Teacher Sensemaking on Computational Thinking

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Abstract

The existing literature regarding teacher sensemaking has identified that ‘‘sensemaking’’ is a plausible and valuable concept in exploring the reasons why teachers have a wide range of differences in perception and understanding of the same reforms or educational innovations. However, little research has shed light on the thorough process of teacher sensemaking of curriculum innovations, such as integrating Computational Thinking (CT) under the setting of Professional Learning Communities (PLCs). Also, few studies have combined sensemaking and actor-network theory (ANT) to examine actors that influence teacher sensemaking toward curriculum innovations. ANT emphasizes actors that can be both human and non-human. Employing ANT in this study provided a thorough picture of teachers’ sensemaking, and how different actors affected their sensemaking. Moreover, CT is almost ubiquitous in education today, as diSessa asserts that CT can be a new form of literacy, namely Computational Literacy (CL). This research was qualitative and aimed to explore how seven mathematics teachers at a school in Singapore made sense of CT and made sense of how to integrate CT into the mathematics curriculum. Teachers in this study applied an unplugged approach of CT to teach math. This study employed a case-study design with seven teachers using observations of teacher meetings, semi-structured interviews with the teachers, and teacher artifacts. The findings showed how teachers made sense of CT and what actors influenced their sensemaking. Also, the four principles of CL were reflected within the findings. This study provided pertinent suggestions based on the findings and directions for future research.

Keywords
Computational Thinking; Computational Literacy; Sensemaking; Curriculum Innovation; Actor-network theory; Mathematics
Summary for Lay Audience

Today, it is inevitable for teachers and schools to deal with rapid changes and the emergence of curriculum policy reforms and educational innovations. There has been a rising interest in integrating Computational Thinking (CT) into the mathematics lessons. CT is almost ubiquitous in education today. Sensemaking is especially vital for understanding how innovations and reforms have made impacts on educators within organizations.

This study aimed to explore how mathematics teachers made sense of and integrated CT into the mathematics curriculum in a PD setting, and it sought to identify and interpret interconnected actors that were involved in producing teacher sensemaking and then influenced the practices of CT. Lastly, this thesis attempted to explore how CL was reflected. The findings indicated the most prevalent property of sensemaking and how teachers made sense of CT in detail. This study offered a comprehensive picture that included how different actors including the exam-oriented culture in Singapore, the way of teaching and learning CT+math lessons, the suitability of mathematics topics, and the arrangement of teacher duties influenced teacher sensemaking. Also, the four principles of CL were reflected within the findings. Pertinent suggestions are provided to educators who are involved in curriculum innovations. These findings are important to support continuing professional development because they indicate the roles and importance of PLCs so researchers and educational sectors can improve or adjust their practices in PLCs based on the findings. It is also useful for educational researchers, practitioners, and governments to understand teachers’ thoughts and needs when they encounter new educational innovations so they can pertinently support teachers and implement the innovations confidently and smoothly. Furthermore, this study gives insights into the development of CL because the thesis showed how CL was reflected in
the practices of CT. Finally, as this study specifically examined teacher sensemaking in CT+math lessons, schools or teachers who are implementing or will implement CT+math in their lessons will benefit from this research because they will explicitly see the challenges, obstacles, and processes of implementing CT+math lessons.
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Chapter 1

1 Introduction

1.1 Background

Sensemaking has been greatly applied in non-educational areas such as research in an organization (Weick et al., 2005); however, in recent years, a growing number of studies on teacher sensemaking have emerged in education (Odden & Russ, 2019). Sensemaking is especially vital for appreciating how innovations and reforms may have some effects on educators within organizations (Seashore Louis & Robinson, 2012). It provides an explanatory framework for why reforms are so arduous (Patrick and Joshi, 2019). Sensemaking is beyond simply interpreting a circumstance or a problem. Sensemaking aims to adapt new insight into existing beliefs and knowledge (Van Veen & Lasky, 2005). It is a useful theoretical framework to help researchers explore how teachers make sense of the myriad of innovations available today.

Today, it is inevitable for teachers and schools to deal with rapid changes and the emergence of curriculum policy reforms and educational innovations. It is indispensable to offer schools and teachers effective and plausible support and approaches to understand and implement the many reforms and innovations that they are unfamiliar with and feel ambiguity in them. Along with the instantaneous digital technology advancement, students need to learn innovative knowledge and skills to equip themselves for higher education and a competitive job market in society. Governments focus on educating learners’ communication, collaborative skills, critical thinking, and problem-solving (Carlgren, 2013). Taylor et al. (2018) succinctly define educational innovations as educators utilizing any innovative teaching practice, technique, tactics, apparatus, or learning resources to accomplish instructive approaches that are helpful for student learning and engagement. Thus, teachers
should improve their practical knowledge that they use day-to-day to schedule and manage their teaching abilities (van Driel et al., 2001) in order to teach students more effectively and implement the policies or educational innovations efficaciously.

1.2 The Problem

However, previous research has found that translating innovative ideas into new educational practices is a sophisticated transformation, as teachers need to coordinate and understand the textbooks, simulation software, or goals that are from educational innovations (Coburn, 2005; Spillane et al., 2006). The relationship between educational reforms or innovations and their authentic enactment or implementation is extraordinarily complicated. The different contexts of schools and classes influence the actual practice of teaching and learning, and thus their potential for change. Teachers may find themselves unclear in the purposes and implementation of innovations as they may interrupt the routine and force teachers to leave their ‘‘comfort zone’’ (Serdyukov, 2017, p. 17) under this complex situation. Teachers’ perception and understanding of innovations determine their practice (Stylianides, 2008). Therefore, teachers must have a thorough understanding of reforms or innovations to enact them sensibly and successfully.

Previous research has found that professional networks of teachers are important as they allow more teachers to gain a deeper understanding of innovations (Cobb & Jackson, 2011). Professional Development (PD) helps teachers change their cognition, beliefs, and practice. Although teachers receive knowledge and training through continuing PD (Darling-Hammond et al., 2017), uncertainty and ambiguity are still the common challenges among teachers and foreclose them to enact innovations smoothly and effectively (Allen & Penuel, 2015).
Various factors that impact teacher implementation of innovations, such as teacher attitudes, beliefs, institutional factors, and factors related to resources support (Ketelaar et al., 2012; Lawrence & Tar, 2018) were the focus of previous studies. The substantial innovations and reforms in this area require more efficacious coordination and cohesiveness among heterogeneous parts of complicated systems in education. The focus should be more diverse and pertinent to how schools and teachers understand or interpret the innovations. Research should, for instance, attend to the detailed processes of teachers converting curricular documents, goals, pedagogies, and notions into practice (Cobb et al., 2003). Previous research identified various popular concepts in education, including agency, ownership, and belief which influence teacher perception and practices toward innovations (Ketelaar et al., 2012). Teachers are active agents. Their uniqueness enables them to have a different interpretation, negotiation, adaptation, and implementation toward the materials from policy messages or innovations (Bunten, 2014; Newcomer & Collier, 2015).

In recent years, “sensemaking” has become a common theoretical concept for research in education (Odden & Russ, 2019; Shaked & Schechter, 2019) and provides researchers with a valuable explanatory framework for why educational changes are arduous (Patrick & Joshi, 2019). Weick et al. (2005) created seven properties of sensemaking in their later work to describe properties of sensemaking in detail. This perspective underlines teachers making sense of novel ideas based on their preceding knowledge, expertise, and experience (Spillane et al., 2006). Research related to teacher sensemaking usually discerns that teacher perceptions towards the same reform can have a wide range of differences because of their dissimilar local context, prior knowledge, and stance. While some teachers engage in sensemaking with their colleagues (Allen & Penuel, 2015; Rom & Eyal, 2019), some studies found that teachers only have sensemaking individually (Schmidt & Datnow,
2005). The social context of teachers importantly affects how they interpret and implement educational innovations in their practice (Chase, 2016).

Although considerable research has applied “sensemaking” to examine teacher patterns of sensemaking (e.g., Lwin, 2019; Luttenberg et al., 2013; Saito et al., 2016) and what factors influence teachers’ sensemaking (e.g., Chase, 2016; de los Santos, 2017; Schein, 2009), the context is mainly in North America. As Asian countries possess distinctive characteristics which are collective and hierarchical, it will be meaningful to have more research to investigate how teachers in Asian countries make sense of educational innovation.

Little research has explored how teacher sensemaking have sensemaking in the setting of Professional Learning Communities (PLCs). According to Spillane et al. (2006), sensemaking covers not only the individual-level practices but also the “practices and common beliefs of a community” (p. 58). This reflects that the social nature of sensemaking and how a community influences one’s sensemaking. Allen and Penuel (2015) explored how teachers responded to professional development (PD) and pointed out that teachers needed more chances to engage in collaborative and sustain sensemaking to help them understand and deal with the incongruities and ambiguity towards changes. Thus, PLCs can be viewed as a community that helps teachers make sense of innovations.

Apart from sensemaking, actor-network theory (ANT) was used in this study. ANT is an approach that allows scholars to understand how different things “come together, manage to hold together, and form associations that produce agency and other effects” (Fenwick & Edwards, 2010, p. 21). While scholars state sensemaking overemphasizes taken-for-granted cognitive processes and underplays other aspects, such as the dynamics of power and influence (Park et al., 2012; Weber & Glynn, 2006), ANT points out that people should look equally at the actors that are human and non-human (Fenwick & Edward, 2010), including but not constrained by concepts, objects, spatial, and short-lived patterns. The “demands and
needs’” from non-human entities can influence human “‘intentions, meanings, relationships, routines, memories, and even perception of self’” (Fenwick & Edwards, 2010, p. 24).

Therefore, employing ANT in this analysis with sensemaking provided a comprehensive picture of teacher patterns of sensemaking, and how different actors enabled and constrained teacher sensemaking then influenced the practices of CT.

In this study, sensemaking was applied to examine how a group of mathematics teachers in Singapore made sense of and integrated a recent popular educational innovation, which is Computational Thinking (CT), into their math lessons. In 2014, Singapore initiated the Smart Nation initiative in order to develop its citizens’ digital literacy through learning coding or CT learning for pre-schooler to adults. For example, primary grades have to learn 10-hour coding classes. Also, there has been a rising interest in integrating CT into mathematics lessons (Chan et al., 2020). CT is almost ubiquitous (Kin et al., 2021) in education today, as diSessa (2018) asserts that CT can be a new form of literacy, specifically Computational Literacy (CL). As such, it is also important to explore how the practice of teacher sensemaking of CT reflects the development of CL. Teachers in this study applied an unplugged approach (Grover & Pea, 2013) of CT to teach math. This study argues that sensemaking combined with ANT offers an explanatory and theoretical framework to explore the complex process of teacher sensemaking of educational innovations.

This study aims to explore how mathematics teachers make sense of CT and made sense of how to integrate CT into the mathematics curriculum in a PLC setting, and it seeks to identify and interpret interconnected actors that are involved in producing teacher sensemaking and then influence the practices of CT. Lastly, this thesis attempts to explore how CL is reflected. Thus, the research questions are:

1. How did teachers make sense of the curriculum innovation?
2. What actors enabled and constrained teacher sensemaking and then influenced the practices of the innovation?

3. How did the practices of CT reflect Computational Literacy (CL)?

This research is significant for five reasons.

First, there is limited research having explored teachers’ sensemaking in the context of PLCs and combining sensemaking and actor-network theory (ANT) to examine actors that influence teacher sensemaking. Also, this study is one of the very few studies that uses CL to explore how CT can change the ways of learning and teaching. Therefore, the findings of this study can give some insights into the existing literature and future research examining teacher sensemaking and the development of CT or other innovations.

Second, since studies in sensemaking are mainly in North America (e.g., Chase, 2016; de los Santos, 2017; Schein, 2009), this study provides an example that is explored in one of the Asian countries.

Third, the previous research has already confirmed the learning benefits of integrating mathematics lessons with CT activities (e.g., Gadanidis et al., 2018), which will give insights to schools and teachers adopting CT in their mathematics lessons so they can implement their lessons more effectively and easily. Students can benefit from this research as well, as the findings help teachers create possibilities for improved accomplishment, learning motivation, and enjoyment in the learning process.

Fourth, exploring teacher sensemaking of innovations and the ways to support teacher sensemaking will help teachers make sense of ambiguous situations and manage uncertainty. Teachers will be able to better appreciate their circumstances when they are working on different innovations including CT and adapt them more easily and confidently.
Fifth, the study provides insights for teachers, policymakers, and leaders by investigating actors such as culture and resources which influence teacher sensemaking. Then, policymakers and leaders can support teachers better in implementing innovations and they all will know what actors enable and constrain them in the midst of innovations.
Chapter 2

2 Literature Review

In this chapter, I review the literature that provides the theoretical framework for my approach to this study. First, curriculum innovation is reviewed. Second, the history and development of PLCs in Singapore are presented. Third, the history and implementation of integrating CT in teaching mathematics and the content of CL are recapped. Fourth, the existing educational research that uses sensemaking as an analytical framework to explore the relationship of teacher sensemaking to innovation is examined. Last, the notions and constructs of actor-network theory are presented.

2.1 Curriculum Innovation and the Role of Teachers

One of the reasons that educational reforms are occurring is because there are unprecedentedly quick changes in the development of technologies (Sharma, 2018). It is indispensable for students to learn lifelong skills at school to be ready for their future education and work (e.g., Trilling & Fadel, 2009). Thus, the knowledge and skills provided in the curriculum must be state-of-the-art in order to overtake these new movements (Jerald, 2009). The field of education needs curriculum innovations.

The aim of curriculum innovation is always to make improvements. This involves the transformation of the learning or teaching circumstances (Leask, 2008). Mourshed et al. (2010) viewed curriculum innovation as a process-based intervention that included different processes and shareholders. A study by Mourshed et al. (2010) examined 20 educational systems which indicated that the most commonly identified school change was process-based interventions. The other changes included structural change or resource change, but they were less common. The process-based interventions included teaching manners, content, and transformation prospects involving learning assessment, pedagogical options, management
skills, and teaching-learning (Koh et al., 2014). Sometimes, policymakers mandate the implementation of educational innovations in a top-down manner, while sometimes classroom practitioners enact the changes from the bottom-up (Hyland & Wong, 2013). In both cases, teachers play pivotal roles as curriculum creators, implementers, and activists (Le Fevre et al., 2015).

Extensive studies have shown the irreplaceable role of teachers in curriculum innovation (e.g., Rahimi et al., 2016; Shawer, 2010). According to Kelly (2009), policymakers should engage teachers in both the establishment of the new curriculum and in developing the foundation for change. Teacher involvement leads to a considerable sense of ownership, which is extremely crucial for implementing innovation. Teachers have an important role as curriculum makers (Handelzalts, 2019). They are also the frontliners in the enactment stage. Therefore, they need to be fully aware of the essence of curriculum innovation. Individuals or groups who are not clear about the intended transformation and the procedure of innovation are the obstacles to implementing educational innovation successfully.

Wallace and Priestley (2017) found that not only were teachers implementing curriculum transformation concerning practices in the classroom, but they were also attentively engaging in developing and organizing curriculum innovation. Curriculum innovation requires teachers to reconceive the curriculum and reconsider pedagogical conventions (Tan & Ponnusamy, 2014). It occurs in contextualized circumstances and engages educators in genuine, sophisticated teaching and learning issues (Măță, 2012). Teachers must be well-equipped to be qualified enough to educate students effectively. Today students are usually learning in a digital environment (Sharma, 2018). To respond, teachers should be able to employ various materials, different pedagogic methods, and use innovative assessments. The teachers’ knowledge, attitudes, and understanding of changes
are important to the outcome of the curriculum innovations (Okoth, 2016; Lawrence & Tar, 2018).

In order to better prepare teachers to work on curriculum innovations, teacher-learning is of utmost importance. Teachers are learners rather than ‘‘passive conduits of someone else’s policy’’ (Priestley, 2005, p. 36). Lieberman and Mace (2008) stated that the central component of educational reform was teacher learning. Teacher expertise depended on the ability of teachers to rethink classroom enactment.

2.2 Professional learning communities (PLCs) in Singapore

PLCs offer an environment that fosters professional development, cooperation, and innovations between teachers and related educators. Hoaglund et al. (2014) define PLCs as groups of committed educators collaboratively working in a continuous process that leads to better student accomplishment. Wilson (2016) further defines PLCs as including shared governance between educators that contributes to school advancement. Thus, a PLC is a community where teachers, experts, and other related contributors work together with common goals and related backgrounds. Mourshed et al. (2010) identified that teachers cooperatively interacted and learned from peers which were significant in advancing education systems. PLCs can be an exceptional opportunity for developing educators and institutional capabilities to pursue rapid changes in educational reforms (Bolam et al., 2005). It is a crucial platform to improve student accomplishment and success, as educators can gain more professional knowledge and experience through PLCs.

One of the most prominent differences between PLCs compared to other cooperative teams in collaboration is that schools or educational organizations establish PLCs for a concrete and specific purpose (Hoaglund et al., 2014). PLCs establish a space for teachers to discuss how to help students learn better, not only what they learn (Hoaglund et al., 2014).
The objectives of PLCs are teacher outcomes and student outcomes. An implicit belief is that PLCs can contribute to considerable changes in teaching cultures and practices (Ning et al., 2015). Compared to individual professional development courses, PLCs can promote continuous collaborative efforts, with better long-term benefits. Collaboration is the elemental foundation of PLCs; it contributes to shared activities and practices in which educators take part to accomplish shared objectives (Ning et al., 2015).

In PLCs, there are two crucial dimensions: collective learning and shared personal practice. Ning et al. (2015) identified that collective learning demanded a prioritization of professional improvement by educators together to establish the best tactics for student learning. The sharing of personal practice, as the second dimension, needed educators to engage in activities, namely classroom observations, discussions, and peer coaching aiming to strengthen their professional development.

In Singapore, the initiative of the PLC policy was started in 2009 by the Ministry of Education (MOE), but the concept and enactments of teacher learning in communities had already existed for 10 years which was known as “learning Circles” (Hairon & Dimmock, 2012). The pilot PLC initiative inspired similar models of teacher-led PLCs to grow in Singapore (e.g., action research, communities of practice, and lesson study). Apart from bringing about suitable curricular innovations and learners’ experiences of learning, the MOE expected teachers to take a greater role in professionally developing other teachers. The pursuit of establishing a strong community requires members of PLCs to interact with one another in a routine and relational manner for continual and sustained ways of learning (Hairon, 2020). Many researchers have discussed how PLCs work. There are five components. The first component is about shared values and goals. This means that members of PLCs have common goals concerning the school’s mission and future plans (Vangrieken et al., 2017; Vescio et al., 2008). The second component, collaborative activity, encourages
group members to share and talk about their teaching knowledge and skills so as to align their practices with that of other members (Stoll et al., 2006; Vescio et al., 2008). The third component focuses on student learning in a shared sense. Members in PLCs take collective responsibility for student learning to establish accountability and maintain commitment. The fourth component is about deindividualizing practice. Group members examine one another’s practices by mutual observations and case analyses to provide meaningful feedback (Lomos et al., 2011; Vangrieken et al., 2017). The last component is reflective dialogue, which is about conversations concerning educational themes or issues related to pedagogy and particular students’ learning (Stoll et al., 2006; Wahlstrom & Louis, 2008). The MOE claimed PLCs could elevate the quality of pedagogical expertise so that students could learn more effectively and lead to conventions to guide teacher-steered professional development. After the PLC initiative in 2009, the MOE passionately advocated that schools initiated PLCs. Therefore, the MOE required schools to come on board the PLC journey (Lee & Lee, 2013).

Singapore adopts a countywide PLC model. The smallness of Singapore and the hierarchical system in education are helpful for the MOE to normalize PLCs across all schools (Lee & Lee, 2013). Schools in Singapore included several Professional Learning Teams (PLTs) (TDD, 2010). Generally, every PLT included teachers teaching at the same grade level (more typical in primary schools) or teaching the same subject (more typical in secondary schools).

The aims of the Singapore PLCs are student learning and school leadership. For student learning, PLCs emphasize “three Big Ideas” and “four Critical Questions”. The three ideas are empowering students to learn, establishing a teamwork culture, and emphasizing the outcomes. The four questions are – What is it we expect students to learn? How will we know when they have learned? How will we respond when they don’t learn? How will we
respond when they already know it? (DuFour, 2004). For school leadership, the PLC model advocates for the procedures of PLCs in developing the Coalition Team which includes principals, school staff developers, and heads of departments. PLTs and the Coalition Team have different effects. The former mainly influences enhancement in teaching practice, while the latter is more concerned with establishing the learning culture in school.

2.3 Computational Thinking

Computational thinking (CT) is a pedagogical innovation that is highly relevant to STEM education. CT was initially defined as “solving problems, designing systems and understanding human behavior that draws on concepts fundamental to computing” (Wing, 2008, p. 3717). Later, Wing (2014) further defined CT as a thought process related to formulating a problem and expressing its solution(s) in such a way that a computer-human or machine—could effectively execute. However, there are different definitions of CT. diSessa (2018) challenges Wing’s idea and states that “the problem is that [Wing’s] model does not extend to some of the core tasks that she implicates for computational thinking” (p. 26). Tedre and Denning (2016) argue that CT does not have clear definitions because the community of education has not finalized a definite definition for CT. Although specific definitions of CT are different, CT in this study is defined as entailing decomposition, pattern recognition, abstraction, and algorithmic thinking (Hoyle & Noss, 2015) because the teacher participants applied the four pillars of CT to their CT+Math lesson. In other words, students could use CT to deal with complicated problems by breaking them down into a small set of more manageable problems (decomposition). Then, students could look at these problems independently, contemplating how they had resolved similar problems before (pattern recognition) and paying attention to the essential details while neglecting the unrelated information (abstraction). Finally, they could design simple procedures, or orders to resolve
each of the problems (algorithms). The Next Generation Science Standards recommended CT as an important competency that should be acquired by students (NGSS Lead States, 2013). Some studies have stated the importance of infusing CT as a core capability that every child should learn to transform traditional teaching and learning ways. Many countries have integrated CT as a crucial constituent of the curriculum (Curzon et al., 2014; Gadanidis et al., 2018; Sanford & Naidu, 2016).

According to Lu and Fletcher (2009), CT is a vital skill to balance fundamental knowledge which includes mathematics, reading, and writing. Barr and Stephenson (2011) posited that the foundational transformations of conventional teaching required a combination of computer science and mathematics to produce a dependable pedagogical method established on CT. Yadav et al. (2016) suggested integrating CT with all subjects and recommend “moving students from merely being technology-literate to using computational tools to solve problems” (p. 565).

The ability to do mathematics is usually seen as a core factor in predicting learners’ capability to learn computer programming. Computer-related subjects require mathematical ability (Balmes, 2017). Computational thinking is closely associated with mathematical thinking as dealing with a mathematical problem is a construction process (Feurzeig et al., 2011) that needs an analytical problem-solving perspective, which is exceptional and fundamental to computer programmers or scientists (Berland & Wilensky, 2015).

Computational aspects have become integral and the principal components of presentation for mathematics in K-12 programs (Farris & Sengupta, 2014). CT can bring two benefits to learners and these benefits justify CT as an important innovation. The first is that CT can help students adapt to this world that is rapidly digitized. Secondly, people who employ CT gain greater problem-solving skills (Denning, 2017).
From the perspective of subject knowledge in mathematics, CT helps in the design of better quality mathematics for the classroom. Erdogan et al. (2014) stated teacher candidates perceived mathematics as a figure with a single correct answer. The beliefs and attitudes of mathematics teachers influence their classroom practices (White et al., 2005) then influence students’ impression of mathematics. Rather than just focus on getting correct answers, students can engage in a range of mathematics and take alternative approaches to mathematics problem-solving because of CT integration. Gadaniidis et al. (2018) applied computational thinking tools to bring an innovative experience to grades 2-6 students to learn about symmetries. Teachers, parents, and students responded positively to this method of learning mathematics.

From a pedagogical perspective, the application of computational tools and skillsets can strengthen the learning of mathematics and science (Sengupta et al., 2013; Wilensky et al., 2014). Mathematics offers a meaningful setting (and series of problems) in which educators can apply CT (Hambrusch et al., 2009; Jona et al., 2014). This is unlike teaching CT as an independent course in which the tasks teachers give students are usually separated from real-life implementation and problems. This sense of genuineness and real-life relevancy is crucial to promoting distinctive and significant engagement in computational and scientific activities (Blikstein, 2013; Ryoo et al., 2013).

2.3.1 diSessa’s Computational Literacy (CL)

diSessa started his work related to computing education at the MIT Artificial Intelligence Laboratory. His research focus is on the use of computer systems in teaching and learning, as well as in physics. Today, he is also exploring a new form of literacy derived from computers that is appropriate for a wide range of subjects, contexts, and domains (Weintrop et al., 2016).
diSessa (2018) asserts that computing is a new form of literacy. He supports the wide application of computers in schools because computing helps transform the teaching and learning of things that are difficult for students to learn (Papert, 2006). diSessa uses algebra as an example of an epistemological entity that converts sophisticated and complicated ideas into a form that every high school student can learn (Papert, 2006). He further explains that CL integrates computing and computer programming concepts in almost the same way that algebra has grown into a ubiquitous tool in mathematics, science, and other subjects.

diSessa (2018) clarifies that his application of the term literacy means the adoption of a “particular infrastructural representational form for supporting intellectual activities” (diSessa, 2018, p. 4) by a broad group, or even a civilization. diSessa (2018) criticizes Wing’s computer science-centric view by asserting that because literacy is a tremendous social and intellectual achievement, it does not make sense that it only belongs to one professional discipline.

Based on the idea of CL, he further develops the “‘four Rs’” for adding detail and core ideas for a literacy-related agenda. The “‘four Rs’” will bring different potential changes to education. They include Re-mediation, Reformulation, Reorganization, and Revitalization. Re-mediation accentuates that the core of literacy is the mass application of a representational system. As the representational infrastructure (Kaput et al., 2002) is changing rapidly for our civilization, the computational medium, as the new form of representational infrastructure, will greatly influence the students’ experience in learning a subject. Reformulation is about a discrete epistemology that substantially changes what, when, and how to teach a subject matter according to an enhanced understanding of human resources. Reformulation also involves “‘understanding the character and potential power of common, ‘naïve’ ideas in scaffolding technical competence’” (diSessa, 2018, p. 19) which helps “‘cognitive simplicity’”. Reorganization is about creating “‘a landmark for deep change in teaching and
learning, concomitant to the more general focus on big cultural changes. Teaching mathematics would and should look very different, given any literacy-scaled change” (diSessa, 2018, p. 37). Textbooks and curriculum documents will reflect a reorganized intellectual terrain. Revitalization is a principle that facilitates the ecology (diversity) of learning activities which is related to revitalizing engagement, interest, and equity in classrooms.

2.3.2 Challenges of CT

Studies have shown that there are different challenges when applying CT in teaching which include curricular, pedagogical, and assessment challenges. Lee et al. (2011) found the challenges of developing CT skills. The challenges included enhancing the learning environment and building teachers’ competency to apply CT in their practices. They found that another challenge was that students were difficult to engage in CT activities (Atmatzidou & Demetriadis, 2016). Teachers may find it confusing to implement CT activities because it requires computer programming. Teachers are not sure if they can teach the rudimentary CT concepts independently (Lu & Fletcher, 2009). Regarding student learning of CT, it is beneficial to students when teachers learn to apply CT as a skill for facilitating student learning. CT is more than just a subject that students normally learn in the classroom (Denning, 2017). Apart from challenges for students, teachers also need cooperation, resources, and support to merge technology in their teaching implementation (Lavicza et al., 2010). Therefore, having a good way for teachers to learn how to integrate CT into their teaching is important. A Sensemaking lens can give insights to researchers about how teachers make sense of CT.
2.4 Sensemaking

2.4.1 Teacher sensemaking

Researchers in education have utilized sensemaking to investigate various outcomes in policy enactment (Mills et al., 2010).

Recently, there is an escalating number of studies about teacher sensemaking in education (Odden & Russ, 2019). Sensemaking is especially vital for understanding how innovations and reforms have made impacts on educators within organizations (Seashore Louis & Robinson, 2012). Patrick and Joshi (2019) argue that sensemaking provides an explanatory framework for why reforms are so arduous.

Luttenberg et al. (2009) define sensemaking of innovation as “the interaction between their own frame of reference and the perception of the situational demands that are inherent to innovations, resulting in the personal interpretation of innovations” (p. 446). As such, sensemaking is beyond simply interpreting a condition or a problem. Sensemaking aims to adapt new insight into existing beliefs and knowledge (Van Veen & Lasky, 2005). Research studies on teacher sensemaking have shown that teachers can establish distinct interpretations of the identical reform according to its context (e.g., Allen & Penuel, 2015; Rom & Eyal, 2019). The interwoven characteristic of individuals’ knowledge, beliefs, and attitudes and different circumstances in an organization lead educators to interpret the same messages of innovations differently. As a result, they can be apprehensive about the reform that can differ significantly from the aim of the new initiative (Coburn, 2004) and hinder the enactment of school improvement efforts because teachers do not adjust their practices (Spillane et al., 2006).

Spillane et al. (2006) focused on the cognitive aspects of sensemaking and its social nature. They stated that individuals understood particular conditions in their social networks,
workplace systems, and social identities which were called situated cognition. They also examined how stakeholders in educational organizations used sensemaking in new initiatives. The authors claimed shareholders were active interpreters that drew on their knowledge, beliefs, and attitudes in the process of interpretation rather than being simply a receiver decoding the policy message. According to Spillane et al. (2006), sensemaking is related to not only the individual-level practices but also the “practices and common beliefs of a community” (p. 58). This reflects the social nature of sensemaking and how a community influences one’s sensemaking. Institutions can provide sources for teachers to make sense but can also constrain sensemaking. Sensemaking is an ongoing process that is influenced by the artifacts and materials contained as educational resources (Spillane et al., 2006).

In other research, Coburn (2005) identified that different sensemakers in an educational organization influenced others’ sensemaking. He investigated the relationship between teachers and principals. Principals are one of the highest decision-makers at schools. They take charge of implementing innovations and reforms. Their direction, thoughts, and interpretation of the innovations highly influence teachers’ interpretation of innovations.

Louis et al. (2013) also acknowledged a social conceptualization of sensemaking. Louis et al. discovered that teachers became contributing sensegivers who “understand the change goals, the school’s culture and history, and who are capable of communicating scenarios of consistency to others” (p. 43). Communicating scenarios of consistency means that teachers tell consistent scenarios to others. For example, they share consistent information or opinions with novice teachers or senior teachers. Teachers as sensemakers give valuable support and motivation for the curriculum innovations. According to Louis et al. (2005), sensemaking is intrinsically social. Teachers in school establish meanings for the innovations cooperatively. Therefore, schools provide them chances to allocate work, act collectively, and learn together to give them a way to make sense socially to improve the
possibility of extensive transformation (Louis et al., 2005) because “the energy that teachers collectively devote to making sense of accountability policies may make them more likely to interpret policies as controllable” (p. 200).

Sensemaking of policy messages is an active process. This process notices messages, processes meaning, and organizes new knowledge (Coburn, 2001). The consequence of this process is inclined to be fragmented and teachers choose which messages are justifiable and suitable to be enacted in their contexts. Chase (2016) analysed the macro-level context in the United States that influenced how teachers made sense of policy messages. She discovered various factors that influenced teacher sensemaking, which included institutional identity, self-interest, national narratives, and perception of the target population. The institutional identity led implementors to align programs or policies to the values that were the most prominent to the institution. Self-interest was about two ideas: first, implementors were less likely to advocate policy if they thought it was a potential threat to their livelihood; second, influential groups and individuals played a role in how policies were made sense. National narratives influenced how implementors interpreted the value and importance they placed on a policy. The perception of the target population was that implementors tended to use their perceptions of students when they were interpreting the value of policies.

Sensemaking provides a lens to develop an overarching image of the specific educational context by three interwoven processes, including creation, interpretation, and enactment (Weick, 2009). Firstly, sensemakers search for the broader picture by acquiring disparate information to articulate the unprecedented circumstances. Sensemaking provides individuals with appropriate and practical mapping skills for coping with ambiguity to have a better understanding of the conditions and then enact more sensible and effective actions (Ancona, 2012). Rather than seeking an “absolute” answer, sensemaking is about establishing a comprehensive picture for sensemakers. The unfamiliarity with new conditions
can stimulate inconsistent interpretations by sensemakers. They establish a preliminary perception but become more organized later. Next, throughout the enactment process, sensemakers transform their ideas into practices. The final process involves incorporating new information and eventually acting in building on the previous interpretation (Shaked & Schechter, 2019). In a nutshell, the sensemaking lens offers policymakers, schoolteachers, and researchers an invaluable theoretical and descriptive framework because sensemaking is more than interpretation as sensemakers proactively make sense of the unprecedented events they are going to appreciate (Smerek, 2011). As such, educators and researchers in the educational field can efficiently utilize “sensemaking” in analysing education-related innovations and reforms (Matsumura & Wang, 2014).

However, throughout the literature on sensemaking in education, few studies have explored teacher sensemaking under the setting of PLCs. Previous studies normally claimed how individuals’ beliefs, attitudes, or knowledge related to sensemaking but did not explore teachers’ properties of sensemaking thoroughly. Weick’s seven properties of sensemaking help describe how teachers make sense of innovations.

2.4.2 Seven properties of sensemaking

Weick et al. (2005) consolidate different researchers’ descriptions and interpretations of sensemaking by formulating seven interconnected properties of the process of sensemaking. The seven properties of sensemaking are: (a) grounded in identity construction, (b) retrospective, (c) enactive of sensible environments, (d) social, (e) ongoing, (f) focused on and by extracted cues, and (g) driven by plausibility rather than accuracy.

The property grounded in identity constructions influences how other properties of sensemaking are enacted (Weick et al., 2005). Identities are relentlessly shaped and reshaped as individuals have their own lives and interact with the surrounding environment. A sensemaker is a collection of different selves. Individuals establish their own identities or
selves by interacting with many people. How people think of themselves also makes up how
they have sensemaking about their experiences. When encountering an equivocal
circumstance, individuals usually make sense of the situation by reflecting on what it
represents to them in their identities as a principal, head of the department, senior teacher, or
new teacher. The development and continuing transformation of selves are important to
understand the other sensemaking properties. A sensemaker perceives things differently in
terms of their own identity.

The “Retrospective” means that a sensemaker pays attention to previous experience
to make sense of present events (Weick et al., 2005). The “retrospective” does not mean all
experiences in the past but in a specific circumstance (Weick et al., 2005). Previous
experiences play a vital role in empowering sensemakers to make sense of present events. By
comparing the existing situation with sensemakers’ experiences, sensemakers classify and
organize their understanding of the events. Interruptions appear repetitively because of the
variety of previous experiences which rarely come together smoothly. Weick argues that an
interruptions is an ongoing flow of events triggers arousal of the nervous system and then
activate sensemaking (Weick, 1995, as cited in Maitlis & Sonenshein, 2010). In order to
resolve a problem, individuals need values, priorities, and clarity about their decisions. Also,
individuals leave out some steps from the original events. Retrospection enables individuals
to make sense until they feel that clarity, order, and rationality have been achieved.

The enactive of sensible environments means that individuals are part of their
environment; their actions build and determine the environment that they are part of (Weick
et al., 2005). Weick et al. (2005) explain the role of enactment in sensemaking by elucidating
that the interaction between individuals and the environment is reciprocal and ever-changing.
This reflects that a “sensible environment” helps sensemakers productively interact with one
another and stimulate their sensemaking. Sensemakers are not in an emotional and hostile
environment. A sensemaker makes impacts on the environment and the environment can create new stimuli for the sensemaker.

The *social* property emphasizes sensemaking is not merely an individual process but a social activity (Weick et al., 2005). People in organizations communicate with many others. Interactions are affected by appearances, beliefs, expectations, memories, promises, trust, and rumours (Weick et al., 2005). Individuals utilize scripts, familiar practices, and roles to make sense of interruptions. Social sensemaking is not only about shared meaning but also about sharing collective action (Czarniawska-Joerges, 1992, as cited in Weiser, 2021). This is especially important because collective action affects how teachers teach in their classrooms. The shared meaning and shared actions enable individuals to make sense in their organizations.

The *ongoing* property shows that sensemaking has neither a clear beginning nor ending. It is a fluid and ever-changing process as people establish and respond to the surroundings they encounter (Weick et al., 2005). Interruptions occur recurrently. For example, an unfamiliar event happens not only once, but after sensemakers react to it, when more unfamiliar situations may also emerge. Thus, sensemaking handles momentary moments in an ongoing flow of experience.

The *focused on and by extracted cues* signifies a trait that individuals identify as a crucial property to make sense of the circumstances or conditions (Weick et al., 2005). This implies that people focus on something and suppress others at the same time. The context is vital because it usually causes individuals to spotlight specific cues, as opposed to others. The cues of the conditions are usually different. Therefore, individuals can make sense in totally different ways according to the cues on which they are focusing.

The *driven by plausibility rather than accuracy* means that sensemaking is “not about truth and getting it right. Instead, it is about continued redrafting of an emerging story so that
it becomes more comprehensive, incorporates more of the observed data, and is more resilient in the face of criticism.” (Weick et al., 2005, p. 415). The rationale behind this property is that even inaccuracy can bring positive outcomes.

The seven properties of sensemaking provide us with a thorough and powerful framework to investigate the sensemaking process of math teachers in integrating pedagogical innovation into the mathematics curriculum. While the seven properties can describe the detail of teacher sensemaking, ANT can explore actors that influence teacher sensemaking.

2.5 Actor-network theory

In this study, actor-network theory’s notions and constructs offer insights into what actors are included during implementing CT and how these actors impact teacher sensemaking.

The researchers in education and curriculum studies have applied ANT to promote understanding of how curriculum is itself a network effect (e.g., Perillo & Mulcahy, 2009). Actor-network theory originated from studies in science and technology and was applied to material-semiotic methods of analysis (Fenwick & Edwards, 2010). I apply ANT as an approach that enables scholars to make sense of how different things “come together, manage to hold together, and form associations that produce agency and other effects” (Fenwick & Edwards, 2010, p. 21). ANT is about “interpreting” rather than “representing” education (Fenwick & Edward, 2010).

Things are everywhere and integral in education (Fenwick & Edwards, 2010). Things come together and are interdependent pieces of a larger combination. All different fragments bond together, and they create an association. The associations connect to grow into an “identifiable entity or assemblage”, which is an actor (Fenwick & Edwards, 2010, p. 27).
Within ANT, actors comprise human and non-human, including but not constrained by concepts, objects, spatial, and short-lived patterns. It emphasizes that people should look equally upon human and non-human actors (Fenwick & Edward, 2010). The “demands and needs” from non-human entities can affect human “intentions, meanings, relationships, routines, memories, and even perception of self” (Fenwick & Edwards, 2010, p. 24).

In curriculum studies, recent research has utilized ANT approaches that involve identifying the components of networks and the interrelationship among actors that generate curricula with implications for teachers and students (e.g., Heydon et al., 2015). ANT enables an examination of the curriculum by an interchange among the commonplaces of teachers, learners, subject matter, and social milieux (Schwab, 1983).
Chapter 3

3 Methodology

3.1 Research paradigm

The qualitative approach has some commonalities with my philosophical stance in this research. I implement the social constructivist paradigm in educational research. This paradigm sees knowledge as constructed by a group of individuals. Moreover, as an educational researcher, I proactively include myself in the process of research: the personal experiences, attitudes, and beliefs of a researcher influence the result of the study because my interpretation and establishment of meanings are drawn from my life experience. As a previous teacher in Hong Kong, my previous journey contributes to my constructivist interpretive paradigm as an educational researcher. My six-year career as a school teacher brings me to this paradigm, as I resonate with its assumptions about epistemology and ontology. I deeply believe that no matter if someone is a teacher or a student, learning never stops. Rather than in isolation, effective learning occurs within a community of colleagues and peers, who offers ideas, opinions, experiences, and perspectives, a collaborative process that optimizes learning for all. While in my MA program, I have the opportunity to read extensively material, such as journals, theses and internet resources that are related to my research objectives and paradigm, allowing me to affirm my methodology.

3.2 A Qualitative Case Study Methodology

As the aim of this study was to explore teacher sensemaking, it attempted to explore teachers’ practices of CT to successfully analyze their curriculum innovation; as such, our team took a qualitative approach. Qualitative methods depend on the researchers’ collection of text and picture data from participants who are experiencing some problems in their classroom settings (Creswell & Creswell, 2018). Indeed, unlike quantitative research,
qualitative research focuses on interpreting the comprehensive meanings of the research subjects instead of assessing one aspect of them. Berg (2009) asserted that qualitative research “refers to the meanings, concepts, definitions, characteristics, metaphors, symbols, and description of things” and not to their “counts or measures” (p. 3). Babbie (2020) defines qualitative research as a scientific approach to collecting data that is not related to numbers. In this qualitative study, teachers’ behaviors, perspectives, and opinions were interpreted (Creswell & Creswell, 2018). They provided substantial data to analyze how teachers conducted sensemaking within their arsenal of educational innovations. This study also aimed to explore the actors that affected their sensemaking and then influenced their practices of CT and how the practices reflected CL.

As part of a large project led by my supervisor and her collaborators in Singapore, this research aimed to address how seven properties of sensemaking and human and non-human actors indicated and explained teachers’ perceptions and decisions in CT. Our team applied the case-study method (Yin, 2018), as it was the most appropriate for this qualitative research. Yin (2018) affirms that the term “case study” is “an empirical method that investigated a contemporary phenomenon in depth and within its real-world context, especially when the boundaries between phenomenon and context might not be clearly evident” (Yin, 2018, p. 44). This method is suitable when researchers aim to figure out a real-life case and assume that their examinations contain crucial contextual conditions (Yin & Davis, 2007). Yin’s definition reflects a case study that differs from other methods of inquiry: in experimental studies, for instance, researchers intentionally separate a phenomenon from its context and address the phenomenon of interest; in case study, researchers facilitate heterogeneity, for, as the case study is unique, researchers can include various methods (Simons, 2020). Indeed, Yin (2018) states that “a case study copes with the technically distinctive situation in which there would be many more variables of interest than
data points, and as one result’’ (Yin, 2018, p. 44). This characteristic is relevant to ANT, as researchers use the case study research method based on the satisfaction of three conditions: first, when they must answer the ‘‘how’’ and ‘‘why’’ research questions; second, when they can control related behaviors; and, third, when the case study addresses contemporary events that primarily rely on direct observation and interview of the participants, rather than on historical research (Yin, 2018); our study fulfilled these three conditions. Finally, the case study method generally utilizes fewer than 10 subjects (Zainal, 2007), an approach that aids my in-depth analysis of teacher sensemaking in curriculum innovations.

Participants were seven secondary-school math teachers (See Table 1) who intended to merge CT in their mathematics lessons in order to improve the efficiency of student learning. Regarding the data, I am grateful that my supervisor gave me a chance to cooperate with renowned scholars and used the secondary data of their research project. To maintain privacy, pseudonyms for the Singapore school [‘‘Jordan Public School’’] were used and all participants in this study. Jordan Public School was a competitive institution based on the scores of students’ Primary School Leaving Exam (PSLE). It had several PLCs and was an innovative school that supported the implementation of CT in math classrooms. Integrating CT in math lessons was a major project of the PLC, which consisted of the following teachers: Robert, who taught mathematics, was the leader of the PLC group; Kevin and Dan taught mathematics; Adam, who taught Normal (Technical) (N(T)) and Computer Applications (CPA); Owen, who taught CPA apart from math; Helen, who joined the project late, so she did not attend initial meetings; Irene, who was the Head of Department (HOD), occasionally joined the meetings, advocated for the project by allowing teachers came together to design the lessons, offered her suggestions, and gave the teachers the opportunities to present their work at a math department meeting.
### Table 1

**Participants' Profile**

<table>
<thead>
<tr>
<th>Teachers’ name ( pseudonyms)</th>
<th>Gender</th>
<th>Years of Teaching</th>
<th>CT teaching experience</th>
<th>Subjects</th>
<th>Secondary(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adam</td>
<td>M</td>
<td>1</td>
<td>N</td>
<td>Mathematics, CPA and N(T)</td>
<td>S1</td>
</tr>
<tr>
<td>Irene (HOD)</td>
<td>F</td>
<td>/</td>
<td>N</td>
<td>Mathematics</td>
<td>/</td>
</tr>
<tr>
<td>Helen</td>
<td>F</td>
<td>/</td>
<td>N</td>
<td>Mathematics</td>
<td>S1</td>
</tr>
<tr>
<td>Kevin</td>
<td>M</td>
<td>8</td>
<td>N</td>
<td>Mathematics</td>
<td>S2</td>
</tr>
<tr>
<td>Owen</td>
<td>M</td>
<td>8</td>
<td>N</td>
<td>Mathematics</td>
<td>S1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CPA</td>
<td></td>
</tr>
<tr>
<td>Robert</td>
<td>M</td>
<td>10</td>
<td>Y</td>
<td>Mathematics</td>
<td>S2</td>
</tr>
<tr>
<td>Dan</td>
<td>M</td>
<td>17</td>
<td>N</td>
<td>Mathematics</td>
<td>S1</td>
</tr>
</tbody>
</table>

Our team conducted this study in 2020; however, by 2018, the school had already started the project of integrating CT into math lessons. Among the participants, Robert was the most experienced in teaching CT, as he had joined the project in 2018; for the remaining teachers, 2020 was their first time using CT. In 2018, at the start of the project, there was a CT+math demonstration lesson showcased by a professor of math education, which had extensive and curriculum-relevant mathematics and included a hands-on activity in which students employed spreadsheets and explicit connections to the computing concept of recursion. Robert was the only teacher who joined this workshop, signifying his experience. The other teachers were novices in incorporating CT to teach math, as they joined this project.
in 2020 so they did not join the workshop. The data of meetings and interviews indicated what sources they had for sensemaking. They referred to CT worksheets created by past members of the PLC group and consulted websites (e.g., online blogs and YouTube) about CT for self-study.

3.3 Data collection

Our team collected diverse sources of data (See Figure 1 for the data collection timeline) to enable the triangulation of data to ensure the validity of the study and capture the many dimensions of teacher sensemaking.

Figure 1

Data Collection Timeline

3.3.1 Artifacts collection

Our team collected artifacts that the teachers designed collaboratively. In this research, artifacts included teachers’ worksheets that were used in their Secondary 1 (S1) classrooms. The S1 topics consisted of Prime numbers, Perfect squares, Square foot, Perfect
cube and cube root, Rational numbers, Algebraic expression, and Number patterns (see Figures 2 and 3 for examples of these worksheets). These worksheets reflected teachers’ individual sensemaking and collective sensemaking as they discussed and shared opinions about these worksheets during routine meetings and interviews. All worksheets contained the four pillars of CT, which were decomposition, pattern recognition, abstraction, and algorithms. Our team did not collect the Secondary three (S3) topic worksheets because the finalized version was not finished yet at that time. But we could know what teachers’ rationale was on S3 topics through transcripts of meetings and interviews.

**Figure 2**

An Example of a Worksheet

**Pattern recognition**
Based on the prime factorization of the denominators, write down some of the patterns you observe.

<table>
<thead>
<tr>
<th>Terminating decimals</th>
<th>Recurring decimals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Abstraction**
Based on your observed patterns, could you come up with a rule to differentiate between the two type of fractions.

<table>
<thead>
<tr>
<th>Terminating decimals</th>
<th>Recurring decimals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Apply your above rule to test $\frac{14}{350}$. What do you observe? Is $\frac{14}{350}$ a terminating or recurring?

Use your calculator to verify your answer.
Figure 3

Another Example of a Worksheet

**Pattern recognition**

Based on what you did in the decomposition step, what are there some patterns you observe in the
columns representing "Number of Stars (s)", "Number of Triangles (t)" and "Total Number of
Objects (T)?

(a) Number of Stars (s): What can you say about the numbers 1, 4 and 9?

(b) Number of Triangles (t): What can you say about the numbers 6, 10 and 14?

(c) What is the relationship between (s), (t) and (T) in each row?

**Abstraction**

Based on the patterns observed above,

(a) write down an expression for p in terms of n.

(b) write down an expression for q in terms of n.

(c) write down an expression for r in terms of n.

**Application**

From the abstraction above, it is found that

\[
\begin{align*}
p &= & \quad q &= & \quad r &=
\end{align*}
\]

Answer the following questions.

(a) Find the values of p, q and r for Pattern 25.

(b) Find the pattern number when q = 70.

3.3.2 Transcripts of meeting observation

Our team aimed to observe the natural reaction and interaction as much as possible, so
we decided to be complete observers during the meetings. Our team engaged in naturalistic
observations. Researchers who take part in the meeting may be seen as intrusive and then
affect participants’ behavior or opinions (Creswell & Creswell, 2018). For the complete
observation, our team employed descriptive and reflective notes for observation (Creswell,
2015) to examine teachers’ sensemaking and their practices of CT in the PLC setting. There were nine meetings in total from January to July and each meeting lasted around 1 hour. Teachers held meetings twice a month. In the meetings, teachers mainly focused on discussing what S3 topics in mathematics were suitable for integrating CT. They were designing lessons, presenting their work, receiving feedback from colleagues, and establishing teaching materials together. Because of the COVID-19 pandemic, the PLC meetings were changed to online using Google Meet in April 2020.

As Table 2 shows, in meeting 1, Robert first introduced the history and background of the PLC to the teachers. Most of them did not join this project before. Robert proposed to design S3 worksheets this year (2019-2020). They would use CT worksheets that were designed in 2018-2019 to teach S1 and Secondary 2 (S2). Robert shared his understanding and experience of CT and asked his colleagues to share theirs. He shared what the PLC group had done in the previous school year. From meeting 2 to meeting 4 (January 30, February 14, and February 27, 2020), teachers discussed what S3 mathematics topics were suitable for CT. After they shortlisted the topics, they chose topics that they preferred to design CT worksheets. From meeting 5 to 7 (April 02, June 10, and June 24, 2020), teachers presented their worksheets and received feedback from one another. In meeting 8 (July 08, 2020), it was supposed to present revised worksheets, but they discussed the arrangement of a presentation instead. In meeting 9 (July 15, 2020), they presented the revised worksheets and finalized the decision of the department’s presentation about CT.
Table 2

The Main Focus of PLC Meetings

<table>
<thead>
<tr>
<th>PLC Meeting</th>
<th>Focus topics</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction, goals, expectations, the experience of CT and CT assessment</td>
<td>16/01/2020</td>
</tr>
<tr>
<td>2</td>
<td>Discuss what S3 mathematics topics were suitable to integrate CT</td>
<td>30/01/2020</td>
</tr>
<tr>
<td>3</td>
<td>Discuss what S3 mathematics topics were suitable to integrate CT</td>
<td>14/02/2020</td>
</tr>
<tr>
<td>4</td>
<td>Discuss what S3 mathematics topics were suitable to integrate CT and made decisions</td>
<td>27/02/2020</td>
</tr>
<tr>
<td>5</td>
<td>Kevin, Robert and Dan presented S3 CT worksheets.</td>
<td>02/04/2020</td>
</tr>
<tr>
<td>6</td>
<td>Helen and Kevin presented S3 CT worksheets.</td>
<td>10/06/2020</td>
</tr>
<tr>
<td>7</td>
<td>Robert and Owen presented S3 CT worksheets.</td>
<td>24/06/2020</td>
</tr>
<tr>
<td>8</td>
<td>The arrangement of department’s presentation</td>
<td>08/07/2020</td>
</tr>
<tr>
<td>9</td>
<td>Teachers shared their revised worksheets and finalized the decision of the department’s presentation</td>
<td>15/07/2020</td>
</tr>
</tbody>
</table>

3.3.3 Transcripts of semi-structured Interviews

As the research questions of this study focused on how math teachers made sense of curriculum innovations under the context of PLCs, our team had semi-structured interviews with participants. Our team interviewed four teachers, they were Adam, Dan, Kevin, and Owen. Our team also interviewed Robert in 2019 but the interview was recorded partly due to technical issues. So, we had an interview note with Robert. The remaining teachers could not do interviews due to their busy schedules. The semi-structured interviews enabled us to get valuable but not confined data from the participants so we could maintain the core investigation of the study (Brinkmann, 2014). The interviews in case study were adjustable rather than rigid (Rubin & Rubin, 2012) and were like “guided conversations” other than
“structured queries” (Yin, 2014, p. 152). The “conversation” could help encourage participants to articulate their own feelings, opinions, and understanding profoundly and insightfully (Yin, 2014).

During the interviews, we asked “what were your first impressions of CT?”, “would you say that there is any relationship between CT and mathematical thinking?”, “how is the role of CT in lessons?”, “how do you implement CT and how does it benefit students?”, “how can you improve the implementation of CT lessons?” and “how do your reflection inform your future lessons and your team?”. These questions addressed how participants perceived CT and how they thought of the possible ways of improving the implementation of CT in math classrooms. More follow-up questions were asked during interviews based on responses from the interviewees. The routine meetings and individual interviews were transcribed by our team after they collected the data.

3.4 Data Analysis

The study utilized both deductive and inductive data analysis using theories of sensemaking (Weick et al., 2005) to explicate the teachers’ sensemaking of their collaborative CT+math lessons planning experience. To respond to the research questions, ANT and CL were used to examine how different actors influenced teacher sensemaking and how teachers’ CT practices reflected CL. This study applied open, axial, and selective coding for inductive data analysis (See Figure 4). For iterative qualitative data analysis, Srivastava and Hopwood’s (2009) guiding questions were used: “what are the data telling me?”, “what do I want to know?”, and “what is the dialectical relationship between what the data are telling me and what I want to know?” Each question has a specific function. The first question enables researchers to make sure they viewed the data through the appropriate lenses. The second question reminds researchers to connect their lenses with the objectives of
the study. The last question helps researchers refine the focus and connect back to the research questions.

**Figure 4**

*Data Analysis Process of Open, Axial, and Selective Coding*

NVivo 11 was employed to process and sort out the considerable data. In the beginning, external sources containing worksheets, routine meeting observation transcriptions, and individual interview transcriptions were imported into NVivo. The coding process went through three stages. In the first stage, to answer Research Question 1, which aimed at examining how teachers made sense of CT, deductive coding was used. Through using seven properties of sensemaking, the frequency of different properties and how teachers made sense of innovations were indicated so that this study could provide suggestions to educators pertinently in order to help them make sense better. Also, the above-mentioned analyses helped understand how teachers in Singapore overcame innovative and ambiguous circumstances and saw if they similarly experienced the evolutionary process.

At the beginning of the first stage, the first question of the iterative analysis was answered, which was about what the data told me. The question was ‘‘what are the
worksheets, meeting transcriptions, and individual interview transcriptions telling me about the seven properties of sensemaking?’” Seven nodes were created based on the seven properties of sensemaking, including grounded in identity construction (P1), retrospective (P2), enactive of sensible environments (P3), social (P4), ongoing (P5), focused on and by extracted cues (P6), and driven by plausibility rather than accuracy (P7). Based upon each definition of properties (See Table 3), interviews and meeting transcripts were coded to reflect specific properties of teacher sensemaking. For example, the definition of retrospective sensemaking was “‘a sensemaker pays attention to previous experience to make sense of present events sensemaking,’” (Weick et al., 2005). As such, when retrospective sensemaking was being coded, it was coded only when teachers were talking about things in the past. Each time they connected previous experience and knowledge with CT, retrospective sensemaking would be coded. The first stage of coding resulted in 135 references (P1(6), P2(45), P3(5), P4(50), P5(3), P6(7), and P7(19)) (See Figure 5). In order to ensure the reliability of the data coding, the codes were discussed with my supervisor for reliable coding. She gave me invaluable suggestions regarding data coding. She suggested that this study could include tables for teachers’ demographics, meetings’ highlights, and interviews’ highlights and create charts to show the frequency of properties of sensemaking. As such, this study clearly showed the background information of teachers and the CT project so that data could be accurately coded. For example, after mapping the table of teachers’ demographics (See Table 1), if teachers had experience in teaching CT+math lessons was instantly recognized. Then, the data was coded again. The coding references were adjusted to 131 in this round (See Figure 5).
<table>
<thead>
<tr>
<th>Code</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grounded in identity construction</td>
<td>People usually make sense of circumstances by reflecting on what they represent to them in their identities.</td>
<td>“Ultimately we want students to be able to see the connection between different types of questions, and be able to see the breakdown to the fundamental concepts, do I make sense? Do you understand what I am saying?” (Meeting 5, April 02, 2020)</td>
</tr>
<tr>
<td>Retrospective</td>
<td>A sensemaker pays attention to specific experiences in the past to make sense of present events.</td>
<td>“I took a basic programming module in the university on Python. So that’s where they introduced computational thinking to us.” (Interview, April 24, 2020)</td>
</tr>
<tr>
<td>Enactive of sensible environments</td>
<td>A sensemaker makes impacts on the environment and the environment can create new stimuli for the sensemaker.</td>
<td>“Pardon me if I am wrong. What I am seeing from Robert's worksheet at the back is that after going through the first part of the worksheet on the idea of discriminant … Robert you might need to find out the main objective at the end of the worksheet…” (Meeting 5, April 02, 2020)</td>
</tr>
<tr>
<td>Social</td>
<td>Sensemaking is not merely an individual process but a social activity.</td>
<td>Robert stated that “… CT is more structured, but [we] take a lot of time to create worksheets.” Kevin then asked that “but how [do you] assess [CT]? We cannot always use tests…” (Meeting 1, January 16, 2020)</td>
</tr>
<tr>
<td>Ongoing</td>
<td>Sensemaking has neither a clear beginning nor an ending. It is a fluid and ever-changing process as people establish and respond to the surroundings they encounter.</td>
<td>“The first few worksheets crafted I have to tell myself that follows the steps… for the first two months… I rather stop using the worksheet to be really honest.” (Interview, April 20, 2020)</td>
</tr>
<tr>
<td>Focused on and by extracted cues</td>
<td>A trait that individuals identify as a crucial and representative property to make sense of the circumstances or conditions.</td>
<td>“I was thinking about the flowchart.” (Interview, January 30, 2020)</td>
</tr>
<tr>
<td>Driven by plausibility rather than accuracy</td>
<td>Sensemakers attempt to use the most effective and plausible way to solve the challenges or interruptions that they are facing.</td>
<td>“So what we had to do was to try to minimize the writing…I don’t expect them to give me full sentences.” (Interview, April 24, 2020)</td>
</tr>
</tbody>
</table>
In the second stage, to answer Research Question 2, which aimed at exploring what actors enabled and constrained teacher sensemaking and then influenced the practices of the innovation. Inductive coding was applied as this study employed ANT as the lens. Researchers have used actor-network theory more and more to examine education research and it is suitable for this study. First, the processes of education unravel in different settings, such as schools, social movements, training centers, and community agencies. The settings related to schools have their similarities but also idiosyncratic characteristics. Education is a complicated and even disorganized process. The issue in education that researchers encounter is an environment of ‘‘precarious correlations’’ (Fenwick & Edwards, 2010, p. 22). The associations among actors are sophisticated. Thus, ANT is a helpful analytic method that can discern and deal with mess, chaos, and uncertainty (Fenwick & Edwards, 2010). Second, apart from focusing on human actors, ANT also focuses on non-human actors. In ANT, the conception of general symmetry gives equal and undivided attention to human and non-human actors (Fenwick & Edwards, 2010). Human actors such as principals, policymakers, or teachers are not superior in the environment but are to be part of it. For investigating the problems or difficulties in education, every actor matters. Latour (2004) stresses that the
reason that people should treat both actors fairly is that humans do not last for a minute if there are no non-humans. ANT enabled me to examine what actors made assemblages, established networks, and cooperated (Fenwick & Edwards, 2010) so this study could have comprehensive pictures of curriculum innovations.

Open coding was used for coding actors (Strauss & Corbin, 1990) at the beginning of the second stage. The process of open coding was for “breaking down, examining, comparing, conceptualizing, and categorizing data” (Strauss & Corbin, 1990, p. 61). During this process, all meeting transcripts, interview transcripts and teaching artifacts were thoroughly looked through with a focus on non-human and human actors. The data were coded according to what teachers talked about concerning actors that enabled and constrained their sensemaking and then influenced their practices of CT. When the actors were being coded, the data showed teachers might not talk about them directly. So, what they said was interpreted based on our understanding of education and the difficulties of implementing CT in mathematics classrooms. Every code was utilized to “represent a theme or idea with which each part of the data is associated” (Hewitt-Taylor, 2001, p. 39). At the end of the open coding process, 26 open codes were generated in total (See Appendix A).

Next, the axial coding process was started. This process aimed to compare, sort out and try to seek associations between the open codes and then created higher-level axial codes. For example, one axial code was “teachers’ time” which consisted of several open codes, such as “Time limit” and “Workload in PLC”, etc (See Table 4).

Finally, in the selective coding, the data was checked again to see if there was any coding was missed and the second iterative question and the third question were asked to connect the objectives of this study and the data with my research questions. The axial codes were grouped in order to obtain selective codes that helped answer directly the Research
At the end of the axial coding and selective coding process, 11 axial codes and 4 selective codes (See Table 4) were generated.

**Table 4**

*The Axial and Selective Coding’s Codebook for Actors that Enabled and Constrained Teacher Sensemaking*

<table>
<thead>
<tr>
<th>Open Code</th>
<th>Axial Codes</th>
<th>Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refuse to learn things that are not examinable;</td>
<td>Students’ expectations</td>
<td>The exam-oriented culture in Singapore</td>
</tr>
<tr>
<td>not interested in learning non-examinable content</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teachers care about exams; if CT can help answer questions on exams</td>
<td>Teachers’ attitudes towards examinations</td>
<td></td>
</tr>
<tr>
<td>Focus on the CT assessment; curious about the assessment of other CT-related subjects</td>
<td>CT assessment</td>
<td></td>
</tr>
<tr>
<td>Different from what they previously taught;</td>
<td>Using worksheets for CT+math teaching</td>
<td>The way of teaching and learning CT+math lessons</td>
</tr>
<tr>
<td>the way teachers designed worksheets;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the original way of thinking about math</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use other ways to teach math; if teachers are familiar with CT artifacts;</td>
<td>The understanding of the four pillars of CT</td>
<td></td>
</tr>
<tr>
<td>students are not familiar with CT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Students are afraid of CT; students have never seen CT before</td>
<td>Students’ feedback</td>
<td></td>
</tr>
<tr>
<td>Don’t dare to make mistakes; focus on getting correct answers</td>
<td>Fear of learning from mistake</td>
<td></td>
</tr>
<tr>
<td>Only apply to specific topics; if the content fits CT</td>
<td>The compatibility of mathematics topics</td>
<td>The suitability of mathematics topics</td>
</tr>
<tr>
<td>Content is too easy; if the content is difficult</td>
<td>The level of the mathematics topics</td>
<td></td>
</tr>
<tr>
<td>Time limit; workload in PLC; spend too much time on one part; too many pages to teach a topic</td>
<td>Teachers’ time</td>
<td>The arrangement of teaching duties</td>
</tr>
<tr>
<td>Not enough teachers teaching the same grade; no experience in teaching that grade</td>
<td>Teaching at different levels</td>
<td></td>
</tr>
</tbody>
</table>
In the final stage, to answer Research Question 3, which aimed at examining how CT practices reflected CL, deductive coding was used. Four nodes were created based on the four principles of CL including Re-mediation, Reformulation, Reorganization, and Revitalization (See Table 5). Each principle described the potential changes of CL. For example, Re-mediation led to the appropriation of a new representational system for our civilization. As such, based upon each principle, interviews and meeting transcripts were coded to reflect the potential changes of CL in this study. Again, my supervisor helped check the coding for reliability. We discussed the meanings, terminologies, and definitions of each principle. Then, the data was coded once again.

It should be noted that teachers in this study applied an unplugged approach (Grover & Pea, 2013) of CT. Although diSessa (2018) has a computer and a coding environment in mind when he talks about CL, his idea of CL still fits this study because the unplugged approach includes CT concepts that are related to the plugged approach. He claims that reformulation can happen without computer mediation by using the example of turtle differential geometry but he still prefers the one with computers. This study is another example to show how reformulation happens without computers and why it is important to include computers when adopting CT for math lessons.
### Table 5

*The Codebook for Four Rs of CT Adapted by diSessa (2018)*

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
</table>
| Re-mediation | • Appropriation of a new representational system for our civilization.  
• Dynamic and interactive representations on computers, accompanied by the capability to design and enact representations on demand and often quickly  
• Any representational system is better applied for some things and less for others | “We applied CT [to] specific topics. CT is more structured, but [we] take a lot of time to create worksheets.” (Meeting 1, January 16, 2020)                                                                                                                                               |
| Reformulation | • A discrete epistemology that substantial changes in what, when, and how to teach a subject matter according to an enhanced understanding of human resources  
• Reformulation helps achieve cognitive simplicity  
• Ones need to consider different ways of thinking about each domain, and how learners understand different domains | “If the topic is difficult enough to confuse them, then the flowchart will help.” (Interview, March 13, 2020)                                                                                                                     |
| Reorganizing | • Changed the intellectual terrain. A reorganized intellectual terrain will appear in new landmark documents (e.g., literature and textbooks)  
• This principle creates a landmark for deep change in teaching and learning  
• Focus on big cultural changes. Teaching mathematics will and should look greatly distinct, granted any literacy-scaled change | “New textbook has some content on coding.” (Meeting 1, January 16, 2020)                                                                                                                                                         |
| Revitalizing | • The ecology (diversity) of learning activities is facilitated  
• Engagement, interest, and equity are promoted | “Why [do] I want to ask this? Our CT worksheet. tend to give me the impression. students sit down [first]. [Then we ask them to] do [worksheets]. [Then they start to] find patterns...maybe my understanding is wrong…” (Meeting 3, February 14, 2020) |
3.5 Validity and Reliability

To ensure the validity and reliability of this qualitative study, this study triangulated different data sources, provided rich and thick descriptions of the setting, used member checking, checked transcripts, and cross-checked codes (Creswell & Creswell, 2018; Gibbs, 2007).

Validity determines whether the findings are accurate from the point of view of the researcher, the participant, or the readers of an account. Trustworthiness, authenticity, and credibility are terms that address validity (Creswell & Miller, 2000, as cited in Creswell & Creswell, 2018). A variety of data, including worksheets, meeting transcripts, and interview transcripts were triangulated. For example, after some teachers described CT worksheets as too robotic, what they meant was clearly understood after consulting the worksheets; the interviews provided information on teachers’ backgrounds, such as what subjects they taught, so the reason why some teachers could use terminologies other than from mathematics during the meetings could be justified. Member checks were conducted with my supervisor in order to enhance the quality of data analysis because this helped prevent misinterpretation of teachers’ experiences, thoughts, and actors that influenced their sensemaking. She gave suggestions to me and checked the codes in every stage of my coding. A rich and thick description was applied to convey the findings. This helped transport readers to the setting which could add to the validity of the findings (Creswell & Creswell, 2018).

In terms of reliability, checking transcripts is one of the qualitative reliability procedures (Gibbs, 2007). The transcripts were double-checked to confirm that they did not include explicit mistakes made amid transcription. This study reassured that there was no drift in the definition of codes by comparing data with the codes more than three times.
(Creswell & Creswell, 2018). My supervisor helped cross-check the codes, and we discussed the codes in several meetings to ensure the reliability of this study.

3.6 Ethical Considerations and Confidentiality

In this study, I used the secondary data of a larger research project I took part in. In September 2020, I joined a research team at a university in Singapore due to my supervisor after receiving ethical approval from it. My supervisor was the CO-PI in this project. The purpose of the project was to design mathematics lessons for topics for lower secondary classroom that uses CT to teach Math, and to study its effectiveness. The team members of the research team included me, my supervisor, and scholars in Singapore. Since I was not in the team when they collected three sources of data, there was no chance for me to participate the process of data collection. As the project was about sensemaking and CT, I helped search their literature and established research questions and research directions with them. We had routine meetings to discuss the project. We had different focuses in different meetings, such as finding the gap between the literature, how different literature connected to our project, what the significance was of our project and the definition of sensemaking. I also analysed the data and presented my ideas to the team. Besides that, we joined an international conference to present our research on sensemaking and CT. We went through a lot during our collaboration. According to Cohen et al. (2011), the main issues include in ethics are the consequences and confidentiality. Although I was using secondary data, I still highly paid attention to the potential risks, confidentiality, and the rights of participants. In order to thoroughly understand the ethical procedure, I completed the Tri-Council policy statement.
Chapter 4

4 Findings

In this chapter, findings are presented to answer the research questions. This study drew on data collected from worksheets, meeting observation transcriptions, and teacher interview transcriptions. In particular, conversations and direct quotes of the meeting transcriptions and interview transcriptions are provided to demonstrate the seven properties of sensemaking of teachers. The demonstration explicitly indicated how they made sense of CT. Also, actors that influenced teacher sensemaking and then influenced the practices of CT were identified. Finally, diSessa (2018) presents four principles of CL that provides detail and focus for his agenda regarding literacy and the four principles of CL were reflected within the findings in this thesis.

4.1 Seven Properties of Sensemaking

Applying Weick et al’s (2005) properties of sensemaking in teacher meetings, teacher interviews, and on worksheets, seven teachers indicated their properties of sensemaking. Teachers held regular meetings to design S3 worksheets and shared their classroom practices. They discussed what topics could be integrated with CT and shared students’ reactions and feedback from their classes. In their discussion, they showed how they made sense of CT. The interviews and artifacts also showed teacher sensemaking. In this section, I first indicate the frequency of each property of sensemaking in order to show the most prevalent property and visualize the circumstances of sensemaking that occurred in interviews and meetings. After that, I explicate how these different data demonstrate seven properties of sensemaking.

4.1.1 Frequency of Seven Properties of Sensemaking

In terms of interviews and meetings (See Figure 6), the most prevalent property was “social” (37%); the second most prevalent property was “retrospective” (33%); the third
most prevalent property was “driven by plausibility rather than accuracy” (12%); the fourth most prevalent property was “grounded in identity construction” (6%); the frequency of the remaining properties was low.

For meetings only, the most prevalent property was “social” (52%); the second most prevalent property was “retrospective” (24%); the third most prevalent property was “driven by plausibility rather than accuracy” (10%); the fourth most prevalent property was “grounded in identity construction” (6%) and the fifth most prevalent property was “enactive of sensible environments” (5%); and the frequency of the remaining properties was low (See Figure 7).

For interviews (including Robert’s interview note) only, the most prevalent property was “retrospective” (55%); the second most prevalent property was “driven by plausibility rather than accuracy” (18%); the third most prevalent property was “focused on and by extracted cues” (13%); the fourth most prevalent property was “ongoing” (8%); and the frequency of the remaining properties was none (See Figure 8).

**Figure 6**

*The Frequency of Seven Properties in Total (Interviews and Meetings)*
Figure 7

The Frequency of Seven Properties in Meetings

The frequency of seven properties in meetings

<table>
<thead>
<tr>
<th>Property</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grounded in identity construction</td>
<td>5%</td>
</tr>
<tr>
<td>Retrospective</td>
<td>20%</td>
</tr>
<tr>
<td>Enactive of sensible environments</td>
<td>10%</td>
</tr>
<tr>
<td>Social</td>
<td>40%</td>
</tr>
<tr>
<td>Ongoing</td>
<td>10%</td>
</tr>
<tr>
<td>Focused on and by extracted cues</td>
<td>5%</td>
</tr>
<tr>
<td>Driven by plausibility rather than accuracy</td>
<td>10%</td>
</tr>
</tbody>
</table>

Figure 8

The Frequency of Seven Properties in Interviews

The frequency of seven properties in Interviews

<table>
<thead>
<tr>
<th>Property</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grounded in identity construction</td>
<td>10%</td>
</tr>
<tr>
<td>Retrospective</td>
<td>50%</td>
</tr>
<tr>
<td>Enactive of sensible environments</td>
<td>20%</td>
</tr>
<tr>
<td>Social</td>
<td>10%</td>
</tr>
<tr>
<td>Ongoing</td>
<td>10%</td>
</tr>
<tr>
<td>Focused on and by extracted cues</td>
<td>10%</td>
</tr>
<tr>
<td>Driven by plausibility rather than accuracy</td>
<td>5%</td>
</tr>
</tbody>
</table>
4.1.2 Grounded in identity construction

People usually make sense of circumstances by reflecting on what they represent to themselves in their identities (Weick et al., 2005). In schools, principals, HOD, and teachers have different roles in terms of innovations. As such, it is not unusual that they have different perceptions and opinions on innovations. Irene was the HOD of mathematics. She occasionally attended the meetings. Every time she spoke, she seldom focused on the content of the worksheets of CT but more on others, such as administrative tasks. In meeting 5, Robert was presenting his CT worksheet in which the topic was discriminant. Irene gave feedback to Robert after he presented. She said:

Do we want to consider the types of solutions [and] the type of breaking down of the questions [and] the concepts or thinking involved behind solving the questions? Ultimately we want students to be able to see the connection between different types of questions, and be able to see the breakdown [of] the fundamental concepts. Do I make sense? Do you understand what I am saying? (Meeting 5, April 02, 2020)

Then, Robert replied and started the conversation that was about the content of the CT worksheet with Dan and Irene:

1 Robert: I think so. Let me think about that…
2 Dan: Sorry…how is [it] related to the discriminant? Am I finding it, or showing something? Or am I finding it to show something?
3 Irene: Yes. Maybe something like this can be how we structure the categorization. Do explore different possible ways. Drill down to the thinking involved behind solving each type [of] question you have listed out. [How about] the rests? Any
Irene expressed her opinions affirmatively. She required Robert to explore more possible approaches. Her tone was explicitly different from others. As the HOD, she needed to ensure her team members were clear about what they were doing. Despite this, she did not command Robert to consider what she suggested. The conversation reflected that she wanted him to adopt her advice and improve his worksheet. She also urged others to give comments although she asked politely. In meeting 8 (See Table 2), teachers were discussing the arrangement of a presentation because they were going to present their CT practices for the mathematics department. After the discussion, Irene reminded Robert of a few things after he allocated the tasks to his colleagues. She accentuated that teachers who did not join the PLC group were unfamiliar with CT, so he must give them an overview of CT. She reminded Robert that the group needed to introduce the ‘‘traditional history of the project’’ (meeting 8, July 08, 2020). She wanted to ensure other members of the mathematics department clearly understood what the PLC group was doing. This showed that when she was making sense of the practices of CT, she especially focused on making sure the history of the CT project was understood by other members of the mathematics department rather than worrying about how her colleagues presented their tailor-made worksheets. At the end of the meeting, Irene said, ‘‘How [do] you want to organize? I will leave it to you’’ (meeting 8, July 08, 2020). Clearly, as the HOD, she made sense and made decisions about her roles, so she gave others autonomy to make sense and decide about their roles. The above-mentioned examples indicated that Irene made sense based on her identity in order to perform duties. She did not focus on making sense of the content of CT worksheets but on another detail of the implementation of CT.
Due to their identities and expected responsibility, teachers made sense of how CT supported student learning and examinations. In the PLC, one of their goals was to teach students problem-solving skills. Ideally, students could even apply CT to other subjects in the future. Concurrently, teachers were expected to maximize student performance in examinations because their educational system emphasizes it. In Robert’s interview note, he defined the effectiveness of CT. He said that if CT could help “answer questions on the exam,” then it was effective. He added that CT was valuable because it gave students a better conceptual understanding, and appreciation for numbers/patterns/math, and helped students answer questions on the national exam (Interview note, April 25, 2019). Robert’s articulation reflected that he made sense based on his teacher identities. Specifically, he made sense of how CT benefited students. In an exam-oriented culture, the identities of teachers are highly associated with test and exam work (Trent, 2012). Robert must consider student performance in exams because of the existence of public examinations. Students expect teachers to teach them exam skills (Yung, 2021) and think this is their responsibility. As such, when teachers were making sense, they thought of student learning and examinations constantly in terms of their identities and related responsibilities. Not only Robert, but teachers such as Dan, also showed he made sense in terms of his identities. In meeting 4, teachers were discussing how to better implement CT. Dan suggested that “since we are still developing the [CT] thing, we should focus on generalization, workflow, and revision for national exams…how this form of CT comes in play for the national exam.” (Meeting 4, February 27, 2020) Supporting student performance in exams was not the only goal of the group, but they never stopped thinking about how to make sense of how CT could benefit examinations because of their identities.

4.1.3 Retrospective

The “Retrospective” means that a sensemaker pays attention to specific experiences in the past to make sense of present events (Weick et al., 2005). This was the most prevalent
sensemaking in interviews. The findings indicated that teachers made sense of CT according to CT teaching experience, learning experience, and specific working experiences which are not directly related to CT.

Teachers made sense of CT according to their CT teaching experience. Robert was the only CT experienced teacher in the group (See Table 1). In meeting 1, Robert stated that they should be ‘‘repackaging what we have already done.’’ (January 16, 2020). This school had implemented CT+math lessons for more than 1 year. But the members of the PLC group kept changing. Robert was the only member still there from the start of the project. He could tell his colleagues firmly that CT worksheets took a lot of time to create because he had CT teaching experience in the past. Moreover, when he was demonstrating his unfinished worksheet in the meeting, he mentioned that he had difficulty designing the part of the algorithm. He said that he ‘‘needed to find lessons from last year.’’ (Meeting 4, February 27, 2020). This reflected that when he was making sense of the difficulties of CT, he instantly recalled his teaching experience in CT last year. Therefore, he was going to revisit the lessons from last year and they allowed him to make sense of the part of the algorithm. Also, he had retrospective sensemaking when he made sense of colleagues’ CT worksheets. In meeting 4, Dan started a conversation by asking Robert a question:

1 Dan: How do you break into known areas where you can easily find the area?

2

3 Robert: You can only do it if you are given lots of exposure.

4 Then, you can think through what I’ve done before.

5 (Meeting 4, February 27, 2020)

Based on what Robert experienced in CT teaching, he suggested that Dan could see what he did before. As such, Robert’s CT teaching experience was the source of sensemaking. Robert paid attention to his CT teaching experience. He recalled worksheets that he used from
previous school years to make sense of present events such as designing the part of the algorithm in meeting 4 (February 27, 2020). This proved why CT teaching experience was so important for teacher sensemaking because it enabled teachers to understand and react to CT practices more quickly.

Teachers recalled their learning experience and specific working experiences for sensemaking. In the study, some teachers learned CT before they joined the PLC while some teachers had not encountered it before. Their unique learning experience allowed them to have different sensemaking on CT. In Adam’s interview, he said:

I took a basic programming module [at] the university on Python. So that [was] where they introduced computational thinking to us, but they didn’t really talk much about it because the focus was still on coding. (Interview, April 24, 2020)

The CT that Adam learned was not directly related to mathematics. This was his first impression of CT. Later on, he talked about why he learned more about CT as a student. He said:

My final year project [was] on image recognition. And that made me have to bring up computational thinking. I had to read up on computational thinking. I had to understand what actually computational thinking is.

(Interview, April 24, 2020)

Although Adam did not have CT teaching experience, he learned a lot about CT as a student. He could make sense of CT through his learning experience. Therefore, when he talked about how he perceived CT, he said that “it is something we have always done in our heads… to me, [an] algorithm is already a form of coding.” (Interview, April 24, 2020). His perception of CT was explicitly related to his learning experience. He learned that CT was about coding when he was a student. In
contrast, Dan did not learn CT before he joined the PLC. As such, his description of CT was different from Adam’s. He did not mention terms such as ‘‘coding’’ to describe it. For example, he said:

CT is largely intuitive and perhaps it articulates a sequence of thinking. But I found [that] if you spend enough time doing Mathematics, enough time engaging with mathematical problems, it would be a very intuitive and logical set of things to do. (Interview, July 9, 2020)

His description was not as concrete as Adam’s. He used some general terms to describe CT. He described CT as ‘‘largely intuitive’’ and ‘‘perhaps’’ because he did not have a specific term to depict CT. He did not have experience in teaching CT or learning CT. Later on, he tried to describe the four pillars of CT (decomposition, pattern recognition, abstraction and algorithms) by using his administrative working experiences. The example was about dealing with the student leadership program. He asserted that searching and selecting student leaders was a logical sequence that was similar to the four pillars of CT. He described:

So, I looked through my experiences across the years, like whenever we need to find student leaders. We first need to identify who are potential candidates and from among [them] who I start to select them. After I select them, what do I need to do next? So I keep asking myself this question… But after a while, I look back at this sequence of series of things that I did, I realised that there were certain steps that I needed to do. I am not sure whether this constitutes as a form of pattern recognition… (Interview, July 9, 2020)

Both Adam and Dan did not have experience in teaching CT. However, since Adam learned CT when he was a student, he made sense of it through his learning experience. Although
Dan did not learn CT before, he still could use the specific working experiences to make sense of it. The difference between their retrospective sensemaking was that Adam could use computational terminologies when he described CT while Dan could not because he had never learned any concepts of CT before. Kevin also indicated his retrospective sensemaking. He made sense of CT through both his working and learning experiences. He mentioned that CT was similar to “Polya’s problem-solving method” and “system of linear equation.” (Interview, April 20, 2020). Kevin taught students Polya problem-solving methods before. He also learned the system of linear equations in the past. Therefore, when he made sense of CT, he recalled the above working and learning experience. The above-mentioned cases reflected that teachers indicated their retrospective sensemaking based upon CT teaching experience, unique learning experience and specific working experiences.

4.1.4 Enactive of sensible environments

A sensemaker makes impacts on the environment and the environment can create new stimuli for the sensemaker (Weick et al., 2005). Throughout the 9 meetings, teachers respected one another and the atmosphere was harmonious. At every meeting, Robert first talked about the agenda in order to keep the meetings well-organized. Teachers gave feedback politely to the presenters. In turn, the presenters discussed the feedback with colleagues and adjusted the worksheets if they reached a consensus. For instance, in meeting 8 (July 08, 2020), Robert had an initial proposal. However, Dan suggested another proposal. After Dan’s elaboration, Robert and others agreed with Dan’s plan. This reflected that Robert as the leader of this group encouraged colleagues to speak their thoughts. Robert would not object if the plan was good. Kevin’s case showed another example. He was very proactive in the meetings. He enthusiastically gave his opinions to colleagues. After Robert presented his worksheet, he commented:
Pardon me if I am wrong. What I am seeing from Robert’s worksheet at the back is that after going through the first part of the worksheet on the idea of discriminant … Robert you might need to find out the main objective at the end of the worksheet [and] what you would like to achieve after the students complete the ‘‘problem solving’’ part. That will help you align to how meaningful the categorization takes place. (Meeting 5, April 02, 2020)

Although Robert was the leader of PLC, Kevin did not hesitate to express his true thought about his presented worksheet. This feedback was of high quality. It not only pointed out the problem but also suggested a possible solution. Robert agreed with Kevin and decided to modify his worksheet. Another example happened in meeting 7 (June 24, 2020), Kevin started a conversation with Robert:

1    Kevin:  We need to consider [the case with what we call the restriction]…
2    I mean [we need to] get some answers back…
3    Robert:  I think I can …This question has a solution that I will check. I think it is a good idea that maybe this type would have a question … (Meeting 7, June 24, 2020)

Robert accepted the criticism from colleagues as a leader. Therefore, others were more willing to confidently express their opinions. Robert created a harmonious environment for the group, so the group members gave more feedback and ideas to one another. Additionally, teachers never pushed one another. For example, in meeting 7 (June 24, 2020), Robert asked, ‘‘any others? …are we looking at different cues? And [do] we try to distinguish a way [to] distinguish tool skills or not? …any comments?’’ When he asked if any others wanted to comment, there were no answers. Therefore, he tried to ask some more questions to nudge
colleagues to speak out. From the above-mentioned examples, we could see that the PLC group was a sensible environment. It was because teachers respected one another. They gave feedback and asked questions to one another politely, so they were encouraged to share their views. Each teacher’s autonomy appeared to be respected and feedback was offered for consideration. That was why teachers were willing to express their opinions. The sensible environment allowed teachers’ sensemaking to happen more easily.

4.1.5 Social

The social property means that sensemaking is not merely an individual process but a social activity (Weick et al., 2005). This was the most prevalent property of sensemaking. The meetings demonstrated how teachers made sense socially. The following examples indicated how teachers made sense of implementing CT+math lessons, the challenges they encountered, and the design of worksheets socially.

The PLC provided a platform for teachers to make sense of CT collaboratively. In the first meeting (January 16, 2020), Robert was sharing his experience and understanding of CT, then Kevin raised some questions.

1 Robert: We applied CT [to] specific topics. CT is more structured, but [we]
2 take a lot of time to create [worksheets].
3 Kevin: But how [do you] assess [CT]? We cannot always use tests. Also,
4 how [do you] determine if the results are significant? When they
5 talk about [the] same problem, the terms [that students] use are
6 evidence. To me, that [is] more valuable than quantitative.
7 (Meeting 1, January 16, 2020)

After Robert introduced his experience in CT+math lessons, Kevin asked questions and expressed his opinions. The responses from Kevin reflected that he was making sense of what
Robert mentioned. Then, Kevin tried to further make sense of the assessment of CT so he asked questions. The questions allowed Kevin to receive more sources for sensemaking.

Moreover, in meeting 4, teachers made sense socially after Dan mentioned the difficulties when he applied CT:

1 Dan: I always mix up with the workflow. Our students get stuck in the workflow. So I wonder if it is more relevant to teach them the whole workflow which is CT, instead of the generalization…What should students be learning?

2 Robert: It is like Polya, you have to think about simplifying.

(Meeting 4, February 27, 2020)

Dan was confused about using CT. He was unsure whether he should use the whole workflow because students did not do well. Robert, as the only CT experienced teacher, tried to explain CT concretely to Dan. He exemplified the ‘‘Polya’’ problem-solving method. Dan further asked ‘‘which one is [more] beneficial to students? Which one is easier to do?’’ Dan’s question triggered Robert to recall other problem-solving techniques such as Polya problem-solving method and allowed him a chance to further make sense of CT easier. Moreover, Polya problem-solving method helped Dan make sense of CT easier because he was more familiar with Polya problem-solving method than CT. It gave him a better picture of what CT looked like. The conversation indicated that they were making sense collaboratively.

Another example was that Adam successfully established a worksheet after he made sense socially. When Adam shared his lesson in meeting 9, he said:

I decided to redo the worksheet. Because the previous time when I did it, I focus[ed] a lot on just one test only so I want[ed] to create one worksheet for one test. Then I kind of thought about what Dan said that [it was not]
feasible because it really [took] a lot of time and it [would] be [hard] to actually put all the tests together. (Meeting 9, July 15, 2020)

At first, Adam made the worksheet in terms of his own sensemaking. However, Dan told him that it was not feasible. Dan’s opinion influenced Adam’s sensemaking. Then, Adam continued, “at the end, I decided to change it and I did a third draft on condense development because I talked to Dan about this. He said that the best way to achieve this was to get them [together].” (Meeting 9, July 15, 2020) Obviously, Adam made a different decision and sensemaking because of Dan’s comments.

In order to have more sources to make sense of CT, Robert asked Kevin how his class performance was. Kevin replied:

[A class] is more willing to try. I don’t know what happened last year.

They have] bad habit. They jumped very fast to abstraction after fill[ing]
in a few numbers in the table.

Kevin described the class performance. Robert replied that his class had a similar situation. Robert added that his class was bad at writing pattern recognition. However, Kevin said his class did well in pattern recognition. The above conversation showed that they were making sense together. The interaction between them provided sources of sensemaking. Robert and Kevin knew of each other’s class performance. What social sensemaking gave sensemakers was something that sensemakers could not depend on individually. Without social sensemaking, Robert and Kevin would have been less stimulated for sensemaking. Their interaction showed how sensemakers make sense collaboratively.

Another example demonstrated that three teachers made sense together. Adam was presenting his worksheet in meeting 9 (July 15, 2020). After the presentation, Robert commented that “you can conclude that you will give [students] three types [of]
triangles…you can explore more’. Adam pleasurably replied that he would explore more.

Then, Owen also commented:

Adam I was thinking the triangle you give them [has] 3 sides, right? Then they compare. So, I was thinking they can compare the angles. Every question, the things that you never give, they are going to compare the things that you never give.

The conversation reflected that Robert and Owen were making sense of the worksheet that Adam was presenting, so they could give feedback instantly after the presentation. Adam received the feedback and then could have further sensemaking of his worksheet. The social sensemaking between teachers was reciprocal. They were all benefiting from social sensemaking. Adam could improve his worksheet after receiving the feedback while Robert and Owen could apply their thoughts on other or similar topics. The sensemaking they did on Adam’s worksheet could be transferred to their own work. Moreover, apart from Robert, Adam, and Owen, other teachers in the meeting who did not join this conversation could also make sense based on their conversation.

4.1.6 Ongoing

Sensemaking is an ongoing flow of experience (Weick et al., 2005). Teachers’ perception of CT was changing over time. Teachers in the PLC group had ongoing sensemaking of CT. At first, Owen thought CT was ineffective. But he changed his mind later. Owen expressed his disappointment with CT. He said, ‘‘the problem is that students do not know what to write (on the worksheet for pattern recognition and abstraction). I [got] impatient and [told] students to just see on the screen.’’ (Meeting 1, January 16, 2020) Obviously, he experienced a frustrating CT+math lesson. That made him have a negative impression of CT. But his sensemaking did not stop at this point. Later, he had more exposure to CT through the meetings and lessons and then expressed different opinions. He
asserted that CT was “more tangible…it will be good to know that thinking can be broken into shapes. And it makes things clearer and easier when [students] are doing their planning.” (Interview, March 13, 2020) This reflected that Owen changed his perception of CT. He described CT negatively initially but now was rather positive. Teacher sensemaking kept changing. Sensemaking had no clear beginning or end.

Kevin also showed his ongoing sensemaking which was different than Owen’s. Kevin thought of another way to implement CT. In meeting 3, he said, “our CT worksheet tends to give me the impression [that] students sit down [first]. [Then we ask them to] do [worksheets]. [Then they start to] find [a] pattern.” (February 27, 2020). Kevin thought that the behavior of students in CT+math lessons was robotic. Below explicitly indicated his ongoing sensemaking:

The first few worksheets crafted I [had] to tell myself [to] follow the steps. And if you ask me how I [was] going to change [the content], [I might craft the] worksheet for the time. That was how I understood [CT] for the first 2 months. I mean when I tried it out with the kids and I realized that using worksheets to teach is not the best way. (Interview, April 20, 2020)

This showed his sensemaking in the first two months that he integrated CT into math lessons. After two months, he posited:

I stopped using the worksheet to be really honest. I mean nothing against my colleagues. But the thing is [that] worksheets become more of a chore for students already. So no matter how much you go through, no matter how much we can ask them to show, there will be the majority or even some of them refuse to know and to them [worksheets] are an extra thing where [they are] not examinable, and you never want to use [them]. (Interview, April 20, 2020)
He thought worksheets were ineffective. He tried to follow the four pillars of CT, but he was not satisfied with the students’ performance in classes. Then, he started to believe that using worksheets to teach CT+math was not a good way to teach. He thought there would be better ways to integrate CT. Both Owen and Kevin showed ongoing sensemaking. The commonality was that they both provided different descriptions after they had more exposure to CT through teaching and meetings. The difference was that Kevin preferred to stop using worksheets while Owen’s attitude was changed from bad to good.

4.1.7 Focused on and by extracted cues

The focused on and by extracted cues signifies that individuals focus on a crucial and representative property to make sense of the circumstances (Weick et al., 2005). Individuals can make sense in totally different ways according to the cues they are focusing on. Owen showed that he focused on “algorithm” to make sense of CT. The algorithm was the last pillar of four pillars in CT. In his interview, he used the term “flowchart” instead of “algorithm.” He was talking about his impression of CT. He said:

I thought I know a lot about the flowchart. So I thought this one is very clear-cut for me. When it comes to actually carrying this out, the different processes then let me think more. Like how to actually get all these different parts out. The flowchart [is] quite easy for me to do. (March 13, 2020)

This indicated that he was familiar with the algorithm, but he did not know much about other pillars. Then, he continued:

if I were to do a flowchart for the problem solving, maybe it is quite simple for me…But before that, how do I put it into three different parts?...because for me as of now, the last part is the one that will last longer with me. But
the front three parts, I [am] slow to see the importance of these three parts.

(March 13, 2020)

This implied that Owen mainly focused on the algorithm when he made sense of CT. In meeting 2, when teachers were discussing the content of worksheets, it was interesting that Owen suddenly said ‘‘I was thinking about the flowchart.’’ (January 30, 2020) Because of his familiarity with the algorithm, he intuitively thought of it when he made sense of CT.

Another example was that Robert designed worksheets based on a demo lesson. When he was making a CT+math worksheet on terminating and non-terminating decimals, his design was based on an expert’s lesson demonstrated in a workshop. Robert made a simplified version according to student ability and tools in school. (Meeting 1, January 16, 2020) In this case, he showed that he focused on the cues from the expert’s lesson.

4.1.8 Driven by Plausibility rather than Accuracy

Regarding driven by plausibility rather than accuracy, sensemakers attempt to use the most effective and plausible way to solve the challenges or interruptions that they are facing (Weick et al., 2005). Accuracy is not their priority. In this study, the teachers in the PLC aimed to help students learn mathematics better. Therefore, they aimed to help students learn CT effectively rather than using CT accurately.

Instead of using all four pillars of CT, Kevin applied parts of the CT in his teaching. It was hard to apply all four pillars of CT to all mathematics topics. In meeting 1, Robert mentioned that not every mathematics topic could integrate with CT (January 16, 2020), not to mention using all four pillars. Teachers found that some topics could only use one or two pillars. In Kevin’s interview, he revealed that he sometimes only applied one or two pillars of CT because he thought it was more plausible for student learning. He said that ‘‘sometimes I only use the 2 of them, even the last 1 or the first 1.’’ This indicated that he occasionally applied specific pillars of CT. Then, he further elaborated on why he made this decision:
Is [CT] a fundamental tool for all the maths? To me, I would say that the first 2 steps [are] definitely yes. Even for everything is a yes. Although a lot of times during [the] discussion, we said that it is a bit hard to find patterns. It is a bit hard to find this. It is a bit hard to use this to decompose this. But if you really sit down and think about it… you can use any of the 4 steps, or even 2 of them and we can still say that it is more or less fulfill [ing] this idea. It may not be perfect, but I mean the steps are still being fulfilled in all the topics if you ask me. (Interview, April 20, 2020)

Kevin thought that CT was an important tool for students. He had a positive attitude towards it. Rather than applying all four pillars of CT, he preferred to apply some of them because he thought that using the pillars partly still fulfilled the idea of CT. He admitted that this was not the ideal approach to applying CT, but it was acceptable and plausible. His practice exactly showed that he did not mean to teach a perfect and accurate CT to students. He wanted to apply a plausible way and effective way to teach CT. He tried to optimize the use of CT, so he decided to use some pillars of CT occasionally. Conversely, he could not apply CT to more topics if he insisted on applying all four pillars of CT. The above-mentioned examples showed Kevin chose to teach a plausible CT but not an “accurate” CT.

Helen decided to shorten the teaching time on a CT worksheet to avoid spending too much time. It was not plausible that teachers spent too much time teaching one topic. When Helen was presenting her worksheet, Owen interrupted. He asked, “how long would [it] take since it appeared that decomposition looks quite lengthy?” (Meeting 9, July 15, 2020) Helen was supposed to teach decomposition during the lesson, but she suggested doing this part for homework after Owen asked the question. In her original plan, she expected to spend two hours teaching the content of the worksheet because teachers needed to spend more time teaching CT+math lessons. The question from Owen reflected that he was concerned that
might affect their teaching schedule if that worksheet was too time-consuming. Therefore, Helen changed her decision in order to save time.

Adam also indicated his plausible decision in CT practice. He adjusted the requirement of CT worksheets for students. Adam shared his practice of CT+math lessons in the interview. He adjusted the requirement for helping students learn CT+math lessons better. He said:

The S2 was that they are very scared of computational thinking because in S1, they had a lot of computational thinking sessions and they had to write a lot of words and they are very scared of writing words. It is because they have to explain what patterns they wrote, what kind of extraction they got, what were their data and so on and so forth. (Interview, April 24, 2020)

Adam mentioned why students were afraid of CT. According to the solutions of the worksheets (See Figures 9 & 10), teachers expected students to explain the patterns and their answers with words in detail rather than just answering with numbers. In order to help students, Adam adjusted the requirement, he continued:

So what we had to do was to try to minimize the writing…I don’t expect them to give me full sentences. I [said] you can give it to me in point form. 1 word [or] 2 words as long as you tell me what you notice about this thing. (Interview, April 24, 2020)

In order to motivate students to engage in the lessons, Adam allowed students to write in point form. What Adam thought was that students would learn better if they could write less. Also, students could still plausibly learn CT even though writing fewer words. Therefore, instead of accurately following the requirement of the CT worksheets, he adjusted them and made the lessons more approachable for students.
**Figure 9**

*An Example of another Worksheet*

**Pattern recognition 1**
Based on what you did in the decomposition 1 step, what are there some patterns you observe within each category?

<table>
<thead>
<tr>
<th>Perfect square</th>
<th>Non-perfect square</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 10**

*The Solution of the Worksheet*

**Pattern recognition 1**
Based on what you did in the decomposition 1 step, what are there some patterns you observe within each category?

<table>
<thead>
<tr>
<th>Perfect square</th>
<th>Non-perfect square</th>
</tr>
</thead>
<tbody>
<tr>
<td>-There are different numbers are multiplied to one another to get the number.</td>
<td>-Different numbers are multiplied to one another to get the number.</td>
</tr>
<tr>
<td>- it has factors that are composite numbers and prime numbers</td>
<td>- Factors are made of composite numbers and prime numbers</td>
</tr>
<tr>
<td>- There is a number multiplied to itself</td>
<td>- they have odd number of factors</td>
</tr>
<tr>
<td>- they have odd number of factors</td>
<td></td>
</tr>
</tbody>
</table>

4.2 Identified Actors that Influenced Teacher Sensemaking

In this section, based on the worksheets, meeting transcripts, and interview transcripts, ANT was applied to identify actors that influenced teacher sensemaking. The
actors included: the exam-oriented culture in Singapore; the way of teaching and learning CT+math lessons; the suitability of mathematics topics; and the arrangement of teacher duties.

4.2.1 The Exam-oriented Culture in Singapore

In an exam-oriented culture, teachers and students highly value exams. Student expectations, as an actor, influenced teacher sensemaking. Regarding the student engagement in Kevin’s class, he said:

No matter how much you go through, no matter how much we can ask them to show, there will still be the majority or even some of them [who] refuse to know and to them [CT] is an extra thing where it is not examinable.’’ (Interview, April 20, 2020)

Kevin asserted that students were not interested in learning CT because it was not examinable. This indicated that students expected to learn something related to exams. They did not have motivation in CT lessons. Kevin mentioned what students said when they knew CT was not examinable, ‘‘the moment you say this one is not examinable, ‘oh! Not examinable?’ They will shut off and they will just do whatever.’’ Kevin further explained his view:

If you use it to something in our normal teaching and tell them, and [it is] subsumed inside, it becomes very natural and they know it is examinable. They will have the motivation. I know it is not really right to say that we have to use this extrinsic motivation. So it is a very bad thing in the current education system to [use] it. (Interview, April 20, 2020)

Kevin explicitly explained why students preferred to learn knowledge related to exams. He thought it was because of the current education system. The student expectations constrained teacher sensemaking and then influenced the practices of CT.
Teachers’ attitudes towards examinations was also a significant actor that influenced teacher sensemaking. Teachers usually talked about examinations because they expected that integrating CT could help students on examinations. In Robert’s interview note (April 25, 2019), he described how teachers implemented CT+math lessons. He said, ‘‘we try as many times as we can. We also assess effectiveness over a period of time and give a better representation. We are assuming [that it is effective].’’ He then defined effective teaching as ‘‘students can answer questions on the exam.’’ He thought that if students could answer exam questions correctly after they learned CT, their teaching was successful and effective. In meeting 4 (February 27, 2020), both Robert and Dan mentioned national exams. Robert said that the value of CT was to ‘‘answer question[s] [on] the national exams’’. Then, Dan suggested that teachers ‘‘should focus on generalization, workflow, and revision for national exams.’’ Both meetings and interviews demonstrated teachers highly valued exams and thought about them a lot. The data identified that teachers’ attitudes towards examinations influenced teacher sensemaking.

The CT assessment, as an actor, also influenced teacher sensemaking. In meeting 1 (January 16, 2020), Kevin expressed his impression of CT and asked questions about it. He especially wanted to know more about the assessment of CT. He asked, ‘‘how [do you] assess [CT]?… how [do you] determine if results are significant?’’ This indicated that he thought that assessment methods were important, so he asked questions related to assessment first. Moreover, the assessment methods of CT were one of the main focuses of meeting 1 (January 16, 2020) (See Table 2). Since Owen and Adam taught CPA which has components of CT (e.g., flowchart= algorithm), Robert asked them to share their assessment methods with the group. The
data identified that the CT assessment constrained teacher sensemaking and then influenced their practices.

4.2.2 The Way of Teaching and Learning CT+math Lessons

Using worksheets for CT+math teaching influenced teacher sensemaking. In meeting 1 (January 16, 2020), Robert told teachers about the goal of CT. He said that they should be “repackaging what we have already done.” The direction was very clear. Rather than creating new ways or methods to teach CT, Robert expected the group to improve and “repack” worksheets that were created previously by the past members. As such, in all the meetings, teachers were discussing how to craft worksheets without mentioning other possible teaching materials for CT+math teaching. In Kevin’s interview, he talked about how he would explain CT+math lessons to new teachers, he said:

I think the first thing is [that] I would [ask them to] look through all the worksheet[s] that they have in the folder. I mean, in the S1, S2, S3, whatever crafted. And there are some documents on computational thinking so I just [ask them to] read through first. (Interview, April 20, 2020)

Instead of directly explaining what CT was for new teachers, Kevin preferred to ask them to look through worksheets that were created for CT+math lessons. This indicated that worksheets were one of the most prominent sources of sensemaking. However, using worksheets for teaching CT constrained teacher sensemaking.

The understanding of the four pillars of CT influenced teaching sensemaking. Since most of the teachers in the PLC group were non-CT experienced teachers (See Table 1), they were not familiar with teaching math with CT. Most of the teachers indicated that they encountered difficulties when they were crafting CT worksheets, such as Helen and Owen. In meeting 6 (June 10, 2020), Helen was presenting the worksheet of Quadratic Inequalities.
She mentioned that she “need[s] some help and comments” for the part of the decomposition. In Owen’s interview, he mentioned his perception of CT:

If I were to do a flowchart for the problem solving, maybe it is quite simple for me. But before that, if I have the [first] three parts … [I am wondering] how I get a decomposition [or] pattern recognition. [For] example, maybe [I need to] find exchange rate [then] I can do algorithm. But before that, how do I put it into three different parts? (Interview, March 13, 2020)

Since there were the four pillars of CT, Owen knew the algorithm well but he was not clear about the other pillars. The above-mentioned examples showed that teachers were unfamiliar with teaching math with CT. This new way of teaching enabled teachers’ sensemaking and then influenced their practices.

Students’ feedback was a key actor that influenced teacher sensemaking. Teachers mentioned that students did not enjoy CT+math classes. Owen described the situation of his class, we “need some time for students [to get used to it]. Students do not know why they need to do this. They [think they] can just do [the math without CT] …I force them to do it.” This indicated that students were not willing to learn math with CT. Kevin shared his view on why students did not enjoy CT+math lessons, he said:

They realize that they have some problems [in] writing a lot. And to them, it is a very complicated thing to do because it is very long. They need to write down the steps [in detail]. Okay, so they don’t really like it.

(Interview, April 20, 2020)

Students did not like this way of learning because they needed to write a lot for the four pillars of CT. Adam had the same feedback from students:
Because in S1, they did a lot of it. [They] had a lot of computational thinking sessions and they had to write a lot of words and they are very scared of writing words. (Interview, April 24, 2020)

Teachers expected students to answer questions thoroughly by writing words for CT worksheets. Students even challenged Adam and asked “why do we have to write so much? It is math, you know, why do we need to write so many words for this whole thing?” In Owen’s interview, he also explained why students were afraid of learning mathematics in this way, he said:

As in the front part, they will have difficulty doing it because maybe it is brand new to them. The second thing is [that] they have to write which differs from previously just [answering in] numbers. Like, oh, I give you a problem. You go and solve it. Now is no. [They need to] observe what the similarity [and] differences [are]. Yeah, so I felt that [we] maybe need more time to let them enjoy this. (Interview, March 13, 2020)

That was why students were afraid of learning in CT+math lessons. In their previous experience, they only needed to answer questions in numbers. They did not need to write so many words to answer questions. Students were not familiar with this way of learning mathematics so they were struggling and not interested in it. The feedback from students influenced teacher sensemaking.

Students’ fear of learning from mistakes was another actor that influenced teacher sensemaking. The CT+math worksheets did not have exact answers and students were expected to answer the questions collaboratively. Owen described how students worked in the group for the answers:

There are people who observe, and they [may] communicate with you, but the terms [may] not be correct. So I feel that there is a minority group that
doesn’t even want to try because [they think that they] cannot write it down. (Interview, March 13, 2020)

Some students were not even trying to do the worksheets because they thought that they were not capable of answering the questions. They did not have enough confidence. Owen further explained why students hesitated to answer. He described what students thought. He said that students would ask ‘‘Is 1 allowed? Should you write about 1 or should you write about…? Oh, there are two factors. Am I right or am I wrong? They don’t dare to make mistakes.’’ (Interview, March 13, 2020) Owen explicitly pointed out that students did not dare to make mistakes. Not only were students unfamiliar with CT, but they were also unfamiliar with making mistakes, especially when they were working in a group during the lessons. This enabled teacher sensemaking and influenced their practices of CT.

4.2.3 The Suitability of Mathematics Topics

The compatibility of mathematics topics influenced teacher sensemaking. In the PLC, teachers aimed to integrate CT into mathematics. However, the four pillars of CT could not apply to every topic in mathematics. They spent three meetings (See Table 2) discussing topics that were appropriate and easy to apply to CT. In Robert’s interview note, he mentioned how he chose topics for CT. He said, ‘‘we tried to look for ones that can generate a bunch of data that students can analyze and make inferences about.’’ (Interview note, April 25, 2019) He accentuated ‘‘look for’’ which reflected that teachers could not easily integrate CT with math. Also, in the first meeting, Robert shared his experience and perception of CT with colleagues and asked colleagues to share their impressions of CT. Kevin said that it ‘‘feels like [CT] works with any topics.’’ Robert replied ‘‘CT works with specific topics. CT is more structured. You need to take a lot of time to create worksheets.’’ (Meeting 1, January 16, 2020). This reflected that Robert did not agree with Kevin. He thought that not all topics were suitable to apply CT. He had more experience than Kevin in teaching CT+math. Robert
disagreed with Kevin because his previous experience was that only specific topics could integrate CT. Adam also shared how he selected topics for integration, he said that “the second would be the suitability of the content as well.” (Interview, April 24, 2020). The compatibility of topics influenced teacher sensemaking.

The level of the mathematics topics influenced teacher sensemaking as well. In the interviews of Adam and Owen, they expressed similar opinions. Adam mentioned how they chose topics for CT. He said that “the first thing is [the] difficulty of the content.” (Interview, April 24, 2020). This reflected that when teachers decided which topics to use for integrating CT, they would discuss the level of the topics. In Owen’s interview (March 13, 2020), he said that it was easy “to figure out whether it is [a] prime number or not. Actually, it is a very simple item… But we took about six pages.” He thought that it was not worth teaching a simple topic with CT. He then gave an example of what he thought was suitable for integrating CT. He suggested:

I can imagine [using] Pythagoras theorem in the future. Then how it was being figured out. Then they have to go through the whole discovery parts. Then they will have an algorithm to help them to make things more concrete. Yeah, then I think that topic would be nice for this.

Owen preferred to apply CT to more complicated topics. The level of topics enabled teachers’ sensemaking and then influenced their practices.

4.2.4 The Arrangement of Teaching Duties

Teaching at different levels influenced teacher sensemaking. In the PLC group, four teachers taught S1 while 2 teachers taught S2 (See Table 1). They all designed worksheets for S3, but no teachers were teaching S3 and no one had experience in teaching S3 CT+math lessons. Robert was the only teacher that had experience in teaching S1 and S2. This meant that other teachers only had
experience in teaching their levels this year. For example, Adam started to teach CT+math this year and he taught S1, which meant he did not have experience in teaching CT+math at other levels. Teachers found this situation difficult. Adam talked about one of his challenges in designing CT lessons. He said:

I guess I enjoyed the process of teaching CT at the start. And now we are actually in the process of crafting up CT for S3. And I think the challenge is [that] I do not teach S3 at the moment. I feel like sometimes I have to guess [what] the students like [and] what [their] responses [will] be. [It] is like a guessing game to figure out what they [would] do. [Would] they be able to understand computational thinking? (Interview, April 24, 2020).

Adam enjoyed teaching CT. However, the challenge was that he did not have any experience in teaching S3 classes. He had to guess what students’ responses and reactions were. In Kevin’s interview, he addressed the problem of inadequate teachers teaching at different levels. He said:

Sometimes I need to check if [my colleagues are] using this. Because for me, the PLC group is only me and Robert [that are teaching] the S2. Then the rest of them are [teaching] S1. So, it is a bit hard for us to check with the rest and I don’t need [to] ask them [what] it is like. [Because] they can only give us more or less this idea but it may not be relevant when it comes to applying S2 topics. (Interview, April 20, 2020)

Although teachers other than Robert were trying to give Kevin ideas, they could not provide relevant suggestions to him because they had no experience in teaching S2. Also, since they taught at different levels, they would face different situations when they were teaching. For example, they would teach different topics. Students would
have different attitudes and reactions. Teachers might not be able to receive high-quality feedback for sensemaking from colleagues. As such, teaching at different levels influenced teacher sensemaking.

Teachers’ time influenced teacher sensemaking as well. The actions of teachers are often time-sensitive (Ghavifekr et al., 2016), subject to the speed/accuracy trade-off. Teachers were aware of how many lessons should be spent on teaching the CT worksheets. When Helen was presenting her worksheet, Owen interrupted. He asked, “How long would [it] take since it appeared that decomposition looks quite lengthy?” (Meeting 9, July 15, 2020) The question from Owen reflected that he worried that if they spent too much time on the worksheet, it might affect their teaching schedule. It is not unusual that teachers are expected to follow their planned teaching schedule tightly. At the same time, they were responsible for duties other than the CT project. In the regular meetings, some teachers were irregularly absent. For example, in meeting 4 (February 27, 2020), Kevin and Owen were absent because they needed to go out for professional development. Teachers had a tight schedule. They must make sure that they had enough time to deal with different tasks. Teachers’ time influenced teacher sensemaking.

4.3 The Development of Computational Literacy (CL)

Although the CT+math project was still in a preliminary stage in the school and even in Singapore, the findings indicated that the CL was developing. diSessa (2018) presents four new principles of CL that provide detail and focus for his agenda regarding literacy and the four principles of CL were reflected within the findings in this thesis (See Table 6).
Table 6

Examples of diSessa’s (2018) Four Rs in Teaching Sensemaking of CT

<table>
<thead>
<tr>
<th>Re-mediation</th>
<th>diSessa’s (2018) description of potential change</th>
<th>Teacher sensemaking on CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Appropriation of a new representational system for our civilization.</td>
<td>• Teachers applied the four pillars (decomposition, pattern recognition, abstraction, and algorithm) of CT to represent the answers in worksheets (See Figure 11)</td>
<td></td>
</tr>
<tr>
<td>• Dynamic and interactive representations on computers, accompanied by the capability to design and enact representations on demand and often quickly</td>
<td>• Rather than using representations on computers, teachers applied an unplugged approach (Grover &amp; Pea, 2013) of CT to teach math</td>
<td></td>
</tr>
<tr>
<td>• Any representational system is better applied for some things and less for others</td>
<td>• Not every mathematical topic can be integrated with CT. Teachers spent a lot of time coming up with suitable topics that can be integrated with CT</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reformulation</th>
<th>diSessa’s (2018) description of potential change</th>
<th>Teacher sensemaking on CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>• A discrete epistemology that substantial changes in what, when, and how to teach a subject matter according to an enhanced understanding of human resources</td>
<td>• Teachers applied CT to teach math in a new way</td>
<td></td>
</tr>
<tr>
<td>• Reformulation helps achieve cognitive simplicity</td>
<td>• Teachers spent much more time applying the CT approach</td>
<td></td>
</tr>
<tr>
<td>• Ones need to consider different ways of thinking about each domain, and how learners understand different domains</td>
<td>• Teachers agreed CT helped simplify difficult mathematics topics. The algorithm part of CT clearly showed the solution to mathematics questions, especially the difficult ones</td>
<td></td>
</tr>
<tr>
<td>Reorganizing</td>
<td>• Changed the intellectual terrain. A reorganized intellectual terrain will appear in new landmark documents (e.g., literature and textbooks)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• This principle creates a landmark for deep change in teaching and learning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Focus on big cultural changes. Teaching mathematics will and should look greatly distinct, granted any literacy-scaled change</td>
<td></td>
</tr>
<tr>
<td>Revitalizing</td>
<td>• The ecology (diversity) of learning activities is facilitated</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Engagement, interest, and equity are promoted</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Teachers were solely using CT worksheets to teach math and students did not involve in creating worksheets</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Teachers mentioned that the feedback from students was not good, and students did not engage in the CT+math lessons</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Not every class in school had CT+math lessons because the project was aiming to apply CT step by step, each form by each form</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Students learned differently. They worked in groups and used words to answer questions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• People are used to thinking that the answers to mathematics questions should be short and succinct and usually use graphs or numbers to represent the answers. Students needed to write a lot In CT worksheets</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Teachers mentioned that the school’s textbook and syllabus had information related to CT</td>
<td></td>
</tr>
</tbody>
</table>
4.3.1 Re-.mediation

Re-mediation was reflected in the findings. Rather than using representations on computers, teachers applied an unplugged approach (Grover & Pea, 2013) of CT to teach math. They used the four pillars of CT, which included decomposition, pattern recognition abstraction, and algorithm to teach mathematics. Although they were using an unplugged approach, these four pillars are highly related to coding concepts. Teachers taught these concepts to students for better problem-solving skills. (Meeting 1, Jan 16, 2020) The four pillars of CT were a new representational infrastructure for teachers and students in this school. The new representational infrastructure allowed teachers and students to teach and
learn mathematics differently. Adam mentioned how this representational infrastructure brought differences to teachers and students. He said “I feel that [CT] is different from the normal curriculum and the normal teaching routines. And that is actually helpful for students to be exposed to different ways of being taught mathematics.” (Interview, April 24, 2020)

The four pillars within this representational infrastructure can re-mediate how students learn about and understand mathematics.

Re-mediation accentuates that any representational system is better applied for some things and less for others. The findings showed that not every mathematical topic was ideal for integrating with CT. In meeting 1 (January 16, 2020), Robert said that “we applied CT to specific topics. CT is more structured, but [we] take a lot of time to create worksheets.” This reflected that teachers had to spend a lot of time coming up with topics that could be integrated with CT because they had to consider the suitability and levels of the topics to decide if it was better to apply CT+math or not. This also indicated that a new representational system does not necessarily replace all previous representational infrastructures which means they can exist together.

4.3.2 Reformulation

Reformulation accentuates three things that will be changed: substantial changes in what, when, and how to teach a subject matter according to an enhanced understanding of human resources; changes in helping achieve cognitive simplicity; different ways of thinking of each domain and how learners understand different domains (diSessa, 2018).

The way of teaching mathematics changed a lot by using CT. For example, Owen talked about teaching “prime numbers.” He said it was easy “to figure out whether it is [a] prime number or not. Actually, it is a very simple item… But we
took about six pages.’’ (Interview, March 13, 2020) This reflected that he would not spend six pages teaching the concept of ‘‘prime numbers’’ in previous approaches. After teachers used CT to teach prime numbers, they needed to apply the four pillars of CT and this approach cost them more time and changed their ways of teaching.

In terms of cognitive simplicity, some teachers mentioned that they thought that integrating CT with difficult topics would be more helpful. Owen said ‘‘if the topic is difficult enough to confuse them, then the flowchart will help.’’ (Interview, March 13, 2020) This reflected that he thought that using CT to teach ‘‘difficult topics’’ was valuable. The algorithm part of CT could clearly show the solutions to mathematics questions, especially difficult ones (See Figure 8). Kevin also addressed how CT helped cognitive simplicity:

Computational thinking will bring everything together and bring consistency... [Students will] become very aware of systematic thinking and [analyze] properly in a very systematic manner. [It is] more than just follow [the steps from teachers]. [There] is nothing wrong with [following the steps but] I mean computational thinking will [create] all [these] puzzles and put [them] in a more systematic manner. (Interview, April 20, 2020)

The ‘‘systematic thinking’’ helped students deal with the ‘‘puzzles’’ and to understand mathematics better.

The data showed that teachers considered different ways of thinking about some domains, and they tried to understand how students construed different domains. Kevin mentioned that teachers might understand CT better through Polya’s problem-solving method. Also, he considered the system of linear equations (SLE)
which is not related to secondary school mathematics when he made sense of CT. Robert asserted that one of the goals of applying CT was that students could apply this approach to other subjects. (Interview note, April 25, 2019) This reflected that he tried to think about how students construed other subjects such as Information Communication Technology (ICT) or Sciences. That was the reason he thought that CT could possibly be applied to different subjects other than mathematics. The above-mentioned examples reflected the Reformulation of CL.

4.3.3 Reorganization

diSessa’s Reorganization of the intellectual terrain, teaching and learning, and cultural change, was apparent from the findings (diSessa, 2018). Teachers mentioned that a school textbook had some content on coding. In meeting 1, when teachers shared their thoughts on CT, they mentioned that a new textbook of mathematics had content on coding. Also, apart from the new textbook, Owen was surprised that he discovered an S1 textbook that integrated CT+math in the first chapter. He showed the textbook to other teachers enthusiastically. Robert also mentioned that the syllabus of the MOE was going to incorporate CT. (Meeting 1, January 16, 2020). This indicated that the new landmark documents included the content of CT and directly influenced the teaching and learning of teachers and students.

The cultural change is a big part of the Reorganization. People are used to thinking that the answers to mathematics questions should be short and succinct and usually use graphs or numbers to represent the answers. In Singapore’s case, the data showed that students had to explain answers with words in order to meet the requirement of the worksheets. As such, teachers stated that students were not happy
about this. Adam mentioned how students challenged him about writing ‘‘too much.’’ The students asked ‘‘why do we have to write so much? It is math, you know, why do we need to write so many words for this whole thing?’’ (Interview, April 24, 2020) Students answered shorter answers, such as numbers in math lessons that did not apply CT. This could explain why they were not engaging in CT+math lessons. Robert, as the only CT experienced teacher in the PLC, told other teachers that both teachers and students would get comfortable with CT+math lessons after they had more exposure to CT. (Interview, April 24, 2020) This can be perceived as a small step of big cultural changes that change the minds of students about only answering mathematical questions with short answers and in numbers.

4.3.4 Revitalization

In terms of the equity of Revitalization, as the CT+math project was still in a preliminary stage, only a few classes (S1 and S2) were officially learning CT+math lessons. However, the findings showed that teachers tried to apply CT to different classes. Kevin shared his experience:

I tried [to apply CT] for the S3… I used the coordinate geometry because [at] that time my worksheet was not out so I had not crafted anything out of it. So I [tried] something new. (Interview, April 20, 2020)

The PLC group did not appoint Kevin to teach CT+math lessons for S3 but he did it. This showed that he tried to let more students learn CT+math lessons.

The findings indicated that the PLC group needed to consider more about the ecology of learning activities and engagement, interest, and equity (diSessa, 2018) regarding CT, in order to have better implementation. The way of learning in CT+math lessons was monotonous. Kevin described the situation. He said that ‘‘our
CT worksheet[s] tend to give me the impression [that students sit down [first]. [Then we ask them to] do [worksheets]. [Then they start to] find [a] pattern…” Teachers were solely using CT worksheets to teach math and students were not involved in creating the worksheets. The objectives of applying CT were to teach them problem-solving skills and helped them answer exam questions rather than trigger their interest in math. Teachers mentioned that the feedback from students was not good. Students did not engage in the CT+math lessons because some said that they needed to write a lot of words (Interview, April 24, 2020), and some said that they did not know why they needed to learn math in this way when it was not examinable (Interview, April 20, 2020).

In this chapter, the transcripts of interviews and meetings, and teaching artifacts were presented to shed light on how teachers made sense of CT in the PLC group. The actors that influenced teacher sensemaking were also identified. The findings indicated that the seven properties of sensemaking clearly described and explained how teachers made sense of CT. The exam-oriented culture in Singapore, the way of teaching and learning CT+math lessons, the suitability of mathematics topics, and the arrangement of teacher duties were the main actors that influenced teaching sensemaking. Finally, this chapter also delineated how the four principles of CL were reflected within the findings. In the next chapter, the findings and the implications of this study will be discussed.
Chapter 5

5 Discussion and Implications

This study explored seven Singapore teachers’ sensemaking of implementing CT in mathematics through transcripts of teacher interviews, transcripts of meetings, and a collection of teaching artifacts. The major actors, including the exam-oriented culture in Singapore, the way of teaching and learning CT+math lessons, the suitability of mathematics topics, and the arrangement of teacher duties that influenced teacher sensemaking, were identified. Then, how the four principles of CL were reflected within the findings was delineated. In this chapter, key findings pertaining to teacher sensemaking and how the identified actors enabled and constrained teacher sensemaking and then influenced their CT practices are discussed. Then, this section examines how the findings relate to the existing literature with a focus on sensemaking and ANT. Next, the implications of the findings regarding teacher sensemaking, ANT, and the development of CL are discussed. Finally, suggestions for future research are provided.

5.1 Teacher sensemaking and seven properties of sensemaking

The first key finding illustrated that the seven properties of sensemaking were present and explained how teachers made sense of CT.

5.1.1 Grounded in identity construction

As demonstrated in the existing literature, teachers make sense of situations in terms of their identities. Weick et al. (2005) assert

[...] who we think we are (identity) as organizational actors shapes what we enact and how we interpret… (p. 416).
Irene was the HOD of mathematics. Her focus was not on crafting the worksheets and CT content. Her enactment in this group was that she provided guidance and directions to the team. This aligns with what Louis et al. (2005) asserted; providing teachers’ chances to allocate work gives them a way to make sense to improve the possibility of transformation. For example, she suggested to the PLC group how they could present CT to other department members. Since she had other duties beyond this group, she made sure she gave enough autonomy to the group to implement CT. She appointed Robert as the group leader. As such, Robert could allocate work to other teachers so he had more ways to make sense as well. This could “‘stabilize’” (Weick et al., 2005, p. 146) their identities and then they kept making sense in terms of their identities.

Teachers were expected to be responsible for student learning and examinations, especially in an exam-oriented system. Spillane et al. (2006) stated that situated cognition was related to specific individuals understanding particular conditions in their social networks, workplace systems, and social identities. Teachers who can help students get higher scores are perceived as effective teachers (Baker et al., 2010). As this study was situated in Singapore, the social networks, workplace systems, and social identities of teachers were highly related to exams. As such, teachers usually thought of the relationship between examinations and the effectiveness of student learning when they were making sense. The transcripts of meetings and interviews indicated that many teachers mentioned exams. Robert related effectiveness to exams (Interview note, April 25, 2019); Dan talked about if CT could help with national exam preparation (Meeting 4, February 27, 2020); and Kevin stated that students did not engage in CT because it was not examinable (Interview, April 20, 2020). They all considered the
workplace systems and social identities (Spillane et al., 2006; Stern, 2016) when they were making sense. Teachers made sense of the situations in terms of their identities.

5.1.2 Retrospective

The findings related to the literature were that teachers made sense of innovation in terms of their previous experience and knowledge. This study aligns with what Spillane et al. (2006) underlined in that teachers made sense of novel ideas based on preceding knowledge, expertise, and experience. Spillane et al.’s (2006) research aligns with the findings of this research project. When Robert had difficulty designing part of the algorithm, in order to gain clarity about his decisions (Weick et al., 2005), he instantly recalled that he had a similar experience the previous year. Therefore, he said he would refer to the lessons from that year. (Meeting 4, February 27, 2020) Dan had problems with crafting some details in a worksheet, so Robert told him that he needed to have more exposure to CT based on his experience of the previous year. (Meeting 4, February 27, 2020) Apart from experience, teachers also made sense retrospectively according to their knowledge and expertise. Adam learned CT and explored it when he was a student. (Interview, April 24, 2020) He could apply familiar terminologies to describe it while Dan could not. (Interview, July 9, 2020) This was because Adam could make sense of CT based on his knowledge and expertise in university. This finding supports the idea that ‘‘retrospective’’ does not mean everything in the past but a specific circumstance (Weick et al., 2005). The above-mentioned examples could see teachers made sense retrospectively based on specific knowledge, expertise, and experience.
Weick et al. (2005) posit that sensemakers eliminate some steps from the original events during retrospective sensemaking. When Adam and Kevin made sense of CT retrospectively, they mentioned “coding” and “Polya’s problem-solving method”, but neither are exactly the same as the CT they were using even though there were similarities. As such, it was obvious that they were “wiping out” something from those concepts in order to make sense of CT.

This research project specifically points out that teachers have retrospective sensemaking based upon CT teaching experience, learning experience, and specific working experiences. In the previous research, for example, according to Spillane et al. (2006), sensemakers are active interpreters who draw on their preceding knowledge, expertise, and experience in the process of interpretation. Luttenberg et al. (2009) define sensemaking as “the interaction between their own frame of reference…” (p. 446). This research project’s findings delineated teachers’ experience in detail. For example, Robert, as the only CT experienced teacher, made sense retrospectively according to his previous CT teaching experience. Dan asked him questions regarding CT and Robert suggested that he could think through what he had previously done on CT (Meeting 4, February 27, 2020). Adam and Dan made sense retrospectively based on learning experience and specific working experiences. Adam recalled his learning experience in university (Interview, April 24, 2020) while Dan thought of his working experiences in selecting student leaders in the school. (Interview, July 9, 2020).

5.1.3 Enactive of Sensible Environments

Teachers make impacts on the environment and the environment creates new stimuli for the teachers (Weick et al., 2005). Weick et al. (2005) claim that an
organization with a higher level of freedom and resiliency may help sensemaking. Conversely, Allen and Penuel (2015) found that “the tight monitoring of instructional practice by … administration forced expedited and constrained sensemaking about practice-focused instruction …” (p. 147). Tight monitoring has negative impacts on sensemaking. In the findings, Irene and Robert showed how good leaders influenced the PLC group, after which the group members gave them new stimuli. Irene explicitly gave the teachers the freedom to organize the presentation (Meeting 8, July 08, 2020). She also occasionally joined the meetings in order to give them directions to design worksheets rather than request that they follow what she thought. Robert was open to his colleagues’ opinions. He was more than welcoming of their criticism of his work. The atmosphere of the meetings was harmonious. Irene and Robert gave autonomy to colleagues, so they were willing to speak. All these behaviours made the team more willing and more confident to face the changes. The higher level of freedom from the school and the leaders changed the nature of the interruption (Weick et al., 2005).

5.1.4 The PLC and Social Sensemaking

*Social* sensemaking is highly related to PLCs. In this part, I first talk about the findings that are related to the literature on PLCs. Then, I discuss the findings of social sensemaking and their relationship to the pertinent literature.

The PLCs provide a good environment for teachers to make sense socially and have a better understanding of CT practices.

According to Wilson (2016), a PLC is a community where teachers and related contributors work together with common goals and related backgrounds. In this study, all members of the PLC group were mathematics teachers. Regarding the
common goals of the PLC, in the first meeting, after introducing the history of the CT project, Robert instantly addressed the goals of the PLC group, such as designing S3 CT worksheets and teaching students problem-solving skills (Denning, 2017). (Meeting 1, January 16, 2020) Hoaglund et al. (2014) claimed that PLCs provided a space for teachers to discuss how to help students learn better. In the study, teachers had regular meetings twice a month (See Table 2) for crafting the worksheets and designing CT lessons together. In meeting 2 (January 30, 2020), Dan claimed that they wanted to teach a thinking process to students. This indicated that the group aimed to help students learn better in mathematics through the thinking process. It also showed that the school established the PLC for a concrete and specific purpose (Hoaglund et al., 2014). According to Ning et al. (2015), an implicit belief is that PLCs can contribute to considerable changes in teaching cultures and practices. Before teachers integrated CT into mathematics, students used to answer mathematics questions by using numbers or short answers. However, teachers must change this requirement because CT worksheets required students to explain in words rather than just numbers. When Kevin talked about what was better after teachers changed their practices, he said:

[Students] really use [those] analytic skills to know what the next upcoming steps [are], so they can recognize that type easily. This is not just memorizing but really [knowing] what the content and technique [are] [and] find a connection to them.

As such, the findings identified that the PLC contributed to considerable changes in teaching cultures and practices.
In the PLC group, the school leaders, Irene and Robert, still were the ones who made the final decision even though the PLC policy initiative emphasized teacher collaborative learning. Hairon (2006) argues that it is because the nature of policy implementation in the education system in Singapore is centralized and top-down. Although the school leaders made the final decision, the findings showed that it was not a hindrance for teachers to learn collaboratively. As the leaders of the PLC group gave enough freedom and encouraged teachers to speak about their thoughts, they learned with one another harmoniously and collaboratively. For example, in meeting 8 (July 08, 2020), Robert made an initial proposal, but then Dan suggested other ideas. After their discussion, everyone agreed with Dan’s plan. This reflected that Robert as the leader of this group accepted colleagues’ opinions even though he could make the final decision. This demonstrated that even though the education system is centralized and top-down, it does not affect the way teachers operate with one another to develop CT and fulfill the needs of students gradually (Dufour & Reeves, 2016).

The findings showed that teachers made sense of CT socially. Czarniawska-Joerges (1992, as cited in Weiser, 2021) claimed that social sensemaking was not only about shared meaning but also about sharing collective action. In terms of shared meaning, teachers shared their perceptions of CT in the first meeting. Owen said that CT was “simpler than coding” while Robert said CT was “making thinking visible.” (Meeting 1, January 16, 2020). In meeting 9, Adam had questions and difficulties in designing worksheets. He mentioned that he sought help from Dan and finally he redid the worksheet. (July 15, 2020) In this case, Adam tried to make sense individually first (Schmidt & Datnow, 2005) but he encountered
difficulties. The social sensemaking allowed him to design the worksheets successfully. This aligns with the study from Allen and Penuel (2015) which identified that teachers needed more chances to engage in collaborative and sustained sensemaking to help them understand and deal with the incongruities and ambiguity towards changes. Coburn (2005) also identified that different sensemakers in an educational organization influenced others’ sensemaking. The members of the PLC group influenced one another explicitly. The shared meaning gave resources to teachers to help them make sense. Since the shared meaning was shared in the group, it influenced the whole group. For example, Dan asked a question about what students should learn in CT (Meeting 4, February 27, 2020). It should be noted that other teachers might also have had the same question. As such, Robert’s answers gave resources to other teachers to help them make sense at the same time.

For the shared action, since teachers were crafting worksheets and designing lessons together throughout the 9 meetings, they would enact the lessons in similar ways. Of course, they would have a different implementation in some details during lessons, such as interactions with students or the pedagogies, but they would generally follow the lesson plans they discussed and designed. The teachers’ sensemaking in this study resonates with Spillane et al.’s (2006) claim that sensemaking is not only about individuals’ own sensemaking but is also about “practices and common beliefs of a community” (p. 58).

5.1.5 Ongoing

Sensemaking is a fluid and ever-changing process (Weick et al., 2005). Weick et al. (2005) claim that interruptions occur recurrently. As such, sensemaking
is an ongoing accomplishment. In the findings, Kevin showed his ongoing sensemaking. At the beginning of the project, the first interruption that Kevin encountered was that he needed to design CT worksheets. He tried his best to fit the four pillars of CT into the mathematics topics (Interview, April 20, 2020) in the first two months. Priestley (2005) stated that “teachers are learners rather than passive conduits of someone else’s policy” (p. 36). According to Lieberman and Mace (2008), the central component of educational reform is teacher learning. Kevin kept learning through the practices of CT, reading different resources, and having discussions in the meetings. He discussed things related to CT with his colleagues throughout the 9 meetings (See Table 2), taught students CT, and read related resources on the internet (e.g., online blogs and YouTube) to make sense of it. (Interview, April 20, 2020) Later, he got into another interruption which was that students were not interested in CT. He found that they did not want to write a lot of words to finish the worksheets. (Interview, April 20, 2020) This stimulated him to think of other ways to teach CT as he thought that the worksheets were not effective. It was not unusual that Kevin had ongoing sensemaking of CT since he had more inputs related to CT throughout the year.

Owen also indicated his ongoing sensemaking. He had a negative impression of CT at first. He found that students did not know how to do CT worksheets, so he decided to write down the answers for them. (Meeting 1, January 16, 2020). According to Spillane et al. (2006), sensemaking is an ongoing process and is influenced by the artifacts and materials contained. After Owen had more exposure to CT artifacts and materials and discussions in the PLC group, he received more resources to make sense of CT. He could also actively provide suggestions to his
colleagues (Meeting 9, July 15, 2020); also, Owen praised CT as ‘‘tangible’’ and that it made things clearer and easier later. (Interview, March 13, 2020) Owen changed his perceptions of CT and this reflected his ongoing sensemaking.

5.1.6 Focused on and by Extracted Cues

The findings showed that teachers made sense of CT by specific cues as crucial and representative properties (Weick et al., 2005). Weick et al. (2005) claim that individuals focus on some points and these points suppress others when people are making sense. In the findings, rather than focus on the four pillars of CT, Owen especially focused on the algorithm. He said that ‘‘because for me as of now, the last part is the one that will last longer with me. But the front three parts, I was slow to see the importance of these three parts.’’ (Interview, March 13, 2020) Since Owen also taught CPA (See Table 1), he used the software ‘‘Scratch’’ to teach flowcharts. (Interview, March 13, 2020) This could explain why he was familiar with the algorithm. His focus on the algorithm suppressed other pillars in CT. He was slow to see the importance of other parts not because the other parts were not important, but because he made sense of CT by making sense of the algorithm first. On the bright side, Owen found it easier to get familiar with CT because he understood the algorithm well. Conversely, he might focus too much on the algorithm and then make less sense of the other pillars. Spillane et al. (2006) claimed that institutions provided resources for teachers to make sense but also constrained sensemaking. In terms of one of the CT worksheets, Robert made it according to a demo lesson. The worksheet in this lesson was made by a university expert. Robert referred to the worksheet to make a simplified one. The expert’s worksheet provided sources for Robert to make sense of and then he designed the new one. It was the same for
Owen. The advantage was that Robert could more easily craft the worksheet based on the expert’s one. However, since Robert focused on the expert’s worksheet, it might “constrain” his sensemaking (Spillane et al, 2006). If Robert did not refer to the expert’s worksheet, he might have a better design or different ways to craft the worksheet because he knew his students better and knew what resources could be applied to it in school. The focus might limit teachers’ imagination and creativity.

5.1.7 Driven by Plausibility rather than Accuracy

Teacher sensemaking was driven by plausibility rather than accuracy. Weick et al. (2005) posit that sensemaking is “not about truth and getting it right. Instead, it is about continued redrafting of an emerging story so that it becomes more comprehensive, incorporates more of the observed data, and is more resilient in the face of criticism.” (p. 415) Even though sensemaking is inaccurate, it can still bring positive outcomes. Adam mentioned that students did not like CT+math lessons because they needed to write a lot of words. (Interview, April 24, 2020) Luttenberg et al. (2009) claimed that sensemakers considered “the perception of the situational demands that are inherent to innovations” (p. 446). Adam considered the situational demands which were about the feedback of students. In order to help students get familiar with CT, Adam allowed them to write fewer words. It was not “accurate” because CT worksheets required students to explain answers in detail. However, the adjustments by Adam helped students engage more in CT+math lessons for positive outcomes.

The sensemaking from Kevin and Helen also showed how teacher sensemaking was driven by plausibility rather than accuracy. Sensemaking is aiming to adapt new insight into present beliefs and knowledge (Van Veen & Lasky, 2005).
The findings indicated that teachers tried to find suitable topics that could fit the four pillars of CT. However, it was difficult to do that. As such, Kevin decided to apply one or two pillars of CT only and it worked. In his present beliefs and knowledge, he thought the idea of CT was good. He did his best to follow the four pillars of CT and applied them to the worksheets. However, after he was exposed more to CT, the new insight influenced him to make some adjustments (Interview, April 20, 2020). Sensemaking provides individuals with appropriate and practical mapping skills for coping with ambiguity to have a better understanding of the conditions and then enact more sensible and effective actions (Ancona, 2012). Kevin understood that CT was good for students so he decided to maximize the use of CT by applying fewer pillars. This indicated that he used a plausible and sensible way to utilize CT.

Regarding Helen, Owen addressed the issue of time after her presentation. As such, the insight from him allowed her to make sense of the situation. (Meeting 9, July 15, 2020) As a result, Helen decided to change her lesson plan plausibly. The modified lesson was not as ‘‘accurate’’ as the original one because students were supposed to finish the worksheet in the lessons rather than do it at home. The above demonstrated the findings related to the literature that teacher sensemaking was driven by plausibility rather than accuracy.

5.2 Actors that Enabled and Constrained Teaching Sensemaking and then Influenced the Practice of CT

Based on the transcripts of teacher interviews, transcripts of meetings, and teaching artifacts, actor-network theory was applied to identify four major actors. This section discusses how the actors enabled and constrained teacher sensemaking and then influenced the practices of CT. Fenwick and Edward (2010) emphasize that ANT is about
“interpreting” rather than “representing” education. As such, the data were interpreted based on the research paradigm and the research context of this study. The findings identified that different actors enabled and constrained teacher sensemaking and then influenced the practices of CT. The actors included the exam-oriented culture in Singapore, the way of teaching and learning CT+math lessons, the suitability of mathematics topics, and the arrangement of teacher duties.

5.2.1 The Exam-oriented Culture in Singapore

The findings indicated that student expectations, teachers’ attitudes towards examinations, and the CT assessment constrained teacher sensemaking and then influenced the practices of CT. Chase (2016) asserted that the social context of teachers importantly affected how they interpreted and implemented educational innovations in their practice. The education system in Singapore emphasizes exams (Cheah, 1998, as cited in Wong et al., 2020). The findings indicated that both students and teachers highly valued exams. Kevin mentioned that students did not engage in CT+math lessons after they knew it was not examinable. (Interview, April 20, 2020) Robert asserted that effective teaching of CT was that students could answer exam questions. Both Don and Robert accentuated the importance of national exams (Meeting 4, February 27, 2020). This could also explain why teacher sensemaking was influenced by the CT assessment. It was because teachers had to have a suitable assessment of CT in order to see if students learned it well or not. Also, teachers were trying to connect CT to the national exams as they mentioned in meeting 4. The above-mentioned examples reflected that when they were making sense of CT, they would think of exams. Berman and McLaughlin (1978, as cited in De Voto & Thomas, 2020) identified that cultural perspective drastically influenced how individuals made sense of and implemented innovations and tools. The culture of Singapore accentuates examinations. The teachers in this study had to consider examinations because they are an utmost important part of
education in Singapore. Students need good results in order to get into university while teachers are expected to help students get good results. As such, this constrained teachers’ sensemaking because they could not avoid considering examinations when they made sense of CT. They eliminated the possible ways of teaching CT that were not related to the examinations.

As the exam-oriented culture in Singapore constrained teacher sensemaking, it influenced the practices of CT. In the first two months of the project, Kevin insisted on applying all four pillars of CT. However, after he found that students were not interested in non-examinable CT, he decided to apply CT without using CT worksheets in some classes (Interview, April 20, 2020). As such, Kevin applied CT for S3 classes without using any worksheets in order to subsume CT into content and let students know it was related to the examinations. Chase (2016) pointed out that national narratives influenced teachers’ sensemaking of policy messages. Dan mentioned that the CT+math lessons should focus on the revision for national exams. (February 27, 2020) This indicated that he preferred to connect CT with national exams in his teaching practice. The above-mentioned cases indicated that the exam-oriented culture in Singapore influenced teachers’ implementation of CT.

5.2.2 The Way of Teaching and Learning CT+math Lessons

The findings showed that using worksheets for CT+math teaching constrained teacher sensemaking but the understanding of the four pillars of CT, students’ feedback, and students’ fear of learning from mistakes enabled teacher sensemaking.

Using Worksheets for CT+math Teaching

Using worksheets for CT+math teaching, as an actor, constrained teacher sensemaking. This study aligns with Spillane et al.’s (2006) claim that institutions can provide resources for teachers to make sense but can also constrain sensemaking. The CT worksheets created by past members of the PLC group were the main resources for teacher
sensemaking. Robert firmly told his colleagues that they were going to repackage what they had already done. (Meeting 1, January 16, 2020) The goal stated by Robert highly influenced teacher sensemaking of CT because teachers knew that what they were going to do in the PLC group was to refer to the previous worksheets and make new ones. They were not expected to do extra things but to focus on the design of CT worksheets. The expected way, which was using worksheets for CT+math teaching, constrained teaching sensemaking.

The findings showed that constrained sensemaking influenced the practices of CT. Throughout the 9 meetings (See Table 2), teachers focused all the discussions on making CT worksheets. They discussed what topics could be integrated into CT (Meeting 2 to Meeting 4) and presented CT worksheets (Meeting 5 to Meeting 9). This reflected that they did not discuss other approaches of teaching CT+math lessons without using worksheets. Even though teachers realized the problem of CT worksheets, they still did not try to think of other ways to teach CT. In meeting 3, Kevin told Robert about his impression of CT:

1 Kevin: Our CT worksheet[s] tend to give me the impression [that] students sit down [first]. [Then we ask them to] do [worksheets]. [Then they start to] find [a] pattern….maybe my understanding is wrong.

2 Robert: You discovered it. (Meeting 3, February 14, 2020)

The conversation reflected that both Kevin and Robert realized the problem of CT worksheets. However, they did not discuss this problem and share their view with other teachers in the later meetings. They kept focusing on crafting CT worksheets without
discussing other possible ways to teach CT+math lessons. The above-mentioned examples indicated that constrained sensemaking influenced the practices of CT.

**The Understanding of the Four Pillars of CT**

The understanding of the four pillars of CT enabled teacher sensemaking. Allen and Penuel (2015) found that teachers were confused by the ambiguity and uncertainty derived from educational innovations. The findings align with part of their study. They clearly showed that teachers encountered ambiguity, uncertainty, and difficulties because they did not understand the concepts of CT well. For example, Owen understood the algorithm well but he was not familiar with the other three pillars. (Interview, March 13, 2020) Helen also told other teachers that she had difficulties in creating a CT worksheet. (Meeting 6, June 10, 2020) As such, teachers were motivated to make sense of more of the pillars that they did not understand well. For instance, Helen had to ask for help and comments in order to make the CT worksheet. These actions allowed her to engage in enabled sensemaking.

The findings showed that enabled sensemaking influences the practices of CT. Teachers had to ask more questions during the meetings in order to get help from others. The frequency of social sensemaking consistently increased over the 9 meetings (See Table 7). Table 7 reflects that after teachers got used to the routine scheduling of the meetings (e.g., the mode of meetings, better relationships), more social sensemaking occurred. The frequency of social sensemaking depended on the interaction between teachers. As such, unlike what Allen and Penuel (2015) asserted, ambiguity and uncertainty constrained teacher sensemaking. Ambiguity and uncertainty enabled teacher sensemaking because teachers were stimulated to ask more questions in order to make sense of the innovation.
### Table 7

*Frequency of Social Sensemaking in 9 Meetings*

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*Students’ Feedback and Students’ Fear of Learning from Mistakes*

Students’ feedback and students’ fear of learning from mistakes enabled teacher sensemaking. Chase (2016) claimed that the perception of the target population influenced teacher sensemaking. The findings showed that students were the target population of teachers. The PLC group integrated CT with mathematics in order to teach students problem-solving skills (Meeting 1, January 16, 2020) and benefit their examinations. (April 25, 2019) Gadanidis et al. (2018) found that CT tools brought an innovative experience for students to learn. Teachers, parents, and students responded positively to this method of learning mathematics. However, the students in this study did not enjoy CT+math lessons. Adam mentioned that students did not like it because they needed to write a lot of words instead of writing numbers (Interview, April 24, 2020) As such, teachers had to consider the feedback of students when they were making sense of CT because the teaching would be ineffective if students were not engaging in the classes. Students also avoided making mistakes when they were working as a group. Owen mentioned that students did not dare to make mistakes in front of their classmates. Some of them even gave up answering the questions. (Interview, March 13, 2020) The feedback and reactions from students influenced teacher sensemaking. Teachers had to consider how they could respond to the students.
Due to the students’ feedback and students’ fear of making mistakes, teachers adjusted their practices of CT. Adam decided to allow students to write in point form or in a few words. He said:

Most of my students struggle with writing words and explaining. They focused on just getting the correct answer[s]. So what we had to do was to try to minimize the writing… [We try to] get them to think [and] explore more and know that it is not the correct answers that matter… (Interview, April 24, 2020)

This reflected students did not want to write words or they did not want to repeatedly try to answer questions because they wanted to get correct answers as fast as possible. The findings align with what Erdogan et al. (2014) stated that students perceived mathematics as a figure with a single correct answer. Then Adam decided to minimize the writing in order to give students more thinking time. He even decided to let students type on the computers:

… I would say [that] we tried different methods and [brought] the whole worksheet into an ICT platform. [It] is actually quite useful… because it gives them [less] writing. They do not need to write much and they do not feel [that] they are writing but actually they are typing, right? So it is actually the same. But at least they do not feel like they are doing a lot of words but they are spending more time thinking. So that was more important. (Interview, April 24, 2022)

After Adam allowed students to type the answers on the computers, they did not feel that they were writing with their hands but typing which helped them feel better. Moreover, Adam knew students were shy to show their answers to others because
they thought they might not answer questions correctly. As such, Adam applied other computer tools with CT+math lessons. He first hid students’ names and then showed their answers on the screen. (Meeting 4, Feb 27, 2022). He found that some students answered well and they did not feel shy to show their answers because their names were hidden. Students engaged more in the lessons after the adjustments of these CT practices.

5.2.3 The Suitability of Mathematics Topics

The findings indicated that the compatibility and levels of mathematics topics enabled teacher sensemaking. The findings showed that it was difficult to find mathematics topics that were compatible with CT. In meeting 1, Robert clearly stated that CT only worked with specific topics. They needed to take a lot of time to create CT worksheets. (January 16, 2020). Later, they spent three meetings (See Table 2) in total in order to choose compatible topics. This reflected that teachers coming up with suitable topics with CT was time-consuming and difficult. This influenced teacher sensemaking because it increased the difficulty for teachers to make sense of CT since not every topic was compatible. Moreover, the findings demonstrated that when teachers were selecting mathematics topics for integrating CT, they considered the levels of the topics as well. Adam stated that the first thing to consider was the difficulty of the content (Interview, April 24, 2020) and Owen had the same thought. (Interview, March 13, 2020) The levels of the content influenced teacher sensemaking because teachers thought that if topics were too simple, it was not worth spending too much time on them. Owen gave an example of the ‘‘easy’’ topic which was prime numbers. (Interview, March 13, 2020) The compatibility of mathematics topics and the levels of the mathematics topics enabled
teachers’ sensemaking because they had to contemplate how to optimize the application of CT if they wanted more students to learn CT.

The findings showed that the compatibility and levels of mathematics topics enabled teacher sensemaking and then influenced practices of CT. Fenwick and Edwards (2014) assert that “demands and needs” from non-human entities can affect human “intentions, meanings, relationships, routines, memories, and even perception of self” (p. 24). The “demands and needs” of CT were compatible mathematics topics. Kevin was affected by the “demands and needs” of CT so he decided to flexibly apply CT+math. Kevin decided to utilize one or two pillars of CT only because he believed that this could optimize the application of CT. (Interview, April 20, 2020) As such, teachers could apply CT much easier because it was hard and time-consuming to find mathematics topics that fitted all the four pillars of CT. Also, they could apply CT on easier topics because they did not have to spend too much time crafting a worksheet so they would not think it was not worth using CT. This gave incentives to teachers to apply CT in different levels of topics which allowed teachers to adopt alternative practices of CT.

5.2.4 The Arrangement of Teacher Duties

The findings showed that teachers taught different forms and teachers’ limited time constrained teacher sensemaking.

Teaching at different levels

Teaching at different levels constrained teacher sensemaking. The findings showed that four teachers taught S1 and two teachers taught S2 (See table 1). They were responsible for designing S3 worksheets but none of them had experience in teaching S3 CT+math lessons. Kevin (Interview, April 20, 2020) and Adam (Interview, April 24, 2020) both
mentioned that they did not know who they could ask since they were teaching at different levels and no one had experience in teaching S3 CT+math lessons. Allen and Penuel (2015) identified the sources of ambiguity and uncertainty derived from educational innovations which include conflicting goals, absence of measures, and lack of resources. Since there were not any S3 CT+math worksheets in schools for references, teachers lacked the resources to make sense of CT which constrained their sensemaking. The ambiguity and uncertainty were derived from the lack of resources in this case which were the lack of worksheets as well as the lack of human resources in the PLC group. In the PLC group, 4 teachers taught S1 and 2 teachers taught S2 (See table 1). Robert was the only teacher that had S1+S2 CT teaching experience. This constrained teacher sensemaking as well. Teachers could only ask him for previous experience of CT because others were still unfamiliar with it.

The constrained sensemaking influenced teachers’ practices of CT. The existing literature has identified that actors, such as teacher attitudes, beliefs, and institutional actors (Ketelaar et al., 2012; Lawrence & Tar, 2018) influence teacher implementation of innovations. The decision of the institution influenced the enactment of CT. Adam asserted that he had to guess students’ responses and reactions when he was creating S3 CT worksheets. His practices could reflect that others might have the same challenges as well since all the teachers had no experience in teaching S3 CT. Guessing was the best they could do. Moreover, Kevin addressed the situation explicitly:

The PLC group is only me and Robert [that are teaching] the S2. Then the rest of them are [teaching] S1. So, it is a bit hard for us to check with the rest and I don’t need [to] ask them how it is like. [Because] they can only give us more or less this idea but it may not be relevant when it comes to applying S2 topics. (Interview, April 20, 2020)
This showed that Kevin did not ask other teachers S2 questions apart from Robert. Throughout the 9 meetings, the findings indicated that Kevin only discussed CT practices of S2 with Robert (e.g., Meeting 2, Jan 30, 2020) because he was the only CT experienced teacher. The practices of CT were influenced by constrained sensemaking.

*Teachers’ time*

Teachers’ time constrained teacher sensemaking. Ghavifekr et al. (2016) stated that the actions of teachers are often time-sensitive. Teachers in this study were concerned about their time as well. The findings showed that Owen interrupted Helen’s presentation because he thought that a part of her worksheet was too lengthy. (Meeting 9, July 15, 2020) The schedule of teachers was tight as they had different tasks other than the PLC group (Meeting 4, February 27, 2020). As such, teachers had to consider their limited time when they made sense of CT. They might avoid doing more time-consuming work. This constrained their sensemaking on CT.

Teachers’ time constrained their sensemaking and then influenced their practices of CT. Due to the time limit, teachers had to be careful in the allocation of time. Owen interrupted Helen’s presentation by asking how long it would take to teach the section on decomposition. Initially, Helen decided to do all parts during the lessons. However, she changed her decision immediately after the question asked by Owen. She suggested that teachers could give the section on decomposition to students as homework. Adam also changed his practice because of time concerns. He explained why he redid the CT worksheet:

> Because the previous time when I did it, I focus[ed] a lot on just one test only so I want[ed] to create one worksheet for one test. Then I kind of thought about what Dan said that [it was not] feasible because it really [took] a lot of time … (Meeting 9, July 15, 2020)
Adam was creating a CT worksheet regarding the four tests of congruency. At first, he wanted to create one worksheet for one test which meant he had to create four worksheets for four tests. However, due to the consideration of time, Dan told Adam that it was not ‘feasible.’ As such, Adam gave up the original plan. The examples above clearly showed that teachers’ limited time constrained teachers’ sensemaking and then influenced their practices of CT.

5.3 Implications for Practice and Recommendations for Future Research

This study revealed seven mathematics teachers made sense of CT in Singapore. Through the collection of worksheets, transcripts of meeting observations, and transcripts of teacher interviews, this study explored the seven properties of sensemaking of teachers. Also, through the lens of ANT, four major actors that enabled and constrained teachers’ sensemaking and influenced their practices of CT were identified. According to the findings and the discussions, this section will provide implications for schools, policymakers, and teachers who want to implement CT+math in schools, and will provide some suggestions for future research as well.

5.3.1 The Insights from the Development of CL

The four principles of CL were reflected within the findings although the CT+math project was in a preliminary stage. As such, the potential for the development of CL is huge. The future direction of CT practices based on the insights from the development of CL will be discussed.

Re-mediation

Re-mediation accentuates the core of literacy is the mass application of a representational system (diSessa, 2018). The implementation of the four pillars of
CT indicated a new representational infrastructure (Kaput et al., 2002) for mathematics. Barr and Stephenson (2011) posited that the foundational transformations of conventional teaching required a combination of computer science and mathematics, which could guide the way to produce a dependable pedagogical method established on CT. Teachers applied an unplugged approach (Grover & Pea, 2013) in this CT+math project. According to Bell and Vahrenhold (2018), unplugged approaches may be less intimidating to teachers who do not have a background in CS or programming. The findings indicated a positive aspect was that teachers did not show any fear towards the unplugged approach of CT in meeting 1 (January 16, 2020) when they expressed their impression of CT. diSessa (2018) argues for the use of computational medium because “computation seems almost an ideal representational system in which to study mathematics” (p. 17). This reflects that the computational medium can highly influence student learning. In this study, Adam was the only teacher that used computers to teach CT+math lessons. For example, he let students type the answers on computers (Interview, April 24, 2020) and hid their names through computers (Meeting 4, Feb 27, 2022). As a result, students engaged more in the lessons. Therefore, schools, policymakers, and teachers should consider how they make use of the computational medium when they enact CT. It should be noted that as the findings showed that not every mathematical topic was ideal for integrating with CT, it will be plausible and sensible that schools, policymakers, and teachers consider different approaches, such as the unplugged approach, unplugged + plugged approach, or plugged approach when they are integrating CT+math. Considering more approaches means that teachers have a greater chance to integrate CT with more mathematical topics.
Reformulation

The insights from this principle show the challenges of enacting CT and how stakeholders can better implement CT. The findings indicated that teachers changed their ways to teach mathematics, CT helped achieve cognitive simplicity and they considered different ways of thinking about each domain and how learners understood different domains (diSessa, 2018). Both teachers and students were not familiar with the changes. Helen asked for help and comments (Meeting 6, June 10, 2020) and students wanted to get correct answers as fast as possible rather than working on them with groupmates. (Interview, March 13, 2020) The insights from these are that teachers should be ready for these challenges. diSessa (2018) accentuates that reformulation can bring “very substantial changes in what, when, and how we teach subject matter.” (p. 36) Teachers and students need time and patience to adapt to these substantial changes. The findings from ongoing sensemaking showed that teachers adapted to the changes and had different perceptions of CT through ongoing learning and more exposure to CT (e.g., Kevin and Owen). Students engaged more in lessons after the adjustment of the practices. (Meeting 4, Feb 27, 2022) Schools, policymakers, and teachers should consider how they can optimize the use of CT in order to achieve cognitive simplicity for students. For example, Kevin applied one or two pillars of CT so that he could apply it to more topics, including easy and difficult topics. (Interview, April 20, 2020) It should be noted that if teachers learn different ways of thinking about each domain and how learners understand different domains, teachers will have more resources for sensemaking (e.g., retrospective sensemaking) as well so they can better enact the practices of CT.
Reorganization

diSessa’s Reorganization of the intellectual terrain and cultural change demonstrate how landmark documents may change and how people may perceive mathematics in the future. diSessa (2018) states that “a reorganized intellectual terrain will show up in new landmark documents (textbooks, or newer and very different interactive forms).” (p. 37) The findings indicated that some textbooks included the content of CT and the syllabus of the MOE mentioned CT as well. This was a good sign because it was showing that the intellectual terrain was reorganizing. Teachers in this study did not have enough resources to make sense of designing S3 CT worksheets as Adam asserted. (Interview, April 24, 2022) As such, schools, policymakers, and teachers can explore if there are new or existing landmark documents for references if they do not have certain school-based resources. Also, they can contribute to the new landmark documents as well through giving feedback to the publishers of textbooks or joining related events of CT that are held by the MOE.

The findings also indicated the cultural changes. Erdogan et al. (2014) stated that students perceived mathematics as a figure with a single correct answer. Students in this study expected they answered mathematical questions in numbers without many words. (Interview, April 24, 2020) They also wanted to get correct answers as fast as possible rather than do them collaboratively. (Interview, March 13, 2020) The practices of CT led to small steps of cultural changes because students had to answer in detail with words and did worksheets with groupmates during lessons. These ways were different from what they expected because they perceived mathematics answers were numbers without many words since they
learned maths. As such, schools, policymakers, and teachers should prepare well for cultural changes so that teachers and students can get familiar with them easier. For example, schools can provide teachers with training on how they can help students face cultural changes and what they should do during cultural changes. They can also promote the cultural changes by addressing their advantages and both teachers and students can be ready for the changes.

*Revitalization*

Revitalization will help revitalize engagement, interest, and equity in classrooms (diSessa, 2018). The CT+math project was still in the preliminary stage. Therefore, teachers only needed to officially teach a few S1 and S2 classes. But Kevin tried to promote CT to other classes, so he taught CT+math lessons to an S3 class as well. (Interview, April 20, 2020) He simplified CT by only applying one or two pillars rather than all four pillars of it. The findings showed that teachers had to spend much time fitting all four pillars of CT with mathematics topics. As a result, they found that not every topic was compatible with CT and even preferred difficult topics only as they had to save time. (Interview, March 13, 2020) So, the insight from Kevin’s act is that schools, policymakers, and teachers should consider how they can universalize CT learning in schools. Teachers do not need to necessarily follow what previous members did to develop CT+math lessons. For example, the findings indicated that teachers had to use worksheets to teach CT (Meeting 1, January 16, 2020) which constrained teacher sensemaking. The goals of the PLC group should encourage teachers to think outside of the box as Kevin did. When it comes to promoting distinctive and significant engagement in computational and scientific activities, real-life relevancy is important (Blikstein, 2013; Ryoo et al.,
2013). Through the collection of artifacts, transcripts of meetings and interviews, the findings showed that CT worksheets did not connect any real-life relevancy. This could also explain why students did not engage in classes. Therefore, schools, policymakers, and teachers should consider real-life relevancy when they are preparing teaching materials.

5.3.2 The Other Implications

Schools should provide workshops or training for PLC groups. The findings indicated that the members of the PLC group kept changing. Only Robert attended the CT+math workshops. As such, other teachers mainly relied on Robert if they had questions regarding the teaching practices of CT. However, although Robert could still share what he learned in the workshops with the group, the problem was that the knowledge and information of the workshops had been filtered by him. For example, Robert simplified the worksheets of the university expert. (Meeting 1, January 16, 2020) According to Darling-Hammond et al. (2017), teacher professional learning is important to support teaching practices and student outcomes. Teachers may lose the opportunity to know original goals and see original teaching materials of CT in the workshops if they do not join them. They can only see the contextualized products. Therefore, schools and policymakers should provide systematic and comprehensive workshops and training for teachers in PLC groups. Also, Robert, as the only CT experienced teacher in the group, the findings showed that his CT teaching experience allowed him to make sense easily and pertinently. Undoubtedly, experienced teachers can share their experiences with colleagues. But it will be much better if PLC groups can learn more in workshops or training.
Schools should arrange teaching duties appropriately. Only two teachers taught CT+math lessons to S2. The rest taught S1. The problem was that teachers who taught S2 might have inadequate support. For example, when Kevin wanted to know how the other S2 students’ feedback, he could only ask Robert because he was teaching the same form. (Meeting 2, Jan 30, 2020) Conversely, Adam, Owen, and Helen could share their practices with one another in order to get more sources for sensemaking. As such, it will be better to have a balanced number of teachers to teach each form. For instance, schools can arrange three S2 teachers and three S1 teachers. In the study, teachers were also designing S3 worksheets, but no one taught S3 CT+math lessons before and present. Without teachers teaching CT+math lessons to S3 students, teachers could only guess what students’ reactions were as Adam said. (Interview, April 24, 2020) As such, it might largely influence the design of the lessons because teachers could not adjust worksheets or lessons based on the students’ feedback. Therefore, schools and policymakers should have better arrangements when they start PLCs. They have to consider that each form has enough teachers so they can discuss the practices of CT with one another because social sensemaking is prevalent and crucial for teacher sensemaking.

Schools and policymakers should give autonomy to PLCs group in order to shape their sensemaking. The findings indicated that Robert was an open-minded leader. Irene did not intervene in the content too much and let her colleagues decide most of the implementation. Allen and Penuel (2015) identified that school-specific instructional management practices played an important role in shaping teacher sensemaking. Teachers served as sensemaking resources for one another. This study is one of the examples that showed how teachers helped one another make sense.
Robert was open-minded so he enabled his colleagues to be glad to express their thoughts. Their interactions provided one another more sources to make sense then enabled their sensemaking. Therefore, giving autonomy to the group members of PLC groups is of utmost importance.

Teachers should think outside of the examinations. In an exam-oriented educational system, teachers consider a lot about the examinations. The findings demonstrated how exam-oriented culture constrained teacher sensemaking. They usually mentioned examinations. (e.g., Robert and Dan) When teachers focused a lot on examinations, their sensemaking was constrained. For example, Dan suggested that CT worksheets should relate to national exams (Meeting 4, February 27, 2020) when teachers were crafting them. As the findings indicated that sensemaking by “focusing on and by extracted cues” had its limitation, too much focus on examinations will constrain teachers’ implementation of CT, such as not using ways of teaching that are not related to examinations or not using ways of teaching that are difficult to be assessed. As such, schools and policymakers should encourage teachers that think outside of examinations. This will stimulate them to think of more ways to implement CT. At the same time, teachers should also remind themselves to think beyond examinations and make a balance between learning and examinations.

5.3.3 Limitations and Directions for Future Research

This study had its limitations but still provided researchers with insights for future research. First, a few math teachers who took part in this study might make it difficult to generalize the findings. There were 7 teachers in the PLC group. But two of them joined late and the HOD did not focus much on the content of CT. Also, only two teachers taught S2
students. It would be better if schools in future research can have adequate teachers to teach at each level. Or the future research can focus on one level with different classes. As such, researchers can see how teacher participants make sense of CT if they have more support from others.

Second, the model of instruction and teachers’ regular meetings were adapted to take place online because of COVID-19. At first, teachers held five on-site meetings but teachers must stop them because of the suspension of schools in Singapore. As such, the interaction, conversation, and motivation of teachers during the meetings might differ from normal in-person circumstances. The students’ reactions and feedback might differ in normal school life as well. Therefore, future research can conduct similar research after the pandemic.

Third, to my knowledge, this study is one of the very few studies that explore CT by using the concepts of sensemaking, ANT, and CL. Since studies in sensemaking are mainly in North America (e.g., Chase, 2016; de los Santos, 2017; Schein, 2009), this study provides an example that is explored in one of the Asian countries. As such, more research in Asia is encouraged, such as in China, Korea, Thailand, and Japan. Since different countries have different cultures and educational systems, similar research in more countries can give a better and more comprehensive picture of how teachers make sense of CT, what and how actors influence their sensemaking, and how the development of CL is. Replication studies are especially welcome because they can lead to findings that are robust and generalizable (Porte & McManus, 2019).

Fourth, the CT project of this school in Singapore was applying an unplugged approach (Grover & Pea, 2013). The finding indicated that students did not enjoy this approach because they needed to write a lot of words on worksheets that do not align with previous studies that CT has a positive influence on student engagement (e.g., Passey, 2017). One of the possible reasons to explain it is that this CT project was using the unplugged
approach although it was still related to concepts of coding, while those previous studies were computer-based CT. As such, future research can explore how teachers make sense of other approaches, such as plugged approach and plugged + unplugged in Asian countries.

Last, the CT of this project was at a preliminary stage, future studies can focus on PLC groups that are at a more mature stage. The teachers in the PLC group kept changing every year. The group only had three levels of worksheets (S1, S2, and S3). Teachers were crafting S3 worksheets in this study and past members of the group made S1 and S2 worksheets in previous years. Also, only a few classes learned CT+math lessons. This study indicated how teachers made sense of CT during the project’s preliminary stage. As such, future research can explore how teachers make sense of CT at the mature stage. The “‘mature stage’” is perceived as schools that have three years or more experience in running a CT project, CT+math lessons are learned from many classes routinely rather than learned by a few classes, and teachers have systematic learning opportunities for making sense of CT. The findings showed that “‘social sensemaking’” and “‘retrospective sensemaking’” were the most prevalent sensemaking in meetings and interviews. It will be interesting to see if there will be different results in other stages of CT projects in order to give pertinent suggestions.

5.4 Conclusion

To conclude, sensemaking is a valuable concept to explore the reasons for teachers having a wide range of differences in perception and understanding of the same educational innovations. There is little research that has shed light on the thorough process of teacher sensemaking of curriculum innovations. Also, no one attempts to combine “‘sensemaking’” and ANT to examine actors that influence teacher sensemaking toward curriculum innovations. Moreover, diSessa (2018) states that CT can be a new form of literacy in education today. This qualitative research explored how seven mathematics teachers at the
school in Singapore made sense of integrating CT into the mathematics curriculum. This study employed a case-study design with 7 teachers during the 2019-2020 school year using the worksheets, transcripts of meeting observation, and transcripts of teacher interviews. The findings indicated teachers’ seven properties of sensemaking in detail. This study offered a comprehensive picture that included actors that enabled and constrained teacher sensemaking and then influenced the practices of CT in a specific setting. Based on the insights from the development of CL and other findings, I pertinently provided implications and suggestions to schools, policymakers, and teachers that are going to implement CT. These findings are important to support continuing professional development because they can indicate the roles and importance of PLCs so researchers and educational sectors can improve or adjust their practices in PLCs based on the findings. It is also useful for educational researchers, practitioners, and governments to understand teachers’ thoughts and needs when they encounter new educational innovations so that they can pertinently support teachers and implement the innovations confidently and smoothly. Finally, as this study specifically examined teacher sensemaking in CT+math lessons, schools, policymakers, and teachers that are implementing or will implement CT+math in their lessons will benefit from it because they can explicitly see the challenges, obstacles, and processes of implementing CT+math lessons. Then, they can have a better picture of how to implement the lessons so their students can learn mathematics more interestingly, more productively, and more easily.
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## Appendices

### Appendix A

**The Open Coding’s Codebook for Actors that Enabled and Constrained Teacher Sensemaking**

<table>
<thead>
<tr>
<th>Open Code</th>
<th>Definitions</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>If teachers are familiar with CT artifacts</td>
<td>Teachers’ understanding of CT worksheets or other teaching materials</td>
<td>“If as an educator or a teacher, we cannot answer this, then the crafting of the worksheet has no meaning because we can't even understand.” (Interview, April 20, 2020)</td>
</tr>
<tr>
<td>Not enough teachers teaching the same grade</td>
<td>Enough support or not in teaching CT in each grade</td>
<td>“Because for me the PLC group is only me and Robert and the Sec 2. Then the rest of them are Sec 1 so for us it's a bit hard for us to check with the rest.” (Interview, April 20, 2020)</td>
</tr>
<tr>
<td>No experience in teaching that grade</td>
<td>Teaching experience</td>
<td>“the challenge that I face to it, for this part is, because I don't teach Sec 3s at the moment…” (Interview, April 24, 2020)</td>
</tr>
<tr>
<td>Refuse to learn things that are not examinable</td>
<td>If students are willing to learn</td>
<td>“there'll be majority or even some of them refuses to know and to them is an extra thing where it's no examinable…” (Interview, April 20, 2020)</td>
</tr>
<tr>
<td>Students are not familiar with CT</td>
<td>If students are comfortable with learning math with CT</td>
<td>“But they [students] don't know how to translate it to writing.” (Interview, March 13, 2020)</td>
</tr>
<tr>
<td>Students have never seen CT before</td>
<td>Students’ experience in CT</td>
<td>“The students have nothing to compare…we just don’t tell them that actually this concept is very simple.” (Interview, March 13, 2020)</td>
</tr>
<tr>
<td>Teachers care about exams</td>
<td>Discuss exams, Focus on exams</td>
<td>“We should focus on generalization, workflow, and revision for national exams...” (Meeting 4, February 27, 2020)</td>
</tr>
<tr>
<td>Content is too easy</td>
<td>Not worth using CT</td>
<td>“It's, it's something not so easy to understand...” (Interview, March 13, 2020)</td>
</tr>
<tr>
<td>Don’t dare to make mistakes</td>
<td>Afraid of answering questions</td>
<td>“They don't dare to make mistakes.” (Interview, March 13, 2020)</td>
</tr>
<tr>
<td>Different from what they previously taught</td>
<td>Teachers used other ways to teach</td>
<td>“When it comes to actually carrying this out, the different processes then it let me to think more.” (Interview, March 13, 2020)</td>
</tr>
<tr>
<td>if the content is difficult</td>
<td>Worth to use CT</td>
<td>“Difficulty of the content.” (Interview, April 20, 2020)</td>
</tr>
<tr>
<td>Focus on the CT assessment</td>
<td>Discuss CT assessment</td>
<td>“How to do evaluation when the CT lessons are implemented to all classes?” (Meeting 1, Jan 16, 2020)</td>
</tr>
<tr>
<td>Use other ways to teach math</td>
<td>Teach math differently</td>
<td>“I can highlight, very good point. the question is on their screens.” (Meeting 4, Feb 27, 2020)</td>
</tr>
<tr>
<td>The original way of thinking about math</td>
<td>How to think math before teaching CT</td>
<td>“We are very used to the rigor of logical thinking.” (Interview, April 24, 2020)</td>
</tr>
<tr>
<td>Curious about the assessment of other CT-related subjects</td>
<td>Assessments that relate to CT</td>
<td>Owen and Adam noted that they do something similar in CPA (Meeting 1, Jan 16, 2020).</td>
</tr>
</tbody>
</table>
| if the content fits CT | Need to find topics that fit CT | “[It] depends on the content… is it easy for
<table>
<thead>
<tr>
<th>The way teachers designed worksheets</th>
<th>How teachers craft CT worksheets</th>
<th>“I purposely write at the start, I would define the things that they might forget, so that we set the context right.” (Meeting 4, Feb 27, 2020)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time limit</td>
<td>Teachers concern time</td>
<td>“One is time and as usual it definitely needs time.” (Interview, July 9, 2020)</td>
</tr>
<tr>
<td>Workload in PLC</td>
<td>Tasks in the PLC group</td>
<td>“This is really wordy.” (Interview, April 24, 2020)</td>
</tr>
<tr>
<td>If CT can help answer questions on exams</td>
<td>If CT is good for exams</td>
<td>“Answer questions on the exam.” (Interview’s note, April 25, 2019)</td>
</tr>
<tr>
<td>Spend too much time on one part</td>
<td>Teachers feel Time-consuming</td>
<td>“I see the decomposition part may take some time…” (Meeting 9, July 15, 2020)</td>
</tr>
<tr>
<td>Too many pages to teach a topic</td>
<td>Spend more time teaching than before</td>
<td>“But actually we took about six pages.” (Interview, March 13, 2020)</td>
</tr>
<tr>
<td>Focus on getting correct answers</td>
<td>Students want to get the right answers</td>
<td>“Focused on just getting the correct answer.” (Interview, April 24, 2020)</td>
</tr>
<tr>
<td>Students are afraid of CT</td>
<td>Don’t want to learn CT+math</td>
<td>“Because the feedback we got from the S2 was that they're very scared of computational thinking.” (Interview, April 24, 2020)</td>
</tr>
<tr>
<td>Not interested in learning non-examinable content</td>
<td>Do not engage in CT+math lessons</td>
<td>“Oh! not examinable? They will shut off and they will just do whatever.” (Interview, April 20, 2020)</td>
</tr>
<tr>
<td>Only apply to specific topics</td>
<td>Not every topic can be integrated with CT</td>
<td>“Specific topics, CT more structured…” (Meeting 1, Jan 16, 2020)</td>
</tr>
</tbody>
</table>
### Appendix B

The Axial Coding’s Codebook for Actors that Enabled and Constrained Teacher Sensemaking

<table>
<thead>
<tr>
<th>Axial Codes</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students’ expectation</td>
<td>What students want to learn</td>
</tr>
<tr>
<td>Teachers’ attitude towards examinations</td>
<td>If teachers care about examinations</td>
</tr>
<tr>
<td>CT assessment</td>
<td>Assessment related to CT</td>
</tr>
<tr>
<td>Using worksheets for CT+math teaching</td>
<td>Worksheets are the teaching material</td>
</tr>
<tr>
<td>The understanding of the four pillars of CT</td>
<td>If they are clear about the concepts of CT</td>
</tr>
<tr>
<td>Students’ feedback</td>
<td>What students tell teachers</td>
</tr>
<tr>
<td>Fear of learning from mistake</td>
<td>Students don’t want to try and they prefer to get correct answers</td>
</tr>
<tr>
<td>The compatibility of mathematics topics</td>
<td>If topics fit CT</td>
</tr>
<tr>
<td>The level of the mathematics topics</td>
<td>If the topics are simple or difficult</td>
</tr>
<tr>
<td>Teachers’ time</td>
<td>teachers’ limited time</td>
</tr>
<tr>
<td>Teaching at different levels</td>
<td>Adequate teachers teach different grades at schools.</td>
</tr>
</tbody>
</table>
### Appendix C

**The Selective Coding’s Codebook for Actors that Enabled and Constrained Teacher Sensemaking**

<table>
<thead>
<tr>
<th>Selective Codes</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>The exam-orientated culture in Singapore</td>
<td>Exam-orientated culture influences teacher sensemaking</td>
</tr>
<tr>
<td>The way of teaching and learning CT+math lessons</td>
<td>New ways for teaching and learning math</td>
</tr>
<tr>
<td>The suitability of mathematics topics</td>
<td>If the mathematics topics are suitable to integrate with CT</td>
</tr>
<tr>
<td>The arrangement of teaching duties</td>
<td>How schools allocate tasks to teachers</td>
</tr>
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</table>
**Curriculum Vitae**

**Name:** Siu Chung Yiu

**Post-secondary Education and Degrees:**

<table>
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<th>Institution</th>
<th>Location</th>
<th>Years</th>
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<td>B.Ed.</td>
<td>The Chinese University of Hong Kong</td>
<td>Hong Kong, China</td>
<td>2011-2015</td>
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