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Relating Teaching and Learning of Science Through the Lens of Variation Theory

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ABSTRACT
The relationship between teaching and learning is a most central issue in education research, but it is yet to be fully understood. Variation Theory provides an explanatory account for teaching and learning and offers a specific view on what it means to learn: to discriminate and to discern critical aspects of the object of learning. This paper explores the use of Variation Theory in a case study of two lessons on density in a secondary science classroom. By explicating what was made possible to learn and what was learned this study demonstrates potentials and limitations offered by Variation Theory in enabling a better understanding of the teaching learning relationship.

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Science learning; classroom research; phenomenography; variation theory

Introduction
Central to education research is the relationship between teaching and learning, but it is yet to be fully understood (Nuthall, 2004; Svensson, 2016). Nuthall (2004) argues that a key determinant of the effectiveness of teaching is what was made visible in a learning situation rather than how or by whom. In other words, the decisive factor in learning is what is focused upon in any teaching situation, regardless of the methods of teaching. Nuthall (2004) further argues for a need of a theory that could provide explanatory accounts of how classroom activities affect student learning outcomes (the changes taking place in the minds of students). Arguably, such a practical explanatory theory will allow researchers (and teachers) to know what to look for and how to interpret observed student behaviors.

While there is a proliferation of theories available for understanding teaching and learning of science, due to the tendency that teaching and learning are often studied separately, there are limited explanations provided in terms of the relationship between the two (Svensson, 2016). This aim of this paper is to argue for Variation Theory of Learning as a potential practical explanatory theory in which teaching and learning can be investigated using theoretically commensurable terms within the same theoretical framework. As argued by Svensson (2016), Variation Theory (VT) and its new development offers a promising ground for integrating descriptions of teaching and learning. Building upon earlier phenomenographical studies, VT offers a specific view on what it means for an individual to learn: to discriminate and to discern critical aspects of the object of learning (Marton, 2016; Marton & Tsui, 2004). Learning, in the VT framework, is defined as (changes in) the capability of seeing something in certain ways, in which a way of seeing can be defined in terms of the aspects that are discerned and attended to simultaneously at a certain point in time (Marton & Booth, 1997).

By focusing on the notion of variations and critical aspects, this theory proposes a mechanism for determining the relationship between teaching and learning: people can only discern things if
they are varied. In order to discern a certain aspect, a learner must experience variation/differences in this aspect against a background of sameness in other aspects. To bring together two different aspects, the learner must experience variations in both aspects simultaneously (Marton, 2016). As such, VT could potentially provide a powerful tool to critically examine the connections between specific aspects of classroom instruction and student learning in relation to subject matter content.

To present an argument for the potential of VT in connecting teaching and learning in the same theoretical framework, this paper explores the use of VT as an analytical lens in a case study of a secondary science classroom in which the scientific concept of density is the focus of discussion. The analysis aims to examine to what extent the intended, enacted and lived object of learning are aligned. Based on the case study, this paper will also discuss the potentials and limitations of this theory in helping us to develop a better understanding of the connections between classroom instruction and student learning.

**Research on Teaching and Learning of Science**

Research studies into classroom learning of science tend to use different theories to generate and analyze data and to frame judgments about teaching strategies. Reviewing the diverse range of theoretical orientations in the science education literature is beyond the scope of this paper. Instead of presenting a comprehensive review of the literature, attention will be paid to a brief review of two major strands of research that have traditionally achieved a prominent status in science education: (1) personal constructivist approaches, evidenced in studies of children’s science and some conceptual change studies, and (2) sociocultural perspectives on science learning. As will be argued in the followings, while both research traditions address the question of what enables learning from a generic perspective, VT offers a sharper focus on the necessary conditions of learning through an emphasis on learner perceptions and provides a specific framework for teachers to reflect on, plan and review teaching in relation to perspectives and roles of learners.

Significantly influenced by constructivist views of learning, a central commitment of a large number of studies of student learning has been to investigate students’ understanding in a given conceptual domain (Erickson, 2000; Fensham, 1992; Taber, 2006, 2014). Research studies undertaken in conceptual change traditions over the past three decades generated significant insight into children’s preconceived views about a variety of science topics, and the difficulties in shifting students’ alternative conceptions (e.g., Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1985). This body of research was underpinned by the development stage model of psychologist Jean Piaget, the “personal construct theory” of George Kelly, the Kuhnian idea of theory change in the history of science, and the radical constructivist ideas advocated by von Glaserfeld (Driver & Erickson, 1983; Duit & Treagust, 2003). In contrast to the focus on ways of changing conceptual structures of an individual learner, a second strand of studies draw significantly on Vygotskian idea of learning to address the social and cultural aspect of science learning through the focus on social contexts (e.g., group work) and cultural artifacts as mediating tools (language use in establishing an argumentative culture) in the learning of science (e.g., Mortimer, 1998; Mortimer & Scott, 2003; Newton, Driver, & Osborne, 1999; Osborne, Erduran, Simon, & Monk, 2001; Scott, 1998). In these studies, social interactions are usually regarded as the central rather than merely ancillary means of facilitating individual conceptual understanding (Lemke, 2001).

While these two main strands of research are not entirely separate, the seminal work in each area could be distinguished on the basis of their epistemological commitment (see Taber, 2006). While conceptual change studies are concerned primarily with changes in the knowledge structure of an individual learner, sociocultural perspectives attempt to characterize the social situations in which learning occurs, and emphasize the role of material and semiotic tools, as well as “more expert others” in mediating the learning processes. Both the cognitive and sociocultural research orientations made significant contributions to knowledge about teaching and learning. Nevertheless, this paper argues that studies of science teaching and learning would benefit from a sharper focus
on what exactly enables learning and relating teacher’s handling of the content to learners’ perceptions of the same content. The tradition of Phenomenography and VT offers such a framework and is argued to have the potential for investigating and developing cases of teaching and learning as a whole (Svensson, 2016).

**Variation Theory of Learning**

Variation Theory of Learning is “a theory of the relationship between learning and the conditions of learning, as seen from a pedagogical perspective” (Pang & Marton, 2013, p. 1065). Originated from the research tradition known as Phenomenography, Variation Theory of Learning aims to provide descriptions about how people come to experience the world and how they learn to act in the world through identifying the *qualitatively different ways of experiencing the world* (Marton & Booth, 1997; Marton & Tsui, 2004, p. 9). Drawing on insights from earlier Phenomenographic studies, VT seeks to answer the ontological questions: “what is a way of experiencing a phenomenon” and “what is the actual difference between two ways of experiencing the same thing” (Pang, 2003, p. 146).

Variation Theory has been employed in three areas of studies. Firstly, it was used to identify the critical differences in experiencing and understanding certain phenomena, conducted within the phenomenographic tradition. Secondly, it was used to investigate the significance of variation in opening up possibilities for student learning. Thirdly, pedagogical principles drawn from VT are used to guide the design and implementation of “learning studies” (e.g., Ling, Chik, & Pang, 2006). In this paper it is the second application that will be explored in detail here.

**Structure of Awareness**

Essentially, VT was developed based on an understanding of the *anatomy of awareness*. Awareness is argued to have its own structures. According to Marton and Booth (1997), to experience something as “something” we must differentiate it from and relate it to a context, and be able to discern parts and relate them to the whole. It is not possible to be aware of all aspects of a situation at the same time. Our awareness is structured with some features at the forefront of our attention, whilst other aspects are at the margins. The things at the forefront could change over time. The totality of all experience delineates an individual’s awareness. In other words, the description of the world is always an experienced entity by a particular individual, and cannot be separated from the structure of an individual’s awareness.

Variation Theory defines a way of seeing or experiencing in terms of “the distinctions made” (Marton, 2016, p. 83) and constituted by the simultaneous discernment of certain features (Runeson, 2005). In other words, a way of experiencing a phenomenon could be delineated by the features of a phenomenon that are discerned and attended to simultaneously at a point in time. The notion of discernment and simultaneity are the essential characteristics of ways of experiencing (Lo & Marton, 2011).

**Object of Learning**

According to Marton and Booth (1997), for a student to learn, she must direct her attention to “something” (e.g., a phenomenon, an object, or a concept). In other words, the learner must discern some parts of the world. She also needs to develop “capabilities” (e.g., remembering, calculating) for making sense of this “something.” These are the two aspects of an object of learning: a general aspect referring to acts of learning (the indirect object of learning), and a specific aspect referring to what is acted upon (the direct object of learning or the content for learning) (Marton & Tsui, 2004). The direct object of learning is of primary concern for most studies employing VT, and this paper will also focus on this aspect.
In a classroom, the object of learning differs according to different perspectives. Marton, Runesson, and Tsui (2004) distinguished three types of object of learning. The first one is the **intended object of learning**, which is defined from the teacher’s perspective as what should be learned. The **enacted object of learning**, on the other hand, is viewed from the researcher’s perspective in terms of what can be possibly learned in a situation. This is the researcher’s account of “whether, to what extent, and in what forms the necessary conditions of a particular object of learning appear in a certain setting” (pp. 4–5). The **lived object of learning** – what is actually experienced – is described from the learner’s perspective. This object of learning is a description of what aspects of the situation that the learner discerns and focuses on, constituting the outcome of learning. From the perspective of VT, learning occurs when a new critical aspect of the object of learning is discerned (Häggström, 2008). The relationship of the object of learning from different perspectives can be illustrated in Figure 1 adapted from Häggström (2008) (Figure 1).

As described by Häggström (2008), each of the circles contains different features of the respective object of learning. The three objects of learning only partially overlap, suggesting that some features intended by the teacher might not be enacted as opportunities for learning in the classroom, and what students experienced might be significantly different from what is expected or enacted. The central overlapping part of the three circles shows the features that belong to all three objects of learning, and it is this area that the teacher should try to expand.

While this model is conceptualized based on the idea that the lived object of learning is somewhat similar, it is possible that due to the varied capabilities and different prior experiences of the students, there are variations in how the intended object of learning is experienced by each individual student. This paper will investigate into the alignment of teaching and learning through interrogating the relationships of the intended, enacted and lived objects of learning, and the extent to which variations among students in terms of the lived object of learning can be connected to the intended and enacted objects of learning.

**Critical Aspects and Patterns of Variation and Invariance**

Since there is a limited number of ways that a particular phenomenon can be experienced, and some ways of experiencing are more powerful in a particular situation than others, it is thus important for the learner to discern those features that are critical to the achievement of certain aims (Marton et al., 2004).

In a recent article, Pang and Ki (2016) revisited the idea of “critical aspects” in framing the object of learning in learning studies. They argue that instead of deriving directly from disciplinary...
knowledge alone, critical aspects should be considered as related to “the qualitative different ways of experiencing the same phenomenon manifested by learners” (p. 328) and can be defined as:

- a set of constituents used to develop categories of description and to structure the outcome space of the phenomenon, denoting the critical differences between the different ways of experiencing the phenomenon in terms of the aspects (or dimensions of variation) that are taken for granted or discerned. (p. 328)

Defined as such, the notion of critical aspects provided the linking construct between the early Phenomenographic studies and VT, and provides a common language for describing and interrogating the alignment between teaching and learning.

According to VT, when certain aspects of the phenomenon vary while other aspects remain invariant, those aspects that vary are likely to be discerned. In other words, we can only discern what varies and what we discern is the dimension of variation (Pang, 2003; Runesson, 2006). Aspects that are attended to simultaneously are discerned as a pattern of dimensions of variation (or a pattern of variation in short hand) and the meaning we assign to something is constituted as a pattern of simultaneously discerned dimensions of variation (Runesson, 2006, pp. 402–403). In order for the learner to discern the critical features of an object of learning, she must experience the potential alternatives or variations in the relevant aspects of a situation against the background of invariance in other aspects of the same object of learning (Marton, 2016). In other words, “new meanings are acquired from experiencing differences against a background of sameness, rather than experiencing sameness against a background of difference” (Pang & Marton, 2013, p. 1066).

Since “the pattern of variation inherent in the learning situation is fundamental to the development of certain capabilities” (Marton & Tsui, 2004, p. 15), to delineate learning and teaching in a particular situation, Marton and Tsui suggested that researchers could focus on the necessary conditions of learning provided in that situation, or, in their words, “the space of learning” (Marton et al., 2004, p. 24). A necessary condition for experiencing a certain aspect of a phenomenon is that the learner has opportunities to encounter differences in the relevant dimensions of variation (Marton, 2016). The space of learning can be described in terms of patterns of variation presented in a situation that pertain to a particular object of learning as observed and experienced by the researcher (Marton, 2016). In other words, the space of learning depicts what is made possible to learn in relation to the intended object of learning – the possibility of seeing something in a particular way.

Marton et al. (2004) identified four patterns of variation. While the first two – Contrast and Generalization – are patterns of variation taking place in one single aspect, Separation and Fusion deal with variations in two or more aspects:

- **Contrast** – in order to experience something, a person must experience something else that it can be compared with.
- **Generalization** – in order to fully understand something, we must also experience it in various forms in order to separate it from other irrelevant features.
- **Separation** – “in order to experience a certain aspect of something, and in order to separate this aspect from other aspects, it must vary while other aspects remain invariant” (Marton et al., 2004, p. 16). Two aspects varying simultaneously cannot be separated.
- **Fusion** – when there are several critical aspects that the learner needs to take into account at the same time, they must be varied at the same time to provide opportunities for these aspects to be experienced simultaneously.

Marton (2016) discussed the relationships between the different patterns of variation and invariance and laid out the stages necessarily occurring in a certain learning sequence: “Contrast – Generalization – Fusion” (p. 54). In other words, the cycle of learning requires moving the experience of a learner “from an undifferentiated whole, through differentiation and integration, towards a differentiated and integrated whole” (p. 53).
Since the space of learning is usually described from the researcher’s perspective, it is possible that students might not discern those intended features of a situation in spite of the presence of relevant patterns of variation. Marton and Tsui (2004) stated that “people act not in relation to situations as such, but in relation to situations as they perceive, experience, and understand them” (p. 8). Therefore, differences in individuals’ perception of the same situation can be attributed to the fact that different people may notice and pay attention to different features of the same situation (Marton & Pang, 2006). For example, a student may experience variations of a certain aspect of a situation by comparing what takes place with his or her previous experience. Pang and Marton (2013) argues that unless the meaning to be acquired is new to every learner, there is no best patterns of variation and invariance, but rather more and less powerful patterns for certain learners in relation to a particular object of learning. While the researcher’s description of the space of learning could not predict with certainty what the students will learn, the framework of VT provides some necessary conditions of learning that could be usefully related to and explain some parts of what the students experienced in their classrooms (Lo & Marton, 2011; Marton, 2016; Marton & Pang, 2006). In this sense, the relationship between teaching and learning is not conceived as a relationship between cause and effect, but as “a relationship between what is made possible and what possibilities are actually made use of” (Marton et al., 2004, p. 22).

In summary, VT regards learning as the changing capability of experiencing something in certain ways. For a student to learn something, she must discern what is to be learned, that is, the object of learning. To discern the object of learning means to discern its critical aspects from other aspects, and to attend to these critical aspects simultaneously. This requires students to experience possible alternatives (variations) in the relevant aspects of the learning object. For the purpose of delineating teaching and learning in a particular situation, VT proposes to focus on the necessary conditions for learning provided in a certain situation as delimited by the patterns of variation and invariance pertaining to a particular object of learning (Marton et al., 2004) and to characterize variations and describe differences (Marton, 2016).

**Data Source**

The study reported in this paper was one component of a larger project, the Causal Connections in Science Classrooms project, funded by the Australian Research Council, in which data related to a common sequence of science lessons were analyzed from a variety of theoretical perspectives. The project employs an extension of the complementary accounts methodology developed by Clarke and his colleagues (Clarke, 2001, 2006; Clarke, Emanuelsson, Jablonka, & Mok, 2006). It captures classroom interactions through a multi-camera approach and identifies participants’ interpretations of classroom events through video-simulated post-lesson interviews. This project was conducted in three science classrooms across two demographically distinct school settings in Melbourne. For each classroom, a lesson sequence (around 6 to 10 lessons) was video recorded over a period of approximately three weeks each. The classroom data was generated using a four-camera approach: one whole-class camera, one teacher camera and two focus student-group cameras. Video-stimulated post-lesson individual interviews were conducted with the teacher and two focus students after each lesson to generate their reconstructive account of the lesson. Apart from the video records of lessons and interviews, other data generated include copies of lesson materials and student written work, the results of the International Benchmark Test for Science (Australian Council for Educational Research, 2000), student class tests and teacher questionnaires.

This paper focuses on a Grade 7 classroom in a government school. This particular classroom was chosen because the data collected from this classroom was relatively richer and more complete, providing a better context for the purpose of investigating the intricate relationships between teaching and learning. The science teacher, Mr. Gardiner, had nearly 16 years of teaching experience. At the time of data generation, he had been teaching Grade 7 science for 8 years in the same school. The science class was a mixed ability class with 11 female and 16 male students.
The two lessons analyzed in this paper form part of a lesson sequence on the topic of states of matter, but the selected lessons have a specific focus on the concept of density. Table 1 describes the structure of the two lessons of the sequence.

### Table 1. The structure of the two lessons on density (Xu & Clarke, 2012, p. 773).

<table>
<thead>
<tr>
<th>Lesson</th>
<th>Sections of the lesson</th>
</tr>
</thead>
</table>
| Lesson 2 | Section 1. Review results from the last practical work on properties of solids, liquids and gases  
Section 2. Introduce the term density as mass divided by volume  
Section 3. Demonstrate density using two metal blocks of the same volume  
Section 4. Student practical work on measuring the density of a marble or a candle |
| Lesson 3 | Section 1. Review student results from the last practical work on a marble and a candle  
Section 2. Class discussion and note-taking on the definition of density and on water as a comparison tool  
Section 3. Students continue report writing |

### Teaching and Learning Density From the Literature

The literature identifies a number of conceptual problems in contributing to student difficulties in comprehending the concept of density. These include the difficulty in dealing with variables (mass and volume) that are changing simultaneously (Smith, Maclin, Grosslight, & Davis, 1997), the related difficulty in dealing with ratio or proportion (Rowell & Dawson, 1977) and the fact that density is not directly perceptible, but can only be comprehended through calculation (Kang, Scharmann, & Noh, 2004). As revealed by a number of studies, the most prevailing misconception among middle school students is that weight and density are usually conflated into an undifferentiated weight-density concept (e.g., Smith et al., 1997). Smith et al. (1997) found that students who conceived of a material object as composed of smaller units were able to differentiate weight from density, whereas students with an undifferentiated weight-density concept had no such conception. A further misconception documented in the literature is the confusing between density and the notion of denseness (Hewson & Hewson, 1984). While density is often defined as the amount of mass per unit volume in many science textbooks, denseness refers to the number of objects in a certain area or volume. Such confusion could be attributed to the use of density in everyday language to mean denseness. Arguably, the particle model provides means through which density can be visualized (Gilbert, 2005). The VT analysis of the two lessons on density presented below confirms the conceptual difficulties identified in the existing literature, but further clarifies the nature of the conceptual difficulties that the students had and what might be the sources of those difficulties and confusions through examining the patterns of variation and invariance presented in the classroom in relation to the density concept.

### Teaching and Learning Density From the VT Perspective

Variation Theory analysis attended to the three different objects of learning and their relationships with each other. The three objects of learning were identified from combinations of available data sources using commensurable terms such as critical aspects and variation. The intended object of learning was identified from the teacher’s planning documents and the teacher post-lesson interviews. The video records of classroom interactions were used to draw out the enacted object of learning. Student private interactions in the classroom, their written work and student post-lesson interviews were used as the main sources for the identification of the lived object of learning. Key to this analysis is the identification of the space of learning. In this paper, this space of learning will be described in the form of dimensions of variation opened up in the classroom relevant to the discernment of a particular object of learning, in this case, the concept of density. Learning outcomes will be described in terms of what was perceived by the students to be the key attributes of the density concept. The three objects of learning will then be compared in the discussion to explicate their possible connections.
It should be noted that the analytical approach employed in the study is different from the established approaches developed in “learning studies” that compare the different classrooms with the same intended object of learning (e.g., Lo & Marton, 2011). Instead, VT is used as an analytical lens to interrogate a “normal” classroom and to see the extent to which this analytical lens might help us to understand the teaching and learning of science in this particular classroom.

**The Intended Object of Learning: What Should be Learned?**

The intended object of learning is generally defined from the teacher’s perspective in terms of what should be learned. To identify this object of learning, two data sources were examined: the unit planner and the teacher interviews. The unit planner outlines the major objectives of student learning, whereas the teacher interviews provide information regarding how the teacher appropriated the curriculum materials for his own classroom use. The main capabilities that the teacher expected the students to develop in terms of the concept density are summarized below:

- To be able to understand “density” in terms of how much mass per volume
- To be able to calculate the density of an object using the formula density = mass/volume with appropriate units
- To be able to discern that density does not depend on the size of an object, but depends on what the object is made up of

The last point was made clear in the post-lesson interviews in which the teacher explained his rationale behind the planning of the lesson sequence while watching the first lesson on video. He said:

I didn’t think they had a really good handle on density, which is why I pulled it out the back of my head to do an example, which is why I pulled out the example of the two blocks just to incorporate that it’s not the size that counts, it’s actually what is made up, what indicated in that um block indicated that. Obviously lead to some of the more intelligent kids that there were more particles and atoms so again I was reinforcing the fact that there are more particles in lead than aluminum that justified that they weigh differently, and obviously then talk about density in terms of mass divided by the volume and we obviously did the practical activity to hopefully reinforce some of these ideas that was discussed in the practical. (0:02:31, L02, Teacher Interview)

According to the teacher, the demonstration of the two metal blocks of the same volume (one lead and one aluminum) was intended to respond to some student misconceptions about density and to show that the volume of an object does not determine its density but that the density of an object depends on what substance the object is made of. The teacher also emphasized the importance of introducing the formula of calculating density as mass divided by volume and reinforcing these views through a practical activity of measuring the density of a marble and a candle.

**The Enacted Object of Learning: What is Possible to Learn?**

While the intended object of learning is usually defined from the teacher’s perspective, the enacted object of learning is a researcher’s account of what is possible to learn. This object of learning can be investigated in terms of dimensions of variation and invariance that are opened up in the classroom interactions. In Table 2, the two lessons were examined in terms of three components. Potential dimensions of variation refer to those aspects that could be opened up using the available materials and resources. Invariant aspects are those dimensions that were kept constant or not evoked. The last column of the Table lists the opened dimensions of variation, showing the aspects that were actually varied in the classroom interactions. These dimensions determine what was made possible for students to learn.
Demonstration Using Two Metal Blocks

Table 3 displays the transcripts of a classroom discussion on the density of the two metal blocks and an illustration of how the analysis of classroom interactions was conducted from the VT analytical lens (the last column). Utterances were scrutinized to see whether a dimension of variation or invariance was opened up in the communicative exchange.

Five views related to the concept of density emerged in the above classroom conversation. Each view represents a particular way of seeing or experiencing (Marton, 2016) in relation to density and is constituted by the aspects (dimensions of variation) discerned simultaneously at one point in time (Runesson, 2005).

The first view is the standard macroscopic definition that density refers to how much mass per volume.

The second view regards density as the arrangement of particles in terms of how compact the particles are in an object (line 2).

The third view is that the heavier an object is, the more particles it contains (line 12). Closely related to the third view was the fourth view of density in terms of the number of particles contained in an object (within a certain volume) (line 16).

The fifth view, repeatedly emphasized by the teacher, is that for objects of the same volume, the heavier one will be denser (lines 13 and 25–26). These are substantial views of clear scientific significance, each representing a distinctive way of seeing or experiencing density, despite being closely related to each other. It is remarkable to find each view voiced in such a relatively concise classroom interaction.

As evidenced in the teacher interview, the teacher’s intention of using the lead and aluminium blocks was to demonstrate that size does not matter, but what an object is made up of. However, neither volume nor substance became a prominent focus of the classroom discussion. This can be explained by analyzing the patterns of dimension of variation presented in the classroom. According to VT, students can only discern those aspects that vary (Marton, 2016; Marton & Tsui, 2004).
the volumes of the two blocks remain the same, it is less likely that the students would discern volume as critical to density. Instead, the availability of the two metal blocks provides possibilities for the students to discern the other two dimensions of variation: mass and material (substance). The dimension of mass was introduced (line 12) and became the subject of student attention. Meanwhile, the attributes of size, color and shape faded into the background of student awareness. Even

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Transcript</th>
<th>Dimension of variation and invariance opened up in the discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>Now let's talk about density. Density you would, what did you say density was, Cliff?</td>
<td>Cliff introduces a variation in “mass” and “number of particles”</td>
</tr>
<tr>
<td>Cliff</td>
<td>How compact the atoms are.</td>
<td>Cliff suggests a variation in the “number of particles”</td>
</tr>
<tr>
<td>T</td>
<td>Alright. Well, which of these two, lead and aluminium, is going to be denser</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>S</td>
<td>Lead</td>
<td>T illustrates the variation in “mass” of the two blocks</td>
</tr>
<tr>
<td>T</td>
<td>And why? Cliff</td>
<td>T illustrates the variation in “mass” of the two blocks</td>
</tr>
<tr>
<td>Cliff</td>
<td>Because because it's heavy and so it must have more particles in it</td>
<td>Cliff suggests a variation in the “number of particles”</td>
</tr>
<tr>
<td>T</td>
<td>It's heavy because it got more particles. Ok. Fair enough. But yet these have the same volume, don't they? [showing the two blocks to Cliff]</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>Cliff</td>
<td>Yep</td>
<td>T illustrates the variation in “mass” of the two blocks</td>
</tr>
<tr>
<td>T</td>
<td>[Pointing at the formula on the student worksheet] So in the formula, which says “mass divided by volume” you said that lead is denser because it has</td>
<td>T illustrates the variation in “mass” of the two blocks</td>
</tr>
<tr>
<td>Cliff</td>
<td>More particles contained in it.</td>
<td>T illustrates the variation in “mass” of the two blocks</td>
</tr>
<tr>
<td>Kim</td>
<td>More mass</td>
<td>T illustrates the variation in “mass” of the two blocks</td>
</tr>
<tr>
<td>T</td>
<td>So therefore if I put this on the s-, if I put these two blocks on the scale, what' gonna, what's lead gonna suggest compared to aluminium? [showing the two blocks together]</td>
<td>T illustrates the variation in “mass” of the two blocks</td>
</tr>
<tr>
<td>Cliff</td>
<td>It'll be heavier.</td>
<td>T illustrates the variation in “mass” of the two blocks</td>
</tr>
<tr>
<td>T</td>
<td>Ok. Well, let's see. I've got the scale here from yesterday. Switch it on ... Well, let just crank it up. [pushing buttons on the scale]</td>
<td>T illustrates the variation in “mass” of the two blocks</td>
</tr>
<tr>
<td>T</td>
<td>So these ... these have the same volume. [Holding one block in each hand and Then place the lead on the scale].</td>
<td>T illustrates the variation in “mass” of the two blocks</td>
</tr>
<tr>
<td>T</td>
<td>So this lead weighs a hundred and seventy-eight grams ... What do you think this gonna weigh? [showing the aluminium to the class]</td>
<td>T illustrates the variation in “mass” of the two blocks</td>
</tr>
<tr>
<td>Kim</td>
<td>Fifty something.</td>
<td>T illustrates the variation in “mass” of the two blocks</td>
</tr>
<tr>
<td>T</td>
<td>Fifty something? ... [placing the aluminium on the scale] Good guess. Forty-four grams.</td>
<td>T illustrates the variation in “mass” of the two blocks</td>
</tr>
<tr>
<td>T</td>
<td>So even though they have the same ... volume [showing both blocks], there is a hundred and forty grams difference.</td>
<td>T separates the “volume” and the “mass” of both objects</td>
</tr>
<tr>
<td>T</td>
<td>So what Cliff said is true. [hanging up the lead] This lead even though is of the same volume [placing the two blocks together, and holding the lead higher] must have particles that are packed more tightly.</td>
<td>T separates the “volume” and the “mass” of both objects</td>
</tr>
<tr>
<td>T</td>
<td>Now we're gonna discuss more about particles and how well they packed when we talk about arrangement, we'll look at the particle theory. [glancing at Drew's worksheet]</td>
<td>T separates the “volume” and the “mass” of both objects</td>
</tr>
<tr>
<td>T</td>
<td>It is important you know what in terms of ah ... Density, what it means. So density is how much mass per ... volume. Ok?</td>
<td>T separates the “volume” and the “mass” of both objects</td>
</tr>
</tbody>
</table>

The use of underlines “___” is the researcher's annotation that was intended to help the reading of the transcript and its analyses.

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Table 3. Variation Theory analysis of the public discussion about the two metal blocks.

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Transcript</th>
<th>Dimension of variation and invariance opened up in the discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>Now let's talk about density. Density you would, what did you say density was, Cliff?</td>
<td>Cliff introduces a variation in “mass” and “number of particles”</td>
</tr>
<tr>
<td>S</td>
<td>Lead</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>T</td>
<td>Lead</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>Cliff</td>
<td>Because because it's heavy and so it must have more particles in it</td>
<td>Cliff suggests a variation in the “number of particles”</td>
</tr>
<tr>
<td>T</td>
<td>It's heavy because it got more particles. Ok. Fair enough. But yet these have the same volume, don't they? [showing the two blocks to Cliff]</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>T</td>
<td>[Pointing at the formula on the student worksheet] So in the formula, which says “mass divided by volume” you said that lead is denser because it has</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>Cliff</td>
<td>More particles contained in it.</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>Kim</td>
<td>More mass</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>T</td>
<td>So therefore if I put this on the s-, if I put these two blocks on the scale, what' gonna, what's lead gonna suggest compared to aluminium? [showing the two blocks together]</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>Cliff</td>
<td>It'll be heavier.</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>T</td>
<td>Ok. Well, let's see. I've got the scale here from yesterday. Switch it on ... Well, let just crank it up. [pushing buttons on the scale]</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>T</td>
<td>So these ... these have the same volume. [Holding one block in each hand and Then place the lead on the scale].</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>T</td>
<td>So this lead weighs a hundred and seventy-eight grams ... What do you think this gonna weigh? [showing the aluminium to the class]</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>Kim</td>
<td>Fifty something.</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>T</td>
<td>Fifty something? ... [placing the aluminium on the scale] Good guess. Forty-four grams.</td>
<td>T reminds the invariance of “volume”</td>
</tr>
<tr>
<td>T</td>
<td>So even though they have the same ... volume [showing both blocks], there is a hundred and forty grams difference.</td>
<td>T reminds the invariance of “volume”</td>
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<tr>
<td>T</td>
<td>So what Cliff said is true. [hanging up the lead] This lead even though is of the same volume [placing the two blocks together, and holding the lead higher] must have particles that are packed more tightly.</td>
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</tr>
</tbody>
</table>
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Simple transcript conventions were adopted in this study. For the speaker column, “T” represent the teacher and “S” indicates a student who was unable to be identified from the voice recording. In the transcript column, the contents in the square brackets “[ ]” are the researcher's descriptions of the orientation and actions of the speaker. The use of brackets “()” indicate the transcribers' best guess of an utterance that was difficult to hear. The use of “...” indicates a less than 5 second’s break within a continuous sentence. But the teacher's continuous speeches were segmented according to the message conveyed and each message was placed into separated rows but with the same time code. The use of “//” indicates overlapping speeches. The use of underline “___” is the researcher's annotation that was intended to help the reading of the transcript and its analyses.
though the teacher tried to remind the class to take into account the volume of the two objects, the students’ contribution to the discussion focused exclusively on the mass of the two metal blocks. In other words, even though the initial intention of comparing the density of the two blocks was to show that volume does not determine the density of an object, what was actually enacted in the classroom interaction was the view that mass of the two blocks holds the key to determine which one is denser due to the dimensions of variation foregrounded in the discussion. This introduced another well-documented student misconception associated with density (see, for example, Smith et al., 1997).

A further investigation of the microscopic explanations during the public discussion of the two metal blocks reveals an implicit assumption about the uniformity of particles. For example, the third view that a heavier object has more particles suggests the proportionality of mass to the number of particles in a particular object. A parallel line of thinking could also have been made which assumed that the volume of an object is also proportional to the number of particles. Both views only make sense on the premise that all particles are uniform in weight and volume across substances. When the weight and the volume of an object are regarded as accumulation of the weight and the volume of single particles, density can be regarded as the number of particles in a certain volume regardless of the substance (Bloom, 2001).

Rather than a naïve conception obtained through everyday experience, the assumption about the uniformity of particles is more likely to be the product of prior instruction received by the students, which was based on the notion that further differentiation can be made once the ideas of “basic” particles were introduced. If considered from the perspective of VT, the assumption about the uniformity of particles in volume and weight can be attributed to the absence of attention to the variation in the dimension of “substance.” In other words, there is a lack of discussion of the differences in properties of individual particles of different substances. In this excerpt, even though there was potential for the variation in substance to be realized, the actual classroom interactions did not attend to this dimension. Therefore, it is less likely that the students would attend to the aspect of substance as critical to the concept density.

**The Practical Activity of Measuring Density**

The practical activity of measuring the density of a candle and a marble was intended to help students to have “a physical feel of the concept” (L03, Teacher Interview). The design of the task is thus the key to shape student understanding of the concept. In this practical task, the objects selected to be measured included a candle and a marble, with the candle usually larger than the marble and also heavier. The choice made about the two objects enabled students to perceive several aspects of the density concept: mass, volume, substance, as well as buoyancy. Firstly, it allows students to consider that an object with a larger mass (e.g., the candle) does not necessarily mean greater density. Secondly, it is also possible for students to discern that an object with a bigger volume (e.g., the candle) can have a lower density. Thirdly, the availability of both a marble and a candle made it possible for students to make connections between the different substances and their relative densities. Even though substance is a potential dimension of variation, the classroom interactions did not provide opportunities for the students to perceive that the density of the same substance remains the same regardless of its mass and volume since the objects used in both the demonstration (the lead and the aluminium) and the practical work (a candle and a marble) were made of different materials. The classroom discussions preceding and following this student practical activity was also limited in allowing students to discern substance as a key to the concept of density (see Table 2). Finally, the difference between the two objects in terms of sinking and floating in water (buoyancy) was also available for student discernment. But the discernment of this variation depends on how a student interpreted the instruction on the worksheet. The student might not see it as a dimension of variation since the instruction of the practical work required students to push down the candle using a thin wire (in order to find out its volume). On the other hand, this instruction could actually focus the students’ attention on buoyancy since the worksheet states that “if it floats,”
which introduces another key aspect of the density concept (the relativity of the density of an object as compared with the density of water).

While these four aspects were designed to be varied in this activity, the water level in the cylinder was intended to be kept consistent for both the marble and the candle. This could be seen as a purposeful instructional strategy that the teacher employed to prevent students from being distracted by irrelevant variables, in this case, the amount of water in the cylinder. However, during the second lesson in which the students were asked to report back their results, the amount of water in the cylinder was mentioned as one of the factors that possibly led to the discrepancies in the results reported by different groups. This means that although the water levels were kept constant for both objects, the students noticed the variations in the amount of water used by different groups, and it became a dimension of variation for the students.

The Lived Object of Learning: What is Actually Learned?

Given the dimensions of variation opened up in the classroom discussion, to what extent were these dimensions experienced by individual students as critical to density? Student practical reports on measuring density were examined to reveal this lived object of learning. Based on the practical activity of measuring the density of a candle and a marble, the report required the students to answer these two questions: (1) which object is more dense; and (2) in your practical book, explain your results using the particle theory. Student answers to these questions give some evidence to show what was actually learned by the students as a result of these two lessons.

Student Practical Reports as Indicative of Student Learning

Apart from 5 missing reports, 22 students’ written reports were examined. Table 4 lists the variables that were considered to either determine or affect the density of an object by the 22 students. Table 5 displays the distribution of individual student responses across these categories. The variables mentioned in the student reports were grouped into three categories: macroscopic, microscopic and idiosyncratic. At the macroscopic level, the reference was made to those observable or measurable properties, such as mass, volume, physical appearance and water level, whereas at the microscopic level, students discussed the arrangements, properties or numbers of particles. The idiosyncratic category includes other responses that did not provide sufficient or consistent information about what

| Table 4. Variables indicated in student practical report as dependent or independent of density. |
|-----------------|--------------------------------------------------------------------------------------------------|
| Category        | Variables indicated in student practical reports as dependent or independent of density          |
| Macroscopic level | M1 Attribute density of an object to its mass                                                   |
|                 | M2 Attribute density of an object to its volume                                                   |
|                 | M3 Water level affects the density of an object                                                   |
|                 | M4 Attribute density of an object to its physical characteristics (e.g., texture, hard or soft) |
|                 | M5 Mass of an object does not contribute to being denser                                           |
|                 | M6 Size/volume does not matter                                                                    |
| Microscopic level | m1 Bigger density means more particles are contained in an object                                |
|                 | m2 Bigger density means particles are more compact/closer to each other in an object              |
|                 | m3 Attribute density to the mass of particles                                                     |
|                 | m4 A liquid is less dense because the particles are not as compacted as in a solid.               |
| Idiosyncratic responses | i1 Density of an object is related to gravity                                                        |
|                 | i2 Contradictory answers                                                                           |
|                 | i3 No explanation given                                                                            |
|                 | i4 No discussion about density                                                                       |

· The inconsistency in the information given makes it difficult to see which variable was considered as dependent or independent of density.
· In this category, student answers did not give explicit explanation as to why one object is denser than the other, but only descriptions of their observation were given.
· Student answers make no reference to the word “density” or “dense”. Only the “mass” of the objects was compared and explained.
was considered to be dependent or independent to density. The inspection of variables that were considered as important in determining the density of a candle or a marble provides indications of which aspect of the concept was discerned as critical by the students (the lived object of learning).

The results in Tables 4 and 5 indicate that the students had a wide range of views as to what density is and what determines or affects the density of a candle and a marble. While some students considered that density was independent of the mass and the volume of an object, others regarded them as the key variables that determine the density of an object. Out of the 14 students, 10 showed their understandings of density using both macroscopic and microscopic levels of explanations. At the microscopic level, the students employed either the number of particles or the compactness of particles as part of their explanation for why one object was denser than the other. These 10 student responses were further analyzed in terms of the relationship conceived between the macroscopic and microscopic explanations. Three types of relationship can be identified (indicated in Table 6).

As illustrated in Table 6, while some students seemed to be able to move between the two levels of explanation and establish some sort of connections between the two, for instance by considering heavier objects have more particles (e.g., Victor), others appeared to appeal to one explanation instead of the other, or refer to both levels without making explicit connections between the two. This difficulty in connecting the two levels of explanation could be attributed to the lack of patterns of variation (e.g., Fusion) in allowing students to discern the connections between the macroscopic properties and the microscopic explanations. In this case, the macro properties and the micro explanations were distinguished (Separation) but they need to be brought together through Fusion in order for students to discern density as “a differentiated and integrated whole” (Marton, 2016, p. 53).

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1It should be noted that even though the word “particle” was frequently used in the student writings, it’s difficult to judge whether the student was referring to “particles” in a scientific sense based on the information given in their report. For the analysis reported here, I assume that the students were referring to “particles” in the same way as the teacher unless there is strong evidence that the word was used to mean other things than “particles.”
Discussion

Based on the above analysis of the two density lessons, the three objects of learning are summarized in Table 7.

The analysis shows that while the teacher aimed to help students understand density in terms of mass divided by volume, and that size does not matter but material does, the actual classroom interaction gave rise to many views related to the density concept. Firstly, it is found that aspects such as
mass of an object, number of particles, compactness of particles in an object, and sinking and floating of an object in water were opened up in the classroom interactions, and thus were available for student discernment. Secondly, it was also found that there was an assumption about the uniformity of particles in terms of their volume and mass between them across different substances. The analysis also shows that some students considered the material, size and amount of water that was used to measure density to play a part in determining the density of an object. But the most prominent student views about density as indicated in student practical reports were: (1) the bigger mass an object has, the denser it is; (2) the size or volume of an object does not matter; (3) more dense means more particles contained in an object; and (4) a denser object has particles that are closer to each other.

What is critical to the concept density is the substance or materials that an object is made of. As discussed earlier, while the density of an object can be calculated in terms of mass divided by volume, density is a constant measure between mass and volume for objects made of the same substance or material. In other words, density is a property of a substance and is “independent” of either the mass or the volume of a specific object made of that substance. The teacher ran a special demonstration that focused on this. From the perspective of VT, to learn the concept density requires students to discern the critical aspect of the object of learning, in this case the substance of an object. However, the results revealed that even though substance was a dimension of variation potentially available, the classroom interactions did not provide the opportunities for the students to discern it as critical to the concept of density because the objects used in both the demonstration (the lead and the aluminium) and the practical work (a candle and a marble) are made of different materials. Therefore, there is little opportunity for students to experience a constant relation between mass and volume across objects of the same substance, varying in mass and volume, and to experience the different constants – density – for different substances. In fact, the lack of focus on the critical constant as a property of substance led to some confusion between the density of an object and the density of a substance. While the students were required to measure density of the objects in which both mass and volume are critical in determining the density, the teacher intended for the students to “discover” that what matters to density is the material that an object is made of, without making the distinction between object and substance in the first place. Such confusion between object and substance has led to contradictory responses among the students. The contradictions in student understanding of the concept density are evident in students’ written reports, among which some considered mass or volume as dependent on density, whereas others regarded mass or volume as bearing no relation to density.

**Conclusion**

This paper explored the use of VT as an analytical lens in examining the relationship between teaching and learning of density in a secondary classroom in Melbourne. The analysis of the two lessons from the VT perspective confirms similar conceptual difficulties identified in the literature, for example an undifferentiated notion of weight-density (Smith et al., 1997) and confusion between the notion of density and of denseness (Hewson & Hewson, 1984). However, the analysis reported in this paper offers further clarity in terms of the nature of the conceptual difficulties or confusions, and provides explanations for why the students might have perceived density in certain ways. The analysis of the two density lessons from the perspective of VT demonstrates that the classroom practice provided opportunities for the students to discern several dimensions of variation, including the mass of an object, number of particles, compactness of particles and buoyancy of an object in water. These dimensions of variation were recognized by the students to be the key factors that distinguish the density of the candle and a marble, as indicated in their practical reports. The VT analysis also reveals that the volume of an object and particle attributes, such as atomic weight, was kept constant and thus are less likely to be discerned by the students as important to the concept of density. In particular, it highlights the confusion between the density of an object and the density of a substance. When density is considered as a property of an object, both mass and volume are critical to its
density. However, density is also a constant measure for distinguishing one substance from another. Given the same atmospheric conditions, the density of a substance stays constant and therefore is independent of either the mass or the volume of the objects that are made of the same substance. It is the density of a substance that was important when considering the buoyancy of an object. Therefore, the analysis highlighted the lack of patterns of variation and invariance in the critical attributes of density: object and substance, which contributed to the student difficulties in distinguishing the density of a substance from the density of an object. Using theoretically commensurable terms, such as dimensions of variation and invariance, opened up and simultaneously attended to by the participants at one point in time (for constituting a way of seeing or “view”) in relation to the critical aspects of the density concept, it was possible to delineate the relationships between what was intended as described by the teacher in the interview and in lesson planning documents, what was made possible in classroom interactions as observed by the researcher and what was perceived as critical as reported in student writings and in student-student classroom interactions. Rather than presuming a causal relationship by which learning is somehow “determined” by teaching, the relationship between teaching and learning as described in the reported analysis can be understood as what was made possible for learning and which possibility was made use of by a learner, acknowledging that a learner can bring and generate patterns of variation and invariance by themselves. As such, VT allows for an integrated understanding of teaching and learning through a specific focus on learner perceptions and opportunities for learners to encounter differences in relevant dimensions of variation.

Variation Theory presumes the connections between classroom instruction and learning by focusing on the patterns of variation and invariance (those aspects of the object of learning that are kept constant or “taken for granted” in VT terms). It conceives learning difficulties to be the difficulties experienced in making distinctions, and attributes these difficulties to the lack of patterns of variation in relation to the key attributes of the intended learning object. By considering what was possible to learn and what possibilities were made use of using the language of variation, VT provides us with a powerful explanatory tool for relating teaching and learning of science and suggests some possible ways to improve instruction. In particular, it focuses specific on learners’ perception and looks for conditions that might enable (or hinder) the desired ways of seeing. In this study, the great variations between individual students’ understandings of density cannot be attributed solely to the patterns of variation opened up in the classroom without considering the variations between individual students’ capabilities and previous experience in relation to the object of learning. It is important to note that the possibilities opened up in the “same teaching” can only partially account for the variations in learning outcomes as identified in the analysis reported in this paper. This suggests that further development and application of VT will need to consider pre-existing variations between individual students in designing instructional activities in order to optimize the conditions of learning for all students. The recent development of VT research in the form of Learning Studies has the potential for a more complete study of teacher and student activity in relation to each other through a common focus on “critical aspects of the dealing with and understanding of subject matter” (Svensson, 2016, p. 276). Research work in this area could contribute to further development of the theory to address the current limitations outlined in this paper.

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