldous, 2016; Macdonald & Tinning, 2003). In this category of description, the teachers’ reflections were structured based on three distinct types of experiences: (1) reflection on personal learning experiences; (2) reflection on teaching experiences (e.g., tutoring); and (3) reflection on personal beliefs about teaching and learning the select topic.

The teacher candidates’ reflections on their experiences of learning the select topic and the challenges helped in their identification of learning gaps, which consequently shaped the way they framed the object of learning and critical aspects. The learning difficulties (e.g. with biology terminology) were seen as obstacles to mastering the object of learning. Moreover, the teacher candidates pinpointed learning gaps and fragmented learning that were commonly found in science teaching. The teacher candidates perceived that the purpose of the object of learning and the critical aspects was to address these issues.

The teacher candidates reflected on their experiences, such as learning difficulties or gaps, instead of focusing excessively on teaching arrangements or strategies that their past teachers used to teach the same content. Teacher candidates need to be encouraged to reflect on their own learning experiences and develop pedagogical knowledge through exploring and reviewing their own understanding of scientific concepts, learning strategies and learning difficulties (Heywood, 2007). This sort of reflection allows the teacher candidates to become more aware of their own learning processes to inform their pedagogy. This opportunity provided
glimpses of how teacher candidates can explore their dual roles as students and prospective teachers during teacher education (Tan, 2018; Tan et al., 2017).

In addition to their own learning experience, some of the teachers’ reflective process (such as that of Mary’s) was guided by their limited experience in tutoring students in informal settings. Because the participants were teacher candidates, their teaching experiences were limited (Sims et al., 2009). However, from this limited teaching experiences, the participants were able to identify the learning gaps and students’ alternative conceptions. They were able to use this knowledge to frame their object of learning and the critical aspects.

These reflections guided the teacher candidates’ approach to identifying the object of learning and critical aspects. Lo et al. (2005) argued that one of the reasons why it is challenging for teachers to identify the critical aspects is that teachers themselves do not find the aspects to be difficult to discern and thus the aspects become taken for granted. However, the reflections on their experience learning and teaching allowed the teacher candidates to identify the learning difficulties and learning gap that would otherwise be left unattended; the object of learning and the critical aspects provided a platform to address these issues. This is one of the educational benefits of teachers learning to work with variation theory as it encourages the teachers to reconceptualise their previous experiences and to build their knowledge of learning difficulties and learning strategies (Msonde et al., 2017).

Apart from reflecting on the learning and teaching experiences, the teacher candidates’ reflection also revolved around their beliefs in science education. The teacher candidates stated that science education should develop students’ critical thinking and ability to get scientific findings across to society. This was portrayed in the object of learning and the critical aspects, which could potentially extend from the curriculum to supporting the dialogues around science-
related issues in the society. It opens up a possibility to expand variation theory to address learning outside of prescribed curriculum and to develop decision-making skills (Pang, 2010).

This study expanded on the research on teacher candidates’ reflection in a learning study. Wood (2013) found that when engaging in learning study, teacher candidates’ reflections were centered around a variety of issues including the object of learning and the role of teachers. The findings of this study extend the issues to including teacher reflection on learning and teaching experiences, as well as their personal beliefs to inform the lesson planning using variation theory. Thorsten (2015) argued that variation theory helps teachers to question their habits and previous experience. This is important for teacher candidates’ development as a reflective practitioner (Schön, 1983).

In this category of description, the experience of identifying the object of learning and critical aspect is enriched with the teachers’ reflections about their own experiences and beliefs. Extending beyond a close examination of curricular content (Category 1), the teachers also focused on students’ learning difficulties and gaps in learning. Through the object of learning and critical aspects, the teacher candidates focused on addressing issues such as fragmented learning and partial understandings of concepts, which constitute learning difficulties commonly found in science teaching.

Category 3: Developing knowledge about students and their prior knowledge as informed by external resources

Category 3 involves teacher candidates developing knowledge about students’ prior knowledge, difficulties, and learning gap, as they draw from external literature resources, their learning and teaching experiences, and their understanding of the select topic. The teacher
candidates recognised that teaching requires taking into consideration both content knowledge and knowledge about students. The teacher candidates’ sensitivity towards students’ learning needs are reflected in their approach to the object of learning and the critical aspects.

Research literature served as an external resource the teacher candidates could refer to (see appendices C – G for the external resources); I made these resources available to the participating teachers through journal articles focusing on students’ difficulties and common conceptions about the topic of rate of reaction, genetics, and cell division. Drawing on the research literature, the teacher candidates were able to identify alternative conceptions students held. Students often come to class with alternative conceptions from their experiences or intuition that may hinder their learning (Duit & Treagust, 2003). The teacher candidates saw the need to address these alternative conceptions in the object of learning and the critical aspects. Many learning studies have been conducted to address students’ alternative conceptions (e.g. Lo et al., 2005; Pang et al., 2012) and have resulted in positive student learning outcomes.

From the external resources, the teacher candidates were able to identify students’ difficulties and learning gap. This helped the teacher candidates pinpoint differences in the understandings that students began with and understandings students were to develop (Davies et al., 2008). The participants pointed out issues and difficulties of learning that were commonly found for the selected topic. The critical aspects were aimed at tackling students’ learning difficulties. This has been commonly found in many learning studies (Lo et al., 2005).

As demonstrated by the participating teachers, research literature constitutes a useful resource to help teachers identify students’ difficulties, prior conceptions and learning gap. It can be used to identify an appropriate object of learning and the critical aspect. Referring to the research literature is a common approach to determine an appropriate object of learning and the
critical aspects (Lo, 2012). Due to the teacher candidates’ lack of teaching experiences, research literature can become an important resource to support more student-centered lesson planning (see Tan, 2018). The teacher candidates were able to go beyond their own perspective and consider the students’ thinking and interest during lesson planning as shown in Bree’s lesson planning. Bree said that:

I think in our usual lesson planning, we tend to do like top-down thing. We make our learning objective, think about our assessment, we fill in the rest. I think the process of doing this force us to think more about where our students are at, where we want them to be and how we can get them there. I think it’s more student-focus.

By embracing variation theory, the teacher candidates searched for appropriate pedagogical strategies which addressed students’ learning difficulties.

Teaching requires teachers to see the content from their students’ perspective (Ball & Forzani, 2009). The teacher candidates also argued that it is critical that students’ perspectives are considered when identifying the critical aspect. This includes students’ interest, what students think, and how the topic can be related to students’ everyday life. For instance, Jim believed that students are interested in the concept of traits as it is related to how they look as an individual. This knowledge allows teachers to design classroom instructions that better facilitates students’ learning, and to empower students to see the object of learning in a more comprehensive way.

When identifying the object of learning and the critical aspects, the participants developed their knowledge of students by analysing literature resources. They argued that the critical aspect is supposed to cover students’ learning needs and to overcome their learning difficulties. Variation in students’ understandings of an object of learning (V1) is an important source for identifying the critical aspects (Bjorkholm, 2015; Thorsten, 2015; Wood, Lu, &
Andrew, 2015). This approach to identifying an object of learning and the critical aspects may develop teacher candidates’ sensitivity towards students’ learning needs and result in a more student-centered pedagogy.

Variation in students’ understanding and focusing on revealing students’ prior conceptions and alternative conceptions allowed the participants to analyse students’ thinking about the subject matter. Identifying students’ different ways of understanding, in order to appropriately determine the critical aspects, is a challenging task. Davies et al. (2008) and Ko (2012) argued that practicing this task may prompt a shift in teacher candidates’ thinking about teaching: from delivering content to preparing students to apply knowledge. Therefore, the teacher candidates may develop a more student-centred pedagogy and increase their awareness of students’ learning needs (Tan, et al., 2013). Such awareness focuses on the relation between the content, the teaching, and students’ learning (Nilsson, et al., 2015).

In this category of description, the teachers drew on research literature and limited teaching experiences (if any) to identify the aspects they deemed critical to learning the object of learning because they could not be discerned by students. Pang et al. (2016) reinforced that critical aspects should not be directly derived from disciplinary knowledge alone as of category 1. By taking into account the knowledge of students, the object of learning and the critical aspects alluded to the differences in the way students could see the object of learning. This is consistent with the purpose of learning study, which is to accommodate the differences among students.
5.3. **Summary of the Study**

This descriptive case study is framed using variation theory as the theoretical framework, and phenomenography as the methodological framework. This study examined how teacher candidates applied variation theory in their lesson planning. This study aimed to investigate the teacher candidates’ experiences in identifying the object of learning and the critical aspects which are important processes in a learning approach albeit being an understudied area. In an attempt to explore the variation in the ways teacher candidates identify the object of learning and the critical aspects, this study is guided with the following research questions:

1. **What is the object of learning as the point of departure and defining it in terms of the critical aspects in the teacher candidates’ lesson plans?**

2. **How are the critical aspects introduced in the form of patterns of variation in the teacher candidates’ lesson plans?**

3. **What are some of the ways the teacher candidates approach the object of learning and the critical aspects?**

This study was designed to introduce variation theory to 27 teacher candidates in a course. Collaboratively in a group of four to five teacher candidates, they learned about variation theory and subsequently planned a lesson focusing on either the topic of genetics and cell division (for biology) and rate of reaction (for chemistry). Among 27 teacher candidates, five were self-selected and interviewed to explore in greater detail their experiences in planning a lesson using variation theory. The interview transcripts were examined collectively with other data sources, such as graphic organisers the teacher candidates created and researcher field notes. A profile was developed for each teacher candidate which consisted of the object of learning and the critical aspects they identified, patterns of variation designed, as well as how they approached
the object of learning and critical aspects. A further analysis, including the construction and ordering of the categories of description was implemented as accorded by phenomenographic methods. I summarize my research findings by answering the research questions that guided my study.

**Research question 1: What is the object of learning as the point of departure and defining it in terms of the critical aspects in the teacher candidates’ lesson plans?**

In this study, the teacher candidates determined the object of learning and corresponding critical aspects that were aimed to develop students’ conceptual understanding and skills as well as address students’ learning difficulties and gaps. Table 2 presents the teachers candidates’ object of learning and the corresponding critical aspects. The table is modified from the analysis provided by Tan et al. (2017). The critical aspects of the object of learning are broken down into its structural and referential aspects (Pang, 2003), where the structural aspect refers to the internal horizon of the critical aspect, that is, the parts of the critical aspect and the relationship between the parts, and the referential aspect refers to the external horizon of the critical aspect which provides meaning to the critical aspect.
Table 2

*The teacher candidates’ identification of the object of learning and the critical aspects for their planned lessons*

<table>
<thead>
<tr>
<th></th>
<th>Mary</th>
<th>Jim</th>
<th>Stacy</th>
<th>Nina</th>
<th>Bree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object of learning</td>
<td>To develop systematic</td>
<td>Build students’ understanding</td>
<td>Develop an understanding of how</td>
<td>Develop conceptual understanding of how</td>
<td>Identify the factors affecting rate of</td>
</tr>
<tr>
<td></td>
<td>understanding of mitosis as</td>
<td>of inheritance at the cellular</td>
<td>mutation may contribute to the diversity</td>
<td>growth occurs at the cellular level</td>
<td>reaction, and to manipulate conditions</td>
</tr>
<tr>
<td></td>
<td>a process</td>
<td>level</td>
<td>of living things</td>
<td></td>
<td>for the chemical reactions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critical Aspects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structural aspects</td>
<td>Different phases in mitosis</td>
<td>Recessive and dominant traits</td>
<td>Different effects of mutations (positive,</td>
<td>Different phases in mitosis and the</td>
<td>The cause and effect of the factors</td>
</tr>
<tr>
<td></td>
<td>and functional relationships</td>
<td></td>
<td>negative, and neutral); the relationship</td>
<td>product of mitosis process</td>
<td></td>
</tr>
<tr>
<td></td>
<td>between the phases</td>
<td></td>
<td>between genotype and phenotype</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Referential aspects</td>
<td>The different phases in</td>
<td>The genes, when expressed,</td>
<td>Mutations, despite their effects on</td>
<td>Each phase of mitosis has different</td>
<td>To obtain the desire rate of reaction,</td>
</tr>
<tr>
<td></td>
<td>mitosis are interconnected</td>
<td>result in visible traits that</td>
<td>populations contributes to the genetic</td>
<td>functions that lead to the end product</td>
<td>the variables (catalyst and temperature)</td>
</tr>
<tr>
<td></td>
<td>to lead to the overall</td>
<td>could be categorised as</td>
<td>diversity of living things. The mutations,</td>
<td>of mitosis that is two identical daughter</td>
<td>can be adjusted accordingly</td>
</tr>
<tr>
<td></td>
<td>purpose of forming the</td>
<td>recessive or dominant for</td>
<td>while altering the genotype, may not</td>
<td>cells</td>
<td></td>
</tr>
<tr>
<td></td>
<td>identical daughter cells</td>
<td>that particular trait</td>
<td>always result in phenotypic changes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The table above presents the teacher candidates' identification of the object of learning and the critical aspects for their planned lessons. Each candidate focuses on different aspects of the subject matter, such as understanding mitosis, inheritance, mutations, and cellular growth, among others. The table highlights their perspectives on how these concepts should be taught systematically and the critical aspects that need to be emphasized for effective learning.
Research question 2: How are the critical aspects introduced in the form of patterns of variation in the teacher candidates' lesson plans?

After identifying the object of learning and the critical aspects, the teacher candidates designed pattern of variation to introduce the critical aspects that model the pattern of “contrast” and “separation”. Table 3 presents the teacher candidates’ patterns of variation and invariant to introduce the critical aspects.

Table 3

<table>
<thead>
<tr>
<th>Pattern of variation</th>
<th>Mary</th>
<th>Jim</th>
<th>Stacy</th>
<th>Nina</th>
<th>Bree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variation in phases of mitosis through demonstrating deviation from the normal process of mitosis while keeping the biophysical entities (e.g. chromosome, spindle, etc.) invariant</td>
<td>Variation in phases of mitosis through demonstrating deviation from the normal process of mitosis while keeping the biophysical entities (e.g. chromosome, spindle, etc.) invariant</td>
<td>(1) Variation in the genotype while keeping the phenotype invariant</td>
<td>Variation in phases of mitosis through contrasting successful and unsuccessful process of mitosis while keeping the biophysical entities (e.g. chromosome, spindle, etc.) invariant</td>
<td>(1) Variation in the temperature of the chemical reactions while other factors (e.g. concentration of reactants, volume) are invariant</td>
<td>(2) Variation in the chemical reaction with and without catalyst while other factors (e.g. concentration of reactants, volume) are invariant</td>
</tr>
</tbody>
</table>
Research question 3: What are some of the ways the teacher candidates approach the object of learning and the critical aspects?

The phenomenographic analysis of the data resulted in three categories of description: (1) Analysing content knowledge in order to develop a coherent learning plan; (2) Reflecting on personal experiences and beliefs about teaching and learning; and (3) Developing knowledge about students and their prior knowledge as informed by external resources. The summary of the categories of description, shown in Table 4, focuses on the structural and referential aspects of each category.

First category of description revealed that the teacher candidates focused on the content knowledge. In identifying the object of learning and the critical aspect, the teacher candidates made reference to the content and concepts in relation to the entire topic or a group of topics. This process requires teachers to have broad and deep knowledge of the relationship between various concepts in order to derive the different aspects that should be learned with respect to the object of learning. This requires the teacher candidates to see the content from a teacher perspective, which has been described in literature as variation in teachers’ understanding (V2) that focuses on unfolding the different ways teachers approach the object of learning (Lo, 2012; Pang et al., 2012).
Table 4

A summary on the categories of description

<table>
<thead>
<tr>
<th>Category of description</th>
<th>Different ways of approaching the object of learning and critical aspect</th>
<th>Structural aspect</th>
<th>Referential aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Analysing content knowledge in order to develop a coherent learning plan</td>
<td>Content of the topic</td>
<td>Objects of learning and critical aspects are derived from teacher candidates’ conceptualisation of the topic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Holistic understanding of the topic</td>
<td>Objects of learning and critical aspects are derived from the need to develop conceptual and contextualised learning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relationship between concepts and between topics</td>
<td>Object of learning and critical aspect are derived to develop a coherent learning</td>
</tr>
<tr>
<td>2</td>
<td>Reflecting on personal experiences and beliefs about teaching and learning</td>
<td>Their own difficulties in learning the topic as students</td>
<td>Through careful consideration of their past learning experiences to identify: (1) own learning difficulties; (2) common teachers’ assumptions of students’ prior knowledge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Their own teaching (tutoring experience)</td>
<td>Identifying common students’ learning gap through previous teaching experiences (tutoring)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Their own beliefs about what is worth learning</td>
<td>Developing students’ critical thinking about scientific knowledge and issues</td>
</tr>
<tr>
<td>3</td>
<td>Developing knowledge about students and their prior knowledge as informed by external resources</td>
<td>Sensitivity about students’ learning needs</td>
<td>Addressing students’ alternative conceptions, learning difficulties, and learning gap that are found in the literature research</td>
</tr>
</tbody>
</table>
The second category of description showed that teacher candidates were able to reflect on their learning and teaching experiences of the topic as well as personal beliefs about science education. Their reflections were focused on student learning difficulties and learning gaps. Reflective practice is encouraged in the teacher education and this study showed that teacher candidates begin to engage in the process by learning to examine their own experiences and personal assumptions about teaching and learning. This category extends teachers’ focus on content to learning processes of the content which indicates that teacher candidates were able to adopt a more dynamic view of the object of learning.

The third category of description includes students’ perspectives as the central focus of the teachers’ experience of determining the objects of learning and critical aspects. What is worth for students to learn (Marton et al., 1997; Lo, 2012) derived from how learning the object of learning may open up opportunities to address alternative conceptions or to counter learning difficulties. Therefore, the relation between the students and the object of learning was explored, and the process was supported by the teachers’ drawing from relevant research literature that were made available to them through the study.

5.4. Significances of the Study

This study provides an insight into the complexity of teacher candidates learning to plan a lesson using variation theory. The study focuses on the teachers’ approach to identifying objects of learning and the critical aspects, which is a gap in the current research literature. This process has been known to be a challenging task for both teachers and teacher candidates. By unpacking the phenomenon, this process becomes clearer and can help inform teacher education programming. Consequently, teacher education programmes can be designed to provide teacher
candidates with opportunities to explore and consequently adopt ways of identifying the object of learning and the critical aspects that would fit into their classroom context.

This study presents the teacher candidates’ experiences in applying variation theory to their lesson planning. The findings show that teacher candidates were able to adopt a variety of ways of identifying the object of learning and the critical aspects, as was captured through the three categories of description presented in the results section. The teacher candidates explored content knowledge, developed knowledge of students, and reflected on their own learning and teaching experiences. This indicates positive teacher candidates learning outcomes that were manifested through the teacher candidates’ participation in variation theory-framed lesson planning. The findings thus support current literature foregrounding the potential of learning study to promote learning amongst teacher candidates. However, like several earlier studies, the current study underscores the need to modify the learning study process for adaptation of the approach in initial teacher education (Brante et al., 2015; Davies et al., 2008).

The findings from this study demonstrate the potential of variation theory in guiding the teacher candidates to develop a theoretical lens (Tan, 2014) in designing a lesson. This study shows teacher candidates’ ability to use theory when exploring the content knowledge, planning a lesson, and to integrate objects of learning and critical aspects with instructional activities they designed (drawing on patterns of variation and invariance) in order to cater to students’ learning needs. Therefore, variation theory may have potential to bridge the theory and practice gap, and thus address this gap area in teacher education, as is commonly reported in research literature.

What should also be noted is this study diverges from typical learning study, where teachers engage with identifying objects of learning and critical aspects through brainstorming, literature reading, social semiotic approach and empirical research (student pre-lesson tests and
interviews) (Bjorkholm, 2015; Fredlund et al., 2015; Lo et al., 2005). Although the teachers could not participate in a regular learning study where affordances like implementing pre-lesson tests are used to ascertain students’ prior knowledge, the participating teachers were able to identify students’ gaps in understandings through the content, their personal learning experience as well as the research literature. This further underscores the need to create opportunities for teachers to engage with reflection and to explore their own beliefs about teaching and learning of specific topics through teacher education programmes.

For teacher educators, this study serves as an insight into the potential of learning study and variation theory implemented as a course and integral element in teacher education program. This study may inform teacher educators to initiate a teaching course that develops teacher candidates’ theoretical lens into teaching approaches. As found in this study, the theoretical lens allows teacher candidates to simultaneously focus on curricular content, their own experiences, and their students, thus developing a more student-centered pedagogy. This further emphasises that variation theory and learning study may have potential to develop teacher candidates’ pedagogical content knowledge (Lai et al., 2013).

5.5. Challenges and Limitations of the Study

The process that the teacher candidates engaged with through my study, although it is based on learning study approach, was far from a “true” learning study because the intervention was done in one session. Some of the essential components of a learning study such as pre-test, research lesson, and cycles of lesson planning were not included in this study. As with other studies which have modified learning study to accommodate constraints within teacher education (Davies et al., 2008; Tan, 2018), this study also adopted some components of learning study
where teacher candidates had to focus only on the collaborative theory-framed lesson planning. I chose to focus on creating experiences that would support the teachers’ lesson planning process (step 1 and step 3 of a learning study (Cheng et al., 2013)), as is consistent with the purpose of the study.

This study focused on three core features of variation theory which are the object of learning, the critical aspects, and patterns of variation (Brante et al., 2015). Due to time constraints, a sophisticated understanding of variation theory by the teacher candidates was not expected. The objective was for them to understand how variation theory can be applied in lesson planning. Davies et al. (2008) brought up similar concern of whether teacher candidates are ready to adopt the intensive focus on students’ learning required by variation theory and learning study. Moreover, Brante et al. (2011) found that many teacher candidates in the process of learning variation theory did not fully understand the essential learning aspect in variation theory; thus, they were unable to articulate the core of variation theory in their teaching. Similar situations may have occurred in this study. There may be the possibility the teacher candidates may not have perceived variation theory in the intended way. This lack of understanding may have limited the complexity in the ways teacher candidates identified the object of learning and the critical aspects. The findings from this study underscore exploring other approaches to increase teacher candidates’ capacity to understand variation theory.

This study has limited generalisability due to the small sample size (five teacher candidates were interviewed) but the purpose of case study is to illuminate the case and provide in-depth understanding and meaning making through thick description rather than generalize findings to other contexts. The five interviewees may not represent the overall sample but that is not an objective of case study research. Moreover, as only two steps of a complete learning
study cycle were implemented, not all approaches to identifying the object of learning and the critical aspects supported by the other steps in the learning study were captured in this study. For example, previous learning studies have illustrated that carrying out a pre-test, research lessons, and multiple cycles of learning study could help teachers to further unpack the object of learning (Bjorkholm, 2015) and could promote a better analysis of the critical aspects (Holmqvist, 2011). Despite the small sample and the incomplete cycle of a learning study, the variation in the teacher candidates’ approaches to identifying object of learning and the critical aspects examined in my study have practical implications for teacher education and practising teacher contexts.

The teacher candidates in the current study had limited classroom experience prior to their school-based practicum. Their teaching experiences may provide a valuable input in their lesson planning. Typically, variation theory is used in a learning study to solve pedagogical problems from teachers’ daily teaching practice (Keung, 2009). Takahashi and Mcdougal (2016) argued that this enables teachers to learn from their own practice. However, this opportunity may not be feasible due to the teacher candidates’ limited teaching experiences. In my study, some of the teachers nevertheless drew from their limited teaching experience (such as tutoring) when crafting the lessons. This insight is valuable as it highlights the value of having teachers engage with their prior experiences of teaching, albeit through informal contexts, to further support their lesson planning and formal classroom instruction.

5.6. Implications of the Study

The findings from this study provide snapshots of the teacher candidates’ approaches to the object of learning and the critical aspects. The findings pointed out that the association of various components such as content knowledge, teacher candidates’ learning experience and
beliefs, and knowledge of students are necessary to the identification of object of learning and critical aspects. The teacher candidates also integrated research into practice as external resources such as literature research was used in the lesson planning. This suggests the importance of these components to support teacher candidates’ lesson planning using variation theory, and by extension, to lesson planning in general.

In this study, teacher candidates were introduced to variation theory and subsequently planned a lesson framed with variation theory. The findings from this study suggest that teacher candidates were able to develop theoretical lens in planning a lesson. This is demonstrated through their focus on the three major components of variation, that is, the object of learning, critical aspects, and patterns of variation and invariance. The teachers showed their ability to work with these components and drew on them to guide their pedagogical reasons for certain teaching actions. This is consistent with the findings of earlier studies (Cheng, 2014). Thus, the results of the current study support further exploration of how variation theory could be used to develop teachers’ theoretical work in initial teacher education.

It is common for teacher candidates to teach according to the textbook or curriculum. However, in this study, the teacher candidates did not rely heavily on the curriculum. It was evident that the teachers had the intention to promote concept-based learning and they managed to point out interconnected concepts within their select topics explicitly. The teacher candidates also critically evaluate the content to determine an appropriate object of learning that was based on what is worth learning and what could present difficulties to students. In this view, the use of variation theory to help guide the teachers’ teaching could help them to overcome challenges students face in learning difficult science topics as the students focused on content and content memorization, rather than understanding the concepts (Lo et al., 2005).
This study further emphasise on learning study as a platform for teacher candidates to develop content knowledge, pedagogical knowledge, and knowledge of students (Lai et al., 2013). As seen in their approaches, teacher candidates integrate their content knowledge as well as develop knowledge of students from literature resources in their lesson planning. Moreover, teacher candidates became more aware of their own learning process as they brought in their personal learning experiences in planning the lesson. This study further emphasises that variation theory-framed learning study approach, when carefully implemented, could potentially be a good approach to develop teacher candidates’ inquiry lens in their teaching practice (Ko, 2012).

5.7. Future Research

As this study focuses on the lesson planning process, future research may explore the enactment of the lesson plans. It would be interesting to see how these teacher candidates bring the lesson plan to their practicum or future teaching practice. By enacting variation theory-framed lesson plan, teacher candidates can engage in learning environment where the focus is on the object of learning (Lai et al., 2013). Therefore, it would be good to study the teacher candidates’ experiences and challenges in enacting the variation of the critical aspects in the actual teaching.

Future research may explore a complete learning study cycle which enhances teacher candidates’ pedagogical content knowledge. Allowing teacher candidates to experience a complete learning study cycle may provide a good step to developing teachers’ inquiry lens (Ko, 2012) to examine and tackle the complexities of teaching. This also may provide a safe platform for teacher candidates to engage in discussion to plan the lesson and provide critique for the
enacted lesson, which are processes that have been reported to support teacher learning (Korthagen et al., 2006). In the context of the study, that is, the Western Canada context, it might be worthwhile extending the research in the aforementioned way as there is a paucity of studies examining the value of engaging teacher candidates in a learning study (c.f., Tan, 2018, Tan et al., 2017).

Furthermore, future research may focus on developing teacher candidates’ ability to observe and gather actual evidence about learning. Although literature research may serve as good resources, the observation and the actual pre-test results may provide a strong support in the inquiry process. Engaging in pre-tests have been shown to provide benefits to the teacher candidates such as exposing teacher candidates to the different students’ conceptions and sharing their interpretation of the pre-test results (Davies et al., 2008) as well as developing their own knowledge of students (Lai et al., 2013).

Brante et al. (2015) have pointed out that teacher candidates found variation theory difficult to understand during teacher education and have also emphasised on the importance of identifying the implications of learning theories in teacher education. Future research could include providing the teacher candidates a more comprehensive course on variation theory, followed by an investigation to probe for their learning experiences and the degree they understood and applied variation theory (c.f., Tan et al., 2017).

Contrasting the current study, studies have ascertained the importance for teachers to collaboratively identify the critical aspects and design the patterns of variations (Pang et al., 2016). Although collaboration is a well-researched aspect of learning study, future research could focus on how teachers collaborate in the process of determining the objects of learning and critical aspects. Collaboration may include shared responsibilities for providing materials and
ideas for teaching, and critiquing each other’s work appropriately; these collaborative experiences could be further examined and theorized as they are less understood in learning studies involving teacher candidates. The collaboration may allow teacher candidates to delve deeper in how to use variation, and to discover different ways of seeing the object of learning. Cohan and Honigsfeld (2006) believe that collaboration among teacher candidates may cultivate cooperative learning attitude. Moreover, collaboration allows a platform to nurture reflective practice which focuses on the lesson rather than the teacher (Garces & Granada, 2016).

5.8. Conclusion

This study suggests that planning a lesson using variation theory can be a platform for teacher candidates to develop their own professional knowledge of science content and students as well as to engage with reflective practice. The teacher candidates were able to experience variation in the ways students understand the object of learning (Davies et al., 2008), show their variation in their perspective of the content (Lai et al., 2013), reflect on their own learning and teaching experiences (Tan et al., 2017) and use patterns of variation as pedagogical tools to introduce the critical aspects of the object of learning (Brante et al., 2015). The findings also illustrated how the theory could support teacher candidates to engage with science teaching that is more conceptual-based, while increasing their sensitivity to students’ common conceptions that make learning of canonical science difficult (Koirala et al., 2008; Sims et al., 2009). By learning variation theory, the teacher candidates appeared to shift to a more complex understanding of teaching and learning with greater ease. Thus, the findings support earlier studies that emphasizes the benefits of introducing learning theories such as variation theory in teacher education programs (Cheng, 2014; Tan, 2018; Tan et al., 2017).
Being explicit with a learning theory has the potential to transform teacher education (Wood, 2013). As variation theory is new to most of the teacher candidates in this study, it can be integrated as part of their future practice. With increasing teaching experience, they might develop a more complex way of identifying object of learning and the critical aspects and design more powerful patterns of variation that are directed at the discernment of the critical aspects. This constitutes a future research direction for initial teacher education, where learning study could be used as an approach to promote teacher candidates’ teaching competency and ownership of designing theory-framed lesson plans.

5.9. Researcher’s Reflection

This thesis serves as my learning journal that illustrate my learning experiences from how I came to accept the challenge of conducting a research and writing this thesis as well as how I have come to build my confidence throughout the process. As I am closing this thesis, I would like to reflect on my experience conducting the research. I also would like to share what I learned throughout the development of this thesis and how I would like to move forward as a researcher, an educator and an individual after the completion of this thesis.

Although initially I was concerned about conducting a research and writing a thesis due to my lack of experience in and knowledge of educational research, I was willing to accept this challenge. I viewed this learning opportunity as a way to grow as a researcher, an educator and as an individual as well as to question my limitation and to explore my potential. Despite struggling in designing and conducting the research, I received both academic and moral support from my faculty advisors and other graduate students. This is also the awareness that I would like to emphasise in my teaching practice. I believe that collaboration in teaching through critical
discussion and sharing teaching resources as well as willingness to change and accept critiques can be beneficial in improving teachers’ teaching practice.

I decided to engage in a research as a way to address the educational issue that I observed during my K-12 education in Indonesia and my first year of graduate study as well as in my own teaching practice, that is teachers’ limited pedagogical knowledge and the theory-practice gap in education. Thus, this study serves as a channel for my wish to empower teachers to understand and improve their teaching practice through the aid of research in the form of teachers’ professional development. Reviews of literatures, critical discussion with other graduate students and faculty members as well as classroom observations have allowed me to better conceptualise the educational issues that underpinned this study and facilitate the growth of my thinking as a scholar in educational research.

Through writing of this thesis, I also realised that this thesis is a representation of myself, my beliefs and my perspective. Although there were expectations that came with the thesis, I learned that this thesis should be written to my best ability and interest. Thus, I could recognise my limitations and simultaneously, I was able to value my strengths. Gradually, I acquired the skills and knowledge that I needed to conduct this research and concurrently, I pushed the boundaries of my limitation further. Certainly, making mistakes were inevitable in the process and thus, being able to embrace mistakes as learning experiences is essential to improve my competence.

In addition to outlining the extensive literature review and the findings of my research, this thesis illustrates my learnings as a researcher, an educator, and an individual. After the completion of this thesis, I am moving forward to live up this thesis in my career and life. The values embedded in this thesis (recognising limitation and appreciating your strength, embracing
mistake as a way of learning and accepting support from others) greatly shape my future
teaching, my research, and my life in general. In my next journey, I would like to continue
empowering teachers to understand their teaching practice and to share with them the knowledge
that I have learned as a way to support collaborative practice. I believe that I still have to learn
more about educational research and teaching practice but I am ready to take up the upcoming
challenges.
REFERENCES


Brante, G., & Holmqvist, M. Forthcoming.


Taber, K. S. (2013). Revisiting the chemistry triplet: Drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemical Education Research Practice, 14*, 156-168.


APPENDICES

APPENDIX A: Variation theory handout

VARIATION THEORY

Three features of variation theory:
1. Object of learning
2. Critical Aspect
3. Pattern of Variation

According to variation theory, learning is a capability to see the object of learning in a new way. Learning is always learning about something (object of learning). An object of learning can be defined as its critical aspects. Discernment of critical aspects is a prerequisite to learning and variation in the critical aspects lead to discernment of the critical aspect.

Object of Learning: What do you want students to learn?

- Teachers need to choose appropriate content that supports students to learn
- An object of learning is something that the students need to learn
- E.g. concept, skill, or capability
- Factors to consider when choosing an object of learning:
  - Time constraint
  - Students’ difficulties and conceptions
  - Curriculum and content knowledge/concept
  - The practicality of the skill/concept learned
- Guiding questions:
  - What is feasible within the time frame of a lesson (45-60 mins)?
  - How is the object of learning related to the curriculum?
  - What is difficult to learn and to teach?
  - What is fundamental to the learning of the topic?
- Examples of object of learning:
  - The students shall develop the ability to describe solutions at a sub-microscopic level as a homogenous mixture of particles. This is considered appropriate as the aim is to increase students’ understanding of particulate matter (Vikstrom, 2014).
  - The understanding of the flow of an electric current in a closed circuit. This is selected because of two major students’ misconceptions: electric current in a closed circuit will be consumed and an electric current does not have to flow through a complete circuit (Lo, Pong, & Chik, 2005).
  - To apply principles of the genetic processes of transcription and translation to real-life genetic phenomena such as mutation. This object of learning is selected through in-depth analysis of the key topics of genetics in curriculum (Tan & Nashon, 2015).
  - Conceptual understanding of the relationship between white light and the spectrum of a rainbow. This object of learning is selected because of students’ difficulties in understanding the concept of white light splitting up to form rainbow
**Critical Aspect: What is critical for this learning and for this way of understanding?**

- An object of learning can be defined in terms of its aspects, that need to be discerned in order to understand the object of learning
- Examples: A cell has aspects such as:
  - Function
  - Structure
  - Biophysical components
  - Size
  - Processes
- These aspects are supposed to help teachers to see links within the object of learning
- A **critical aspect** is an aspect that students have not learned and need to learn in order to see the object of learning in the intended way
- A critical aspect can be found through in-depth analysis of the object of learning, sharing of teaching experiences, literature review, class observation
- Critical aspect is relational to both students and object of learning
- Identifying critical aspect:
  - Unpack the object of learning in terms of content/concept/context
  - Identify students’ common conceptions of the object of learning
  - Analyse/conceptualise this information together to identify the learning gap
- Key components to consider:
  - Essential aspect related to the object of learning
  - Students’ learning gap
  - Students’ common mistakes that are related to the object of learning
  - Students’ prior knowledge
- Guiding questions:
  - Why is learning [the object of learning] difficult?
  - What is it that makes the learning of [the object of learning] difficult?
  - How can we conceptualise [the object of learning]?
  - What is critical to [the object of learning]?
  - What are the different ways of seeing [the object of learning]?
- Examples of critical aspects

<table>
<thead>
<tr>
<th>Object of learning</th>
<th>Critical aspects</th>
</tr>
</thead>
</table>
| Understanding of the flow of an electric current in a closed system (Lo, Pong, & Chik, 2005) | - An electric current flows in a closed circuit with a battery  
- An electric current flows in only one direction in a closed circuit and around a complete circuit. |
| The students shall develop the ability to describe solutions at a sub-microscopic level as a homogenous mixture of particles | - The notion of empty space between atoms and molecules  
- The differences between solutions that are homogenous and mixtures that are heterogenous |
To apply principles of the genetic processes of transcription and translation to real-life genetic phenomena such as mutation (Tan & Nashon, 2015)

- The relationship between structural aspects of genetic entities (genes, DNA, chromosomes)
- The relationship between the functional aspects (translation and transcription) with structure of genes

Pattern of Variation: How to make it possible for the learners to understand those aspects that are critical for that learning?

- To discern the critical aspect of an object of learning, students need to experience variation in the critical aspect.
- Systematic use of variation is a necessary condition to promote learning
- Coherency between the critical aspect and the pattern of variation is the key to the discernment of the critical aspect in the intended way
- A pattern of variation is directed towards the critical aspects of the object of learning and indicates what is varied and what is kept invariant
- Pattern of variation could be done in the form of diagrams, instructions, examples, variables, solving strategy, questions posed
- Variation theory encourages you to develop a more systematic and focus pattern of variation
- Guiding question:
  - How can we use variation in order to point out the critical aspects?
  - How can the examples be structured so that students can experience the variation in the critical aspects?
- Different ways of doing variation:
  - Variation which contrast what something is with what something is not
    - e.g. to understand what an atom is, teachers can explain what atom is, followed by what atom is not
  - Variation in the critical aspects by varying an aspect and keep other aspects invariant

<table>
<thead>
<tr>
<th>Invariant</th>
<th>Variation</th>
<th>Critical Aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>A small 1.5 V light bulb connected to two wires (Lo, Pong, &amp; Chik, 2005)</td>
<td>Circuit with a battery lights up. Circuit without a battery does not light up</td>
<td>A battery is needed for the bulb to light up</td>
</tr>
<tr>
<td>The amount of water and the amount of other substance added (Vikstrom, 2014)</td>
<td>Sugar is added to the water. Oil is added to the water. Alcohol is added to the water. (the substances show different final volume)</td>
<td>The substances added fill the empty space in the water (sugar and alcohol fill the empty space between water, but oil does not)</td>
</tr>
</tbody>
</table>
| Process (transcription and translation) | Gene structure results in | The relationship between the
Examples of a lesson plan based on variation theory

Using Variation Theory to Design a Lesson about Solution Chemistry in Grade 8

(Vikstrom, 2013; Vikstrom, 2014)

**Learning objective:** students will be able to use chemical concepts in discussions about chemical processes in nature, in the human body, and in society.

**Concept:**
Concept of solubility in the different context
A dynamic and particulate view of matter

**Object of learning:**
The students shall develop the ability to describe solutions at a microscopic level as a homogenous mixture of particle

**Pre-test:**
1. **Which of these substances are soluble in water?**
   - 50% students answered correctly
   - 25% students only select solid substances as soluble in water

2. **Explain, as well as you can, what a solution is.**
   - Students use the word “melt” instead of “dissolve”
   - Students focus on macroscopic level and use of everyday language
   - Students relate dissolving as disappearing of solid substances in liquid

**Students’ conceptions:**
Matter is static, continuous and non-particulate
Prefer to use everyday language
Students pay attention to the mechanical process such as stirring
Students lack microscopic explanation for macroscopic observation of dissolving phenomena

**Teachers’ understanding of the topic/approach to teaching:**
Teachers believe that it is important to show the difference between soluble and not soluble.
There is a need to show sharp contrast.
Teachers think that it is necessary to emphasise on empty space between particles in solution.
It is not necessary to go into dissolution of gas as it is too complicated.
Dissolution and particulate nature of matter are fundamental to learning chemistry.

**Lesson 1:**
This lesson focuses on solution at the macroscopic level
Solubility is demonstrated by mixing different substances e.g. water, cooking oil, salt, sugar, sand. The resulted solution is categorised as soluble or non-soluble and then is compared
Variant: substances
Invariant: mixing of only two substances (liquid mix with liquid, liquid mix with solid)
What was soluble and what was not is clearly shown by contrasting different experimental examples.

Lesson 2:
Empty space is introduced for students to discern solution at the microscopic level
A few different solutions are made: sugar and water (soluble), water and oil (non soluble), water and alcohol (soluble)
Variant: substance added to water
Invariant: volume of water
Students’ awareness is brought to the presence of empty space where the substance added can be found at a microscopic level in a homogenous solution.
APPENDIX B: Graphic Organiser

Teacher candidates: ________________

1. Determination of the object of learning

Topic: _____________________________

<table>
<thead>
<tr>
<th>Content / concept</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Object of learning:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rationales:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>
2. Identifying the critical aspects of the object of learning

<table>
<thead>
<tr>
<th>Aspects of the object of learning</th>
<th>Student’s Difficulties</th>
<th>Student’s Alternative Conceptions</th>
<th>Learning gap</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Critical aspects:

Rationales:
3. Designing patterns of variation

<table>
<thead>
<tr>
<th>Variation</th>
<th>Invariant</th>
<th>Discernment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Lesson plan
APPENDIX C: Biology literature resources

Students’ conceptions, misconceptions, and difficulties in genetics as revealed in research literature (Osman et al., 2017) were highlighted. The resources were formatted to include only the relevant resources.

<table>
<thead>
<tr>
<th>Grade level</th>
<th>Students’ conceptions and misconceptions</th>
<th>Relevant resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>- DNA contains information about one’s body.</td>
<td>- Genes show the characteristics or traits of a person</td>
</tr>
<tr>
<td></td>
<td>- Chromosome is something carrying information inside a DNA</td>
<td>- DNA determines person traits</td>
</tr>
<tr>
<td></td>
<td>- Genes form chromosomes</td>
<td>- DNA is a test. It helps identify paternityhood and family relations</td>
</tr>
<tr>
<td>8</td>
<td>- DNA is used to identify the identity of individuals</td>
<td>- DNA is a test for our origin</td>
</tr>
<tr>
<td></td>
<td>- Genes determine eye color, body form</td>
<td>- Different DNA determines different traits</td>
</tr>
<tr>
<td></td>
<td>- Brain determines my traits</td>
<td>- Chromosomes mean abnormalities</td>
</tr>
<tr>
<td></td>
<td>- My height is determined by glands</td>
<td>- Traits are determined by G or parents</td>
</tr>
<tr>
<td></td>
<td>- DNA is a structure in the cell. It helps us determine blood group</td>
<td>- DNA helps show relation with relatives</td>
</tr>
<tr>
<td>9</td>
<td>- DNA is a test</td>
<td>- A gene is found on a chromosome and carries information</td>
</tr>
<tr>
<td></td>
<td>- Chromosomes and karyotype determine my traits</td>
<td>- Genes determine traits &amp; DNA determines identity</td>
</tr>
<tr>
<td></td>
<td>- Karyotype is used to determine whether we look like our mother or father</td>
<td>- Each cell exists in a location that changes its function</td>
</tr>
<tr>
<td></td>
<td>- Alleles are inside genes</td>
<td>- Finger print is part of skin</td>
</tr>
<tr>
<td></td>
<td>- DNA is a blood test to detect paternity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Different traits are determined by different alleles</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>- Gene is one pair of chromosome, while DNA is all the chromosome</td>
<td>- DNA is a sequence of genes</td>
</tr>
<tr>
<td></td>
<td>- Chromosomes carry DNA &amp; Genes hold alleles</td>
<td>- DNA is related to characteristics, but I don’t its structure</td>
</tr>
<tr>
<td></td>
<td>- DNA is the test used to determine paternityhood and relationship</td>
<td>- DNA is information from parents</td>
</tr>
<tr>
<td></td>
<td>- Height is inherited from my father</td>
<td>- Genes determine traits but I don’t know how</td>
</tr>
<tr>
<td>11</td>
<td>- DNA is a double helix containing nucleotides called around an axis of chromosomes</td>
<td>- Gene is a trait found on a chromosome and chromosomes make DNA</td>
</tr>
<tr>
<td></td>
<td>- Gene is a segment of DNA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Chromosomes hold the genes and DNA holds specific characteristics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Each chromosome codes for one molecule of DNA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- DNA is a section of chromosome. A gene is the trait on chromosome and it’s a DNA segment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- DNA is a protein and chromosomes are made up of DNA</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>- Genes make up DNA and DNA makes chromosomes</td>
<td>- Gene is part of DNA and DNA is part of chromosome</td>
</tr>
</tbody>
</table>
### Table 2: Students’ conceptions of the link between genes and traits

<table>
<thead>
<tr>
<th>Views of the link between genes and traits</th>
<th>Percentage of responses</th>
<th>Pre-test</th>
<th>Post-test</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ryan</td>
<td>Douglas</td>
<td>Ryan</td>
<td>Douglas</td>
</tr>
<tr>
<td>Genes as passive particles associated with traits</td>
<td>34.8</td>
<td>16.7</td>
<td>37.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genes as active particles that determine traits</td>
<td>34.8</td>
<td>6.2</td>
<td>16.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genes as informational</td>
<td>10.9</td>
<td>12.5</td>
<td>17.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genes as productive instructions (code for proteins)</td>
<td>4.4</td>
<td>14.6</td>
<td>2.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein as central mechanisms in creating traits</td>
<td>2.2</td>
<td>4.2</td>
<td>2.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genes as productive instructions for protein and proteins are central mechanisms in making traits</td>
<td>8.7</td>
<td>43.8</td>
<td>8.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unintelligible/irrelevant response</td>
<td>4.3</td>
<td>0</td>
<td>1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No response</td>
<td>0</td>
<td>20.2</td>
<td>14.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Table 3: Students' conceptions of protein functions

<table>
<thead>
<tr>
<th>Category of protein function</th>
<th>Level of specificity and examples</th>
<th>Number of student responses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre-test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ryan</td>
</tr>
<tr>
<td><strong>Vitalistic</strong></td>
<td>General—Proteins help us stay healthy, help us grow, help us move, repair our body, make us strong; fight disease, keep us from getting sick</td>
<td>32</td>
</tr>
<tr>
<td><strong>Energy and nutrition</strong></td>
<td>General—Proteins give us energy, they are nutrition, we need to eat proteins</td>
<td>5</td>
</tr>
<tr>
<td><strong>Proteins as structural or functional components of tissues</strong></td>
<td>General—Proteins make up hair, muscle, skin, bone, are in blood; help immune system Specific functions in tissues—Proteins help muscle contract, absorb shock, involved in blood clotting, carry oxygen, build blood cells, are pigments; proteins are antibodies, proteins are hormones, help break down food, help in digestion</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td><strong>Proteins as structural/ functional components of cells</strong></td>
<td>General—Help cells work, help cells function, help build/repair cells Specific structure or function in cells - part of cell and nuclear membranes, regulate what comes in and out of cells, proteins are channels, receptors, help chemical reactions, are enzymes, specific enzyme mentioned (lactase)</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td><strong>Proteins as determinants of traits</strong></td>
<td>General—Proteins determine our traits, proteins make us look the way we do, Proteins can cause genetic disorders Specific connections between genes and proteins—If a gene is mutated a protein can be mutated, specific genetic disorder is explained at protein level</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Proteins as carrying information or helping genes</strong></td>
<td>General—Proteins tell genes what to do, help DNA, make up genes</td>
<td>12</td>
</tr>
<tr>
<td>Composition</td>
<td>General—Proteins are made of amino acids, proteins are made by ribosomes</td>
<td>3</td>
</tr>
</tbody>
</table>
**APPENDIX D: Biology content**

Biology content as revealed in the research literature was highlighted and formatted to the relevant content (Chattopadhyay, 2005).

<table>
<thead>
<tr>
<th>Subject</th>
<th>Topic</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genetics (classical)</td>
<td>Continuity of life</td>
<td>Heredity, variation</td>
</tr>
<tr>
<td></td>
<td>Mendel's laws of inheritance</td>
<td>Incomplete dominance, multiple alleleism, quantitative inheritance</td>
</tr>
<tr>
<td></td>
<td>Chromosomes</td>
<td>Bacterial and eukaryotic cells; parallelism between genes and chromosomes, genome; linkage and crossing over; gene mapping; recombination; sex chromosomes, sex determination, sex-linked inheritance; mutational and chromosomal aberrations; human genetics—methods of study; genetic disorders</td>
</tr>
<tr>
<td>Genetics (molecular)</td>
<td>DNA as genetic material</td>
<td>DNA structure and its replication; structure of RNA and its role in protein synthesis; gene expression, transcription, and translation in prokaryotes and eukaryotes (regulation of gene expression, induction and repression, housekeeping genes, nuclear basis of differentiation, and development); oncogenes</td>
</tr>
<tr>
<td>Basics of recombinant</td>
<td>DNA technology</td>
<td>Cloning; gene banks; DNA fingerprinting; genomics principles and applications; transgenic plants, animals, and microbes</td>
</tr>
<tr>
<td>Cell biology</td>
<td>Cell as basic unit of life</td>
<td>Discovery of cell, cell theory, cell as a self-contained unit; prokaryotic and eukaryotic cells; ultrastructure of the prokaryotic and eukaryotic cell—cell wall, cell membrane, unit membrane concept (fluid mosaic model); membrane transport; cell organelles and their function—DNA and RNA; nucleus, mitochondria, plastids, endoplasmic reticulum, Golgi complex, lysosomes, microtubules, centriole, vacuole, cytoskeleton, cilia and flagella, ribosomes</td>
</tr>
<tr>
<td></td>
<td>Cell cycle and cell division</td>
<td>Cell cycle—significance of cell division, mitosis, mitosis and meiosis; karyotype analysis</td>
</tr>
</tbody>
</table>
APPENDIX E: Chemistry students’ common alternative conceptions

Students’ common alternative conceptions on rate of reaction were highlighted (Cakmakci, 2010)

Table 1. Distribution of Students' Common Alternative Conceptions Regarding Chemical Kinetics

<table>
<thead>
<tr>
<th>Alternative Conceptions Identified</th>
<th>Secondary School N = 108</th>
<th>University First Year N = 48</th>
<th>University Third Year N = 35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defining reaction rate as reaction time</td>
<td>35 (32.4)</td>
<td>14 (29.2)</td>
<td>1 (2.9)</td>
</tr>
<tr>
<td>Difficulties explaining how reaction rate changes as the reaction progresses:</td>
<td>65 (60.1)</td>
<td>26 (54.2)</td>
<td>25 (71.5)</td>
</tr>
<tr>
<td>The rate of a reaction increases with time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A rise in temperature does not affect the rate of exothermic reactions</td>
<td>5 (4.6)</td>
<td>6 (12.5)</td>
<td>3 (8.6)</td>
</tr>
<tr>
<td>An increase in temperature decreases exothermic reactions rates</td>
<td>6 (5.5)</td>
<td>27 (56.3)</td>
<td>10 (28.6)</td>
</tr>
<tr>
<td>Exothermic reactions occur faster than endothermic reactions</td>
<td>34 (31.4)</td>
<td>12 (25)</td>
<td>13 (37.1)</td>
</tr>
<tr>
<td>Endothermic reactions occur faster than exothermic reactions</td>
<td>16 (14.8)</td>
<td>9 (18.8)</td>
<td>3 (8.6)</td>
</tr>
<tr>
<td>Activation energy is the kinetic energy of reactant molecules</td>
<td>17 (15.7)</td>
<td>4 (8.3)</td>
<td></td>
</tr>
<tr>
<td>Activation energy is the (total) amount of energy released in a reaction</td>
<td>23 (21.3)</td>
<td>5 (10.4)</td>
<td></td>
</tr>
<tr>
<td>A catalyst increases the yield of products</td>
<td>25 (23.1)</td>
<td>4 (8.3)</td>
<td>12 (34.3)</td>
</tr>
<tr>
<td>A catalyst does not affect or does not change the mechanisms of a reaction</td>
<td>60 (55.5)</td>
<td>38 (79.1)</td>
<td>21 (60)</td>
</tr>
<tr>
<td>An increase in the initial concentration of reactants would increase/decrease the rate of a zero-order reaction</td>
<td>71 (65.7)</td>
<td>24 (50)</td>
<td>11 (31.4)</td>
</tr>
</tbody>
</table>
APPENDIX F: Chemistry rate of reaction content

The content for rate of reaction was highlighted and formatted to be relevant to the teacher candidates (Wright, 2004).

- the factors influencing rates of reaction,
- the dependence of the rate of the reaction on concentration, called the order of the reaction,
- the rate expression, which is an equation which summarizes the dependence of the rate on the concentrations of substances which affect the rate of reaction,
- this expression involves the rate constant which is a constant of proportionality linking the rate with the various concentration terms,
- this rate constant collects in one quantity all the information needed to calculate the rate under specific conditions,
- the effect of temperature on the rate of reaction. Increase in temperature generally increases the rate of reaction. Knowledge of just exactly how temperature affects the rate constant can give information leading to a deeper understanding of how reactions occur.
APPENDIX G: Chemistry students’ pre-test result

Students’ pre-test questions and result was obtained from literature resource (Lam, 2012).

Pre-Posttest of Pilot Study (2007)

Name: ___________________ Class: F.4__ ( ) Date: __________

F.4 Chemistry: Conceptions of Rate of a Chemical Reaction

1. In order to investigate the relative strength of hydrochloric acid and ethanoic acid, a student measures the pH of a 50 cm³ of 1M hydrochloric acid and a 50 cm³ of 2M ethanoic acid by means of a pH meter. Is it a fair test? Explain your answer.

2. What are factors that affect the rate of a chemical reaction?

3. Draw an experimental set-up that would enable you to measure the rate of the reaction between magnesium and a dilute acid in a school laboratory.

4. For the reaction between magnesium and a dilute acid, sketch a graph to show the relationship between (a) mass of the reactants against time, and (b) volume of hydrogen gas produced against time.

![Graph showing mass of reactants and volume of hydrogen gas produced against time.](image-url)
5. Excess magnesium is added to 15 cm³ of 0.1 M hydrochloric acid. After 5 minutes, a total of 20 cm³ of hydrogen gas has been collected, which denotes the end of the reaction. Sketch the graph of the volume of hydrogen gas evolved against time using the axes below.

![Graph](image)

6. The above experiment is repeated with same amount of magnesium (in excess), but with acid solution of different situations:
   - A. 7.5 cm³ of 0.2 M hydrochloric acid
   - B. 15 cm³ of 0.2 M hydrochloric acid
   - C. 30 cm³ of 0.1 M hydrochloric acid
   - D. 15 cm³ of 0.1 M ethanoic acid
   - E. 15 cm³ of 0.1 M sulphuric acid
   - F. 7.5 cm³ of 0.2 M sulphuric acid

Sketch, on the same graph above, the results that would be obtained in repeated experiments A to F. Label the curves clearly.

7. Which of the followings below would affect the rate of the above reaction and the amount of product formed, assuming that Mg is in excess? Put a “✓” in the appropriate boxes. Explain your choice.

<table>
<thead>
<tr>
<th>Rate of reaction</th>
<th>Amount of product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of the acid</td>
<td>✓</td>
</tr>
<tr>
<td>Concentration of the acid</td>
<td>✓</td>
</tr>
<tr>
<td>Strength of the acid</td>
<td>✓</td>
</tr>
<tr>
<td>Basicity of the acid</td>
<td></td>
</tr>
<tr>
<td>Number of moles of the acid</td>
<td></td>
</tr>
</tbody>
</table>

Reason

Reason
(APPENDIX G: Chemistry students’ pre-test result)

<table>
<thead>
<tr>
<th>General responses observed in the pretest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q.1 Most students had the concept of a fair test, but they did not discern all the critical aspects that affect the pH of a solution. Some students thought that “number of moles” of the acid should be kept constant for a fair test. Instead, “concentration” of the acid should be kept constant rather than the number of moles because the critical aspects which affect the pH of an acid solution involve concentration, strength and basicity.</td>
</tr>
<tr>
<td>Q.2 Quite a number of students knew that temperature, surface area and reactivity of substances (metals) were factors affecting the rate of a chemical reaction, but some had the alternative conceptions that volume, number of moles of substances or humidity affects the reaction rate.</td>
</tr>
<tr>
<td>Q.3 When students were asked to design an experimental set-up to determine the rate of the reaction between magnesium and a dilute mineral acid in a school laboratory, some set-ups were workable (e.g. measuring the volume of the gaseous product at regular time intervals), but some were not (e.g. measuring the temperature of the reaction mixture).</td>
</tr>
</tbody>
</table>
(APPENDIX G: Chemistry students’ pre-test result)

### General responses observed in the pretest

**Q.3**

- Count the time used to fill in the whole gas jar completely

![Diagram of gas jar and delivery tube]

*(4B0127)*

**Q.4**

In the reaction between magnesium and a dilute acid, students were weak in graphical representation of the rate curves. In general, they could not show the correct relationship between (a) mass of the reactants against time, and (b) volume of hydrogen gas produced against time. e.g. Many gave straight line graphs, or curves with wrong curvatures.

- For the reaction between magnesium and a dilute acid, sketch a graph to show the relationship between (a) mass of the reactants against time, and (b) volume of hydrogen gas produced against time.

![Graphs of mass of reactants vs. time and volume of H₂(g) produced vs. time]

*(4B0120)*
(APPENDIX G: Chemistry students’ pre-test result)

<table>
<thead>
<tr>
<th>General responses observed in the pretest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q.5 Nearly all students were unable to display graphically the correct relationships between rate/amount of products versus time upon changes in certain factors (e.g., volume, concentration) of the reacting acid.</td>
</tr>
</tbody>
</table>

5. Excess magnesium is added to 15 cm³ of 0.1 M hydrochloric acid. After 5 minutes, a total of 20 cm³ of hydrogen gas has been collected, which denotes the end of the reaction. Sketch the graph of the volume of hydrogen gas evolved against time using the axes below.

<table>
<thead>
<tr>
<th>Volume of Hydrogen evolved/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>40</td>
</tr>
</tbody>
</table>

Q.6 & 6

<table>
<thead>
<tr>
<th>Rate of reaction</th>
<th>Amount of product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of the acid</td>
<td>✔</td>
</tr>
<tr>
<td>Concentration of the acid</td>
<td>✔</td>
</tr>
<tr>
<td>Strength of the acid</td>
<td>✔</td>
</tr>
<tr>
<td>Basicity of the acid</td>
<td>✔</td>
</tr>
<tr>
<td>Number of moles of the acid</td>
<td>✔</td>
</tr>
</tbody>
</table>

Most students could not discern all the critical aspects of the rate of reaction and amount of products, e.g., they got 4 correct choices out of 10 in identifying factors.

(4A0129)
APPENDIX H: Interview question sample

Focusing on the Object of Learning and the Critical Aspects: A Case Study of Teacher Candidates Applying Variation Theory

Examples of Teacher Candidate Interview Prompts

- Tell me about your learning about variation theory
  - What do you understand about variation theory?
    - What is your understanding of an object of learning?
    - What is your understanding of critical aspect?
    - What is your understanding of pattern of variation?

- Tell me about your object of learning
  - Can you explain a little more detail about your [object of learning]?
  - Why do you choose [object of learning] to focus on?

- Tell me about the critical aspects of your [object of learning]
  - Why do you choose that critical aspects?
  - What do you think the essential elements to consider when identifying the critical aspects?
  - Which of the elements that you focus on more? Why?
  - Were there any suggested critical aspects that are rejected?
  - What are some of the challenges in identifying the critical aspects?
  - What do you think might help you in identifying critical aspects?

- Tell me about your pattern of variation
  - Which style of pattern do you follow?
  - How do you vary the critical aspect?

- Handout, literature resources and graphic organiser
  - Do you think the graphic organiser and handout help you? In what ways?
  - Do you refer to the literature resources? For what source of information?