A MODEL FOR THE INTEGRATION OF CRITICAL THINKING IN THE CLASSROOM

MARTÍN FELIPE CÁCERES MURRIE

Thesis submitted to the Office of Research and Graduate Studies in partial fulfillment of the requirements for the Degree of Doctor in Engineering Sciences

Advisor:
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Santiago de Chile, January, 2019
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Santiago de Chile, January, 2019
To Rosario, for her love and support.

To my parents, for giving me the foundations of my thought and action.
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RESUMEN

Alrededor del mundo existe una creciente urgencia por desarrollar sistemas educativos capaces de responder a los desafíos contemporáneos. La implementación de una pedagogía capaz de preparar a los estudiantes a un futuro incierto requiere un cambio paradigma, desde la transmisión del conocimiento a su construcción activa. A pesar del consenso que existe sobre la necesidad de este cambio, existen múltiples desafíos a la hora de implementar este tipo de metodologías en el aula. Por esta razón, la presente tesis propone un modelo para integrar el pensamiento crítico en el aula, entendiendo el pensamiento crítico como el ejercicio y desarrollo de agencia de los distintos actores. El modelo propuesto aborda distintos actores del proceso de enseñanza y aprendizaje y sus respectivas relaciones, desde una perspectiva situada. Los estudios presentes en esta tesis se situaron en el aprendizaje de resolución de problemas por parte de alumnos de primaria, ya que la resolución de problemas es central en las metodologías de aprendizaje del siglo XXI, y existe escasa evidencia acerca de cómo promoverla en edades tempranas. En el nivel de aula se estudiaron dos problemas. En primer lugar, se estudió cómo se puede integrar la argumentación a la resolución colaborativa de problemas para mejorar el aprendizaje en matemáticas. En el nivel de la interacción entre profesores y alumnos, se estudió cuánta guía se debe dar a los estudiantes mientras aprenden a resolver problemas. Por otro lado, se estudió cómo los profesores conceptualizan la implementación del pensamiento crítico en su trabajo diario. Los primeros dos estudios fueron diseñados desde una metodología cuasi experimental, con el objetivo de contribuir con evidencia sobre los problemas que enfrentan los docentes al implementar estrategias innovadoras en las aulas que están alineadas con el aprendizaje del siglo XXI. El tercer estudio tiene un enfoque diferente, más interpretativo, y tiene como objetivo contribuir a cerrar la brecha entre la investigación y la práctica mediante el estudio de la perspectiva de los docentes.

Los principales hallazgos son los siguientes. A nivel de estudiantes, se encontró que incorporar explícitamente la argumentación ayuda al aprendizaje en resolución de problemas. En la interacción entre profesores y alumnos, se encontró que para la resolución de problemas interactivos, es beneficioso entregar retroalimentación menos detallada. Con respecto a la perspectiva de los profesores, se encontró que los profesores
implementan mayoritariamente el pensamiento crítico como una parte integrada a sus disciplinas, equiparando esta habilidad con el aprendizaje profundo de los conocimientos y prácticas de cada disciplina. En su conjunto, estos hallazgos entregan evidencias y recomendaciones acerca de prácticas pedagógicas específicas, basadas en el desarrollo de competencias del Siglo XXI, que pueden ser integradas para enriquecer el aprendizaje, fortaleciendo la agencia de profesores y estudiantes.

Esta tesis contó con el apoyo de los proyectos Fondecyt/Conicyt 1150045 y 1180024.

Palabras Claves: Habilidades del Siglo XXI, Pensamiento Crítico, Diseño Instruccional, Resolución de Problemas, Argumentación, Guía, Retroalimentación, Perspectiva de Profesores, Agencia.
ABSTRACT

Around the world there is a growing urgency to develop educational systems capable of responding to contemporary challenges. The implementation of a pedagogy capable of preparing students for an uncertain future requires a paradigm shift, from the transmission of knowledge to its active construction. Despite the consensus that exists on the need for this change, there are multiple challenges when implementing this type of methodologies in the classroom. For this reason, this thesis proposes a model to integrate critical thinking in the classroom, understanding critical thinking as the exercise and development of agency of the different actors. The proposed model addresses different actors in the teaching and learning process and their respective relationships, from a situated perspective. The studies present in this thesis were situated in the learning of problem solving by primary school students, since problem solving is central in 21st century learning methodologies, and there is scant evidence about how to promote it at an early age. At the classroom level, two issues were studied. First, we studied how to integrate argumentation with collaborative problem solving to improve learning in mathematics. At the level of interaction between teachers and students, we studied how much guidance should be given to students while they learn to solve problems. On the other hand, we studied how teachers conceptualize the implementation of critical thinking in their daily work. The first two studies were designed from a quasi-experimental methodology, with the aim of contributing with evidence on the problems that teachers face when implementing innovative strategies in the classrooms that are aligned with 21st century learning. The third study has a different, more interpretive approach, and aims to help closing the gap between research and practice by studying the perspective of teachers.

The main findings are the following. At the student level, it was found that explicitly incorporating argumentation helps learning in solving problems. In the interaction between teachers and students, it was found that for the resolution of interactive problems, it is beneficial to provide less detailed feedback. Regarding the perspective of the teachers, it was found that teachers mainly implement critical thinking as an integrated part of their disciplines, equating this skill with deep learning of the knowledge and practices of each
discipline. As a whole, these findings provide evidence and recommendations about specific pedagogical practices, based on the development of XXI Century competencies, which can be integrated to enrich learning, strengthening the agency of teachers and students.

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Keywords: 21st Century Skills, Critical Thinking, Instrucional Design, Problem Solving, Argumentation, Guidance, Feedback, Teachers’ Perspective, Agency.
1. INTRODUCTION

1.1 The challenge of transforming the classroom

Across the world, there is a strong urgency for transforming educational systems. This concern is shared by developed and developing countries, and by countries that already have accomplished high-levels of achievement and those who haven’t. Multiple voices have increasingly highlighted numerous global challenges that require educational system’s capacity to prepare citizens to address them (Reimers & Chung, 2016; Pellegrino & Hilton, 2012; Senge, 2012; Trilling & Fadel, 2009). At the core of this need for transformation, lies what happens inside the classrooms. The paradigm of classroom instruction centered on transmitting information must shift to a pedagogy focused on the construction of knowledge (Gilbert, 2007). As suggested by Wiggins & McTighe (2005), this means to change from covering a set of subject matter to uncovering knowledge. This change is necessary if the goal of education is that students can transfer what is being taught in school in different situations that the school setting (Halpern, 1998).

The assertion that the transmission paradigm must be changed is not new. John Dewey, in the first half of the 20th century, proposed a philosophy of education that is similar to what is now being spread by the 21st century skills movement (Pieratt, 2010). Dewey called for a child centered curriculum, focused on the development of real world action and the subsequent organization of experiences through active reflection (Dewey, 1915). This focus challenges the idea of isolating learning to an artificial setting in which only abstract relationships between concepts are memorized. In Latin America, we can also find voices even from the 19th century, like the educator and thinker Simón Rodriguez, tutor and
mentor of Simón Bolivar. Rodríguez, concerned about the absence of a citizenry that could enable the formation of democratic regimes in the new born societies of Latin America, believed that the only way that the new republics could survive was on the basis of active, critical and creative citizens (Ortega, 2011). Similar to Dewey’s thought, Rodriguez educational theory was funded on the believe that “educating is to achieve understanding. It is to employ understanding, not to make memory work” (Rodríguez, 1842, pp. 104). Even though the ideas proposed by the 21st century skills movement are not new, what is certainly new in the present time is that there exists the urgency to make everyone acquire them (Reimers & Chung, 2016).

One way to address the challenge of transforming the classroom is considering the integration of Critical Thinking into the everyday teaching and learning process. Critical Thinking is a key educational outcome because it is a necessary condition to enable citizenship. It helps to make more mindful every day decisions in a world overflooded with information, by contributing to detect our own and other biases when we are confronted to real world problems (Butler, Pentoney, & Bong, 2017). Martha Nussbaum (2012) argues that cultivating the ability to think critically is crucial for maintaining the vitality of multicultural democracies. Furthermore, Critical Thinking would increase the possibility of transferring what is learned to new situations, which is the central goal of education (Halpern, 1998).

Despite the recognition of its importance, there is an enduring and still open discussion about its definition. In the decade of 1980’s, a strong movement led by philosophers like Robert Ennis and Richard Paul elaborated definitions. According to Ennis “reflective and reasonable thinking that is focused on deciding what to believe or do” (Ennis, 1985, p.
Paul defines critical thinking as “disciplined, self-directed thinking that exemplifies the perfections of thinking appropriate to a particular mode or domain of thought” (Paul, 1992, p. 9). Facione (1991), led a group of experts in the field and developed the following definition: “purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based” (pp. 2). Along with this definition, the group proposes that critical thinking is comprised of the intertwining of two dimensions: skills and dispositions. On the skills side the group agrees that critical thinking is comprised of the use of interpretation, analysis, inference, explanation, self-regulation and evaluation. In the dispositions side, they propose a list of approaches to life and living in general, like open-mindedness, self-confidence and inquisitiveness, between others, and approaches to specific issues, questions or problems, like clarity, persistence and precision. More recently, cognitive psychologists like Christopher Dwyer (2014) have introduced ways of operationalizing it focusing on cognitive processes. As such, Dwyer defines critical thinking as “a metacognitive process, consisting of a number of sub-skills (e.g. analysis, evaluation and inference) that, when used appropriately, increases the chances of producing a logical conclusion to an argument or solution to a problem” (Dwyer, Hogan & Stewart, 2014, p.43). Bailin (1999) approaches the issue asserting that despite of the definitions of Critical Thinking, for pedagogical means, the definitions must be operationalized in a normative way. This author calls for avoiding lists of psychological states or cognitive process and constructing standards that clarify what educators expect when giving students tasks where critical thinking should be applied. In her conception, critical thinking is comprised of four components: Background
Knowledge, Knowledge of the standards of good thinking, Knowledge of key critical concepts, Heuristics and Habits of mind. This approach is similar to the proposal of Robert Swartz (2007), who, in a work of several decades, has developed material for infusing creativity, critical thinking and problem-solving skills, altogether “skillful thinking”, in any content, in what he calls Thinking-Based Learning. This material consists in guides and rubrics that exemplify and scaffold different thought processes like decision making, finding and processing relevant information, and analyzing problems by identifying the relationships of the parts and the whole (Swartz et al., 2007). According to Lai (2011), it is possible to identify different groups of definitions depending on the discipline of the authors. In this sense, whereas philosophers see it as a product, psychologists focus on the process.

Despite the abundant literature and expert recommendations, Critical thinking is not systematically integrated in the classrooms. International tests like TIMSS (IEA, 2015) and PISA (OECD, 2015), even though do not measure explicitly Critical Thinking, can illustrate us about the advancement in the development of higher order skills and the use of disciplinary knowledge, requirements of performance of Critical Thinking. In Chile, where this thesis is situated, these tests show that even though this countries’ students are the better performing students in the region and are continuously improving, the ability of students to solve problems is far below the average of OECD countries and even countries with similar GDP. The last TIMSS test shows in 4th grade only 2 percent of students are in the advanced level and 45 percent are in the lowest levels in solving problems related to science (IEA, 2015). Meanwhile, the latest PISA test, shows that almost the half of the students have not acquired basic competences related to solving mathematical problems.
These results are consistent with the standardized national test SIMCE, which shows that the majority of students do not accomplish the minimum proposed learning objectives. Furthermore, all these tests show a high level of correlation between the outcomes and the socioeconomic level, showing that the opportunities to attain learning outcomes are not equally distributed among society.

Critical Thinking, in all its versions, can be considered as the pursuance of agency. An agentic perspective of human development has been proposed by Albert Bandura in his social cognitive theory (Bandura, 1999). According to Bandura (2006), to be an agent is “to influence intentionally one’s functioning and life circumstances” (p. 164). In order to exercise agency, four properties must be considered: intentionality, forethought, self-reactiveness and self-reflectiveness. In this view, metacognition, as the capability to reflect on one’s thoughts and actions and their adequacy, “is the most distinctly human core property of agency” (p. 165). Even though these properties emerge at an individual level, as humans do not act isolated from others, they always take place in a socially situated way. Thus, the integration of Critical Thinking must not only consider psychological and individual factors, but also different actors that can enable or disable its development. This thesis will propose a situated perspective for achieving this aim. The overarching question that will be addressed is, then, the following: How can Critical Thinking be integrated into the classroom?

To address this question from a situated perspective, a specific domain of knowledge and student age will be considered. Mathematics is an important part of the curriculum and has usually been highlighted as a way of teaching problem-solving skills. Therefore, this study will focus on mathematics teaching and learning. On the other hand, even though there is
evidence that critical thinking can and should be developed from the first years in primary (Kuhn, 2001), there is scarce research on it (Abrami et. al, 2014). To address this gap, this study will focus on primary.

1.2. **Identifying the actors**

As previously discussed, the aim of this thesis is to study how to integrate Critical Thinking into classroom instruction. To address this issue, we propose analyzing different actors and their relationships. If we conceptualize the teaching and learning process as a network of actors, we can identify multiple actors and complex relationships between them (Fenwick and Edwards, 2010). For this thesis, we propose focusing on three actors and their relationships: The curriculum, teachers and students.

![Diagram of actors and relationships](image)

**Figure 1-1. Identification of actors that shape the learning experience.**

Figure 1-1 identifies the actors that will be considered, and the relationships between them.

The curriculum is the prescription of the learning objectives that teachers should implement in their teaching practice. This implementation is more complex than a translation of objectives into student minds. Teachers enact the curriculum through the structuration of
lessons and the following enactment of them through a process of interaction with the students inside the classroom. The aim of this process is the development of competencies in students. In the following sections these actors and their relationships will be analyzed.

1.2.1. Critical Thinking and the Chilean curriculum

The Curriculum is a national prescription of objectives and contents, and establishes what, why, and for what of the cultural transmission that school education carries out (Cox, 2018). The curriculum is based on study plans, which list in detail the learning objectives for all the subjects and levels. The learning objectives are divided in knowledge, attitudes and skills, and are integrated in different ways in the study plans.

In the Mathematics study plan (MINEDUC, 2012A), critical thinking is described as the ultimate purpose of the subject: “the formative purpose of the subject is to enrich the comprehension of the reality, facilitate the selection of strategies to solve problems and contribute to the development of critical thinking in all students”. This cite is the beginning of the study plan and is more than a declaration of intentions. The learning objectives are separated in Skills, Contents and Attitudes. The skills are highly related to the subskills of Critical Thinking proposed by several authors: Solving Problems, Argument and Communicate, Modeling and Representing. The attitudes also similar to the dispositional dimension of Critical Thinking: work in a methodic style, approach in a flexible and creative way to the solution of problems, manifest curiosity and interest for learning, manifest a positive attitude for oneself, demonstrate effort and perseverance. This approach is similar to Facione’s operationalization of critical thinking, which is formed of a
number of skills, on the one side, and dispositions on the other, both of them related with a particular domain content.

In Language (MINEDUC, 2012B), Critical Thinking is also explicitly alluded. In the plan, it says “critical and reflective thinking is sustained in a solid development of language. It is this intertwining that allows thinking with clarity, broaden knowledge, express them and relate them”. The study plan for this subject is organized by three content strands: Lecture, Writing and Oral Communication, and a series of Attitudes. Both within the content strands and the attitudes there are strong relations to critical thinking subskills.

In Science (MINEDUC, 2012C), it is stated that learning the subject “promotes critical thinking, reflective capacity and the valuation of error as a source of knowledge”. This is also aligned to the most common critical thinking frameworks. The skills that this subject aims to develop are also related: observing and questioning, experimenting and analyzing evidence and communicating.

In Social Sciences (MINEDUC, 2012D) it is proposed that “In order for students to achieve the learning objectives proposed for the subject, it is important that they gradually identify, internalize and apply the fundamental methods of the Social Sciences, since these contribute to the development of critical thinking”. The skills proposed are Temporal and Spatial thinking, analysis and work with sources, critical thinking and communication. “As a whole, these skills have as a central objective the development of critical thinking of students and their ability to solve problems”. In this subject Critical Thinking is one of the skills explicitly. “During the basic cycle, students are expected to begin to recognize the interpretative character of the Social Sciences task. It seeks to learn to distinguish the multiple perceptions that may exist around the same phenomenon. It is also intended that
they begin to evaluate the arguments and evidence that underlie each vision. As they progress, they will be able to develop their own vision of the contents of the level and of nearby topics of interest, relying on sources and other resources to support their own ideas”.

From the previous analysis we can identify that critical thinking is incorporated mainly in two aspects across the curriculum. On one side, it is proposed that learning the contents, skills and attitudes of each discipline is a mean to develop critical thinking and that this is the aim of each subject. On the other side, critical thinking itself or some subskills are incorporated by intertwining them with specific contents, skills or attitudes of each subject.

1.2.2. Into the classroom

In the classroom setting, teachers enact the prescribed curriculum. This enaction is at the core of a teacher’s work. According to Vieluf et al. (2012), there are three dimensions of classroom practices that must be considered to foster learning: structuring, student orientation and enhanced activities. Specifically regarding the integration of Critical Thinking, Ennis (1989) proposes four different approaches: general, which are focused exclusively in critical thinking, infusion, which combines direct instruction of critical thinking to address specific contents of a particular domain, immersion, which doesn’t address critical thinking itself but tries to put into practice its components in the learning process, and mixed approaches, which combine elements of the previous options. Underlying the choice of strategies, there exists the debate if Critical Thinking is a general
or a subject specific skill, therefore, if it should be thought explicitly as a separate course or if it should be integrated.

Despite this debate, there are several specific critical thinking instructional strategies that have been proposed. Meyers’ Teaching Students to Think Critically proposes four elements: student motivation and interest, meaningful discussion, exposure to other perspectives, and a supportive environment (Meyers, 1986). Lipman’s (2003) focus on critical thinking development in children takes the general approach and proposes rehearsing cognitive skills in an environment where these come naturally with reflecting, reasoning, and devising original ideas. Halpern’s (2003) proposal includes an attitude to foster critical thinking, training activities designed to facilitate transfer across contexts, and a metacognitive component to guide and evaluate thinking. Brookfield (2005) centered on group activities to apply critical thinking to real experiences. Nieto and Saiz (2008) showed that structure training, i.e., recognizing the structure of correlational problems in different contexts, improved critical thinking. Paul and Elder (2008) consider that a subject is learned if the student masters the thinking associated with that subject and that learning activities require students to think within the concepts of the subject. With their in-classroom strategy, students individually review and apply a new concept related to a problem; small groups are formed to read, explain, and assess what is understood; students are instructed on how to assess peers’ work and then evaluate their classmates. Deanna Kuhn (1999), contributes to the debate about the implementation of critical thinking strategies some developmental issues that, according to cognitive science, should be regarded for understanding better the underlying structures of the thought process related to Critical Thinking. For Kuhn, there are two important areas that are part of cognitive
development and contribute to critical thinking that should be explicitly taken into account to foster its development: metacognition and epistemic knowledge. These strategies have some agreements that are worth to acknowledge. Both general and domain-dependent approaches using instructional methods centered on the student (Angeli and Valanides, 2008). All of these methods encourage explicitly putting into practice the components of critical thinking by different means, like questioning, analyzing material, solving non-routine or real-life problems and focusing on core concepts and practices of each discipline. Furthermore, we can observe that there is a close relation with strategies for developing “deeper learning”, defined as “the process through which an individual becomes capable of taking what was learned in one situation and applying it to new situation” (Pellegrino & Hilton, 2012, p. 5). According to Pellegrino and Hilton (2012), in order to develop “deeper learning”, it is necessary to engage students in complex problem-solving scenarios and explicitly put into practice higher order skills and metacognitive skills. One framework commonly used for curriculum design focused on deeper learning is Understanding by Design (Wiggins & McTighe, 2005). It is possible to link what they call the “facets of understanding” with the integration of critical thinking. For Wiggins & McTighe one way to observe that students have achieved a good understanding, i.e., they have learned something, when they can explain, interpret, apply, have perspective, empathize, and have self-knowledge. These indicators are similar to what is agreed throughout the revised critical thinking literature.

The relationship between “deeper learning” and Critical thinking are similar to the proposal of integration of this competence in the Chilean curriculum. Therefore, in order to follow a
situated approach, we will conceptualize the integration of Critical Thinking from an immersive perspective.

In the last paragraphs we have shown how Critical Thinking is integrated in the Chilean curriculum, on one side, and how is it recommended to be integrated into classroom instruction in general according to the literature, on the other. Nevertheless, there are key aspects that should be studied for the integration in real world classrooms in the current context. Figure 1-2 shows the aspects that will be studied in detail in this thesis.

![Figure 1-2: objectives at different levels](image)

First of all, the focus will be set on students. In order to develop complex competencies, students do not passively receive subject-matter. Instead, they elaborate knowledge through the interaction between them and the teacher, their peers and the learning material through active reflection. In this process it is paramount to scaffold the integration of complex skills. With this aim, the first study will focus on to integration of argumentation in the
problem-solving process. Secondly, the focus will be aimed in the interaction between teachers and students. This interaction is a complex process, and determining the amount of guidance that should be provided is an open debate in the literature. Finally, on the teachers’ level, their perspective on how Critical Thinking can be integrated will be studied.

1.3. Fostering Critical Thinking

1.3.1. Embedding argumentation

Argumentation is proposed as a central critical thinking skill. Van Eemer et al. (1996) define argumentation as “a verbal and social activity of reason aimed at increasing (or decreasing) the acceptability of a controversial standpoint for the listener or reader, by putting forward a constellation of propositions intended to justify (or refute) the standpoint before a rational judge” (Van Eemeren et al., 1996 p.5).

According to Jonassen and Kim (2010), embedding and fostering argumentative activities in learning environments promotes productive ways of thinking, conceptual change, and problem solving, because it engages deeper and more mature epistemological levels of learning. It has been shown that evaluating peer’s explanations, requesting and providing explanations, and working with statements provided by peers in order to improve ideas lead to a greater level of understanding (Vogel et al., 2016). Argumentation leads to conceptual change (Asterhan & Schwarz 2007; Baker 1999; Nussbaum and Sinatra 2003; Wiley and Voss 1999). Cho and Jonassen (2003) showed that the production of coherent arguments to justify solutions and actions is a more important skill for solving ill-structured problems than for well-structured problems.
Argumentation can be integrated in many ways into instruction and learning environments (Jonassen & Kim, 2010). According to Asterhan and Schwartz (2016), although there exists agreement of the importance of argumentation, it is not possible to conclude that any kind of argumentation is beneficial for all learning activities.

Because of the evidence of the benefits of argumentation for learning, it is important to understand its effect while learning problem solving skills. Thus, the second question raises: How does adding argumentation to collaborative problem solving enhances learning?

1.3.2. Guidance in problem solving

In order to implement pedagogical strategies that require students to apply higher order skills, teachers usually find challenges related to the higher cognitive load that students must manage in comparison to direct instruction (Kirschner et al., 2006). According to Shutte (2008), feedback can effectively reduce the cognitive load of a learner, especially novice or struggling students (Paas, Renkl, & Sweller, 2003; Sweller, Van Merriënboer, & Paas, 1998). Novice students can become cognitively overwhelmed during learning due to high performance demands. Thus, they may benefit from supportive feedback designed to decrease the cognitive load. Hattie (2007) found that despite feedback is one of the most relevant factors that contribute to quality instruction, there was little research how to implement it. More recently Attali and van der Kleij (2017), show that research evidence is inconsistent in many respects. It has been shown that not all feedback is always beneficial for learning (Kluger and DeNisi, 1996, Hattie, 2007). There are issues like timing, the type of problem, the previous knowledge (Fyfe, 2016) that can even help some students but hinders the learning of others.
Furthermore, there is an open debate about how much to guide students. Kirschner et al., (2006), opened a discussion between authors who stand for the benefits of direct instruction versus more constructivist approaches. According to Kirschner, constructivist approaches are not consistent with what we know about cognitive science, because they ignore that there cannot be learning if there is too much cognitive load. Several researchers (Hmelo-Silver, Duncan & Chin, 2007; Schmidt et al., 2007; Kuhn, 2007), replied Kirschner et al. arguing that, on one side, constructivist methods can be compatibilized with cognitive load theories if scaffolds are well designed, and on the other, constructivist methodologies are more consistent with an approach that seeks to engage students in real world settings. Alfierei et al., (2011), in a meta-analysis, show that not guiding students at all is not effective, which is not the case with certain types of feedback, worked examples and other types of scaffolding. Another approach to the issue of guidance is Productive Failure (Kapur, 2010). Kapur suggests that mistakes are an essential part of deeper learning, because they force students to face knowledge that they have not yet acquired and question for themselves how they might improve. In this sense, letting students mistake could help deeper learning.

There is scarce evidence about feedback on primary students in learning complex problem solving (Fyfe, 2017). This motivates the third research question: Is more detailed feedback better for learning problem solving?

1.3.3. The teachers’ perspective

In the previous sections, research issues related to instructional strategies have been discussed. Nevertheless, a key issue in the implementation of 21st century competences in the curriculum, concerns the role of teachers. Although this role has been widely
acknowledged in the past decades (Fullan, 2007; Lieberman and Pointer Mace, 2008), the characteristics that teacher training programs should have, and/or the competences teachers need are only addressed in few documents. It is, therefore, paramount to understand and incorporate the voices of those who finally are the ones implementing what research and policy in the every-day practice: the teachers (Voogt & Roblin, 2012). Teachers are ‘key agents’ and ‘final policy brokers’, and their ability to change classroom practice has a direct impact on policy enactment (Spillane, 1999), as they do not only do reinterpret and finally implement education policies, they also adopt selective aspects of the policy to achieve goals that are proposed by themselves (Tan, 2017). Van de Oudeweetering and Voogt (2018) study teachers’ conceptualization and enactment of twenty first century competences in the Netherlands. According to these authors, since teachers’ interpretation of innovations play a prominent role in their enactment of curricula, what teachers understand about it can provide relevant information about how the implementation of instructional can result (März & Kelchtermans, 2013; Van den Berg, Vandenberghe, & Sleegers, 1999).

The quality of teachers’ practices is highly influenced by the sense of agency, because if supported their commitment can be enhanced (Priestley & Biesta, 2013, Ketelaar et al., 2012). Aligning the written curriculum and teachers’ perception of their professional responsibilities can help to improve teachers’ agency and, therefore, the realization of curricula. Task perceptions and knowledge guide their professional actions (März & Kelchtermans, 2013), and the practical choices that teachers make affect their perception of their practices. Hence, acknowledging these perceptions could facilitate the actual implementation of curricular goals (van de Oudeweetering and Voogt, 2018).
In critical thinking research related to school education there is an outstanding lack of evidence about how teacher interpret and enact this competence in their everyday practice. Thus, the two final research questions arise: What do teachers do to implement the teaching of critical thinking in their classrooms? and lastly: Is there a difference between what teachers do to develop critical thinking when comparing the subjects they teach?

1.4. Research Questions

Q1) How can Critical Thinking be integrated into the classroom?

Q2) Does adding explicit argumentation to a collaborative problem solving methodology enhance learning?

Q3) Is more detailed feedback better for learning problem solving?

Q4) What do teachers do to implement the teaching of critical thinking in their classrooms?

Q5) Is there a difference between what teachers do to develop critical thinking when comparing the subjects they teach?

1.5. Hypothesis

H1) The integration of Critical Thinking needs to take into account different actors and the relationships between them.

H2) Adding explicit argumentation to collaborative problem solving does enhance learning in math lessons

H3) More detailed feedback is better for learning problem solving

H4) Teachers implement general strategies to develop critical thinking
H5) There are no significant differences between disciplines

1.6. Objectives

O1) To develop a model of integration of Critical Thinking considering different actors and the relationships between them.
O2) To discover if adding explicit argumentation to a collaborative problem solving scaffold enhances learning
O3) To discover if more detailed feedback is better than less detailed feedback
O4) To discover what teachers do to develop critical thinking in their everyday practice
O5) To discover whether there are differences between disciplines in teachers conceptualization of Critical Thinking strategies.

1.7. Results

R1) A model that takes into account the embedding of argumentation, fosters students autonomy giving less detailed feedback and the teachers perspective is presented
R2) Explicit argumentation does enhance learning
R3) More detailed feedback is better immediately, but for the long term is better less detailed feedback
R4) Teachers implement critical thinking as an integrated part of their disciplines, resembling critical thinking with mastering the practices of each discipline
R5) There are significant differences between disciplines regarding the implementation of critical thinking
1.8. Thesis Structure

The structure of this thesis is based on the research questions, hypothesis and objectives mentioned above. Figure 1-3 provides a model to demonstrate the connections between the aforementioned components.

Research question 1, i.e. How can Critical Thinking be integrated into the classroom? is the overarching question of this thesis. Its related hypothesis, H1, i.e., The integration of Critical Thinking needs to take into account different actors and the relationships between them, motivates objective 1, O1, i.e., To develop a model of integration of Critical Thinking considering different actors and the relationships between them. From this objective two research questions arise. First, Q2, does adding explicit argumentation to a collaborative problem-solving methodology enhance learning? And secondly, Q3, Is more detailed feedback better for learning problem solving? Research question Q2 relate to hypothesis H2, i.e., adding explicit argumentation to collaborative problem solving.
does enhance learning in math lessons, and is addressed by objective 2: to discover if adding explicit argumentation to a collaborative problem-solving scaffold enhances learning. Q2 is answered in Paper 1. The result of this question is that explicit argumentation does enhance learning (R2). Regarding Question 3, the proposed hypothesis is that more detailed feedback is better for learning problem solving (H3), and objective 3 (O3) is proposed to address it: To discover if more detailed feedback is better than less detailed feedback. The result of this question is presented in P2, and it is summarized in R3: More detailed feedback is better immediately, but for the long term is better less detailed feedback. R2 and R3, and to deepen O1 from a different perspective are the motivation for Q4: What do teachers do to implement the teaching of critical thinking in their classrooms? and Q5: Is there a difference between what teachers do to develop critical thinking when comparing the subjects they teach? The hypothesis for these questions are H4 and H5: Teachers implement general strategies to develop critical thinking and: there are no significant differences between disciplines. To address this questions objectives O4 and O5 where proposed: To discover what teachers do to develop critical thinking and: To discover whether there are differences between disciplines. The answers of these questions are presented in Paper 3, Teachers implement critical thinking as an integrated part of their disciplines, resembling critical thinking with mastering the practices of each discipline (R4), and R5: There are significant differences between disciplines regarding the implementation of critical thinking. Finally, all the results contribute to respond the overarching question and are summarized by R1: For integrating critical thinking in problem solving, explicit argumentation and less detailed
feedback should be implemented. On the other hand, critical thinking must be integrated by practices of each discipline.

1.9. Thesis Outline

This thesis is divided into four separate chapters, each one of them is a paper that was submitted or published in refereed journals. The list of chapters within this thesis is as follows:


Chapter 3: Cáceres, M., Nussbaum, M., González, F., Gardulski, V. Is more detailed feedback better for problem solving? Computers & Education, under review. This chapter reports on a quasi-experimental study aimed to determine whether if more detailed feedback is better for learning problem solving.

Chapter 4: Cáceres, M., Nussbaum, M., Ortiz, J., Implementing critical thinking from a teacher’s perspective. Teachers and Teaching, under review. This chapter reports on a study aimed to elaborate how teachers implement Critical Thinking in their everyday teaching practice.
1.10. Research Limitations

This thesis presents some limitations related to the scope and possibility of generalization of the presented results.

First of all, it is important to recognize that even though the thesis focuses on integrating Critical Thinking strategies, we couldn’t actually measure if Critical Thinking itself was being promoted in the interventions. This is because, as discussed in section 1.1., there is a still open debate on the definition of Critical Thinking and there are not available tests to measure this skill for fifth grade students in the domain of problem solving. Although in some moment developing a test to fulfill this gap was intended to be part of the project, it wasn’t possible to pursue it until a robust validation, as it showed to be much complex than initially thought. The multicollinearity of the construct of Critical Thinking is a still open debate, and trying to isolate from other competences is not a simple task. Thereby, this thesis only shows results in learning and not in Critical Thinking as a separate skill.

Another important limitation in all the studies is that the sample sizes where limited, so the results are not representative of larger populations. Study one and two where developed by quasi experimental designs, where confounding factors could affect the results. Furthermore, these studies were not complemented by rigorous quantitative observations, which could have been valuable to interpret with more depth the quantitative results.
In the third study, an important limitation is that the information was collected as self-reports, so we cannot affirm that what teachers describe is actually how they implement Critical Thinking in their actual everyday teaching practices.

Lastly, it is important to highlight that Critical Thinking is a competence that should be developed in a holistic way through life, and should consider factors that go far beyond interventions that last a limited number of sessions in a specific domain of knowledge. Despite these circumstances, the results of this thesis show some recommendations that can be useful to teachers, schools and policy makers in the present time to start integrating Critical Thinking in the classrooms.
2. BUILDING ARGUMENTS: KEY TO COLLABORATIVE SCAFFOLDING

2.1. Abstract

Collaborative problem solving in the classroom is a student-centred pedagogical practice that looks to improve learning. However, collaboration does not occur spontaneously; instead it needs to be guided by appropriate scaffolding. In this study we explore whether a script that explicitly incorporates constructing arguments in collaborative problem solving activities improves learning. In order to do so, a study was conducted involving 75 students from a lower-middle class state-subsidized private school in Santiago de Chile. These students were divided into three groups, each of which worked on geometry activities over 10 sixty-minute sessions that were held across a period of four weeks. To isolate the effect of incorporating technology, the first of these groups did not work with technology. The second group worked with a collaborative script that was developed for use with a tablet, while the third group used the same technology with an integrated tool that explicitly allowed the students to build arguments. We conclude that having students reflect on their own processes and outcomes by arguing their point of view can lead to an improvement in learning, more so than the technology itself.

2.2. Introduction

The world’s leading education systems are asking how they can maintain their good results, while developing countries are looking to catch up with them (OECD, 2012). There is therefore huge interest in introducing student-centred teaching methodologies into the
classroom (Sriprikash, A., 2010), where the focus is on developing skills that allow citizens to actively participate in a society that is increasingly dependent on information (Dede, 2010; Griffin, 2012). These skills include collaboration, problem solving and critical thinking (Darling-Hammond 2011; Halpern, 2003).

2.2.1. Critical Thinking

Critical thinking is considered a fundamental skill in school curricula as developing this skill allows students to make autonomous decisions (Mulnix, 2012; Kamii, 1991; Paul, R., & Elder, L.2001). A wide variety of definitions of critical thinking are available in the literature, ranging from an ethos (Ellis, 1989) to a problem solving skill (Dwyer, 2014). In an effort to develop an operational definition of critical thinking, Facione (1990) conceptualizes critical thinking as a series of higher-order skills, i.e., interpretation, analysis, inference, explanation, evaluation and self-regulation. According to this conceptualization, critical thinking allows self-regulated judgements to be provided based on solid evidence. One way of infusing these skills is to have students explain their own thought processes (Gelerstein, 2016) while solving domain-specific problems. Accordingly, several authors (Noroozi, 2012; Paul 1990; Halpern 1998) state that the ability to develop arguments is key to foster critical thinking.

2.2.2. Argumentation

Deanna Kuhn (2003) suggests that argumentation is not only central to critical thinking; rather it is a way of developing thinking skills in general. This is because the ability to propose, critique and defend a position is required transversally across all domains of knowledge. Moreover, as Jonassen (2010) states, learning to argue fosters conceptual change. This is because in order to construct arguments learners must be highly engaged with the topics under discussion. In this
sense, empirical studies (Schwartz, 1995; Shirouzu et al., 2002) have shown that, when embedded in learning practices, argumentation in collaborative problem solving activities helps lead to abstraction. According to Kirschner et al. (2009), involving students in argumentation facilitates higher-level learning, going beyond merely recalling concepts. Furthermore, explicitly writing arguments can be beneficial to the learning process, as it helps learners to self-regulate their understanding of the subject matter (Nückles et al., 2009) and improves peer interaction in collaborative tasks (Papadopoulos et al., 2014). Structuring argumentation through writing helps learners to become more involved in their own construction of knowledge, and to be more clear and precise when subsequently communicating their thoughts orally (Jang, 2007).

2.2.3. Collaborative problem solving and argumentation

Introducing collaborative problem solving into the classroom is one student-centred approach that has often been proposed for developing higher-order thinking skills (OECD, 2013; Roschelle, 1995). This is because it allows students to build their knowledge, while developing their capacity for metacognition and critical thinking (McCormick et al., 2015; Dwyer, 2014). Collaborative problem solving activities are ideal for incorporating argumentation. This is because argumentation has been shown to support learners when solving both well-structured and ill-structured problems (Jonassen, 2010). Encouraging students to collaboratively develop arguments is considered key to acquiring critical thinking skills (Andriessen, 2006).

Despite of its promises, implementing collaborative activities in the classroom presents a series of challenges. Dillenbourg (2002) notes that collaboration does not occur spontaneously and that free collaboration does not necessarily lead to better learning outcomes. Developing an effective collaborative learning activity depends on multiple factors that interact with each other in a multifaceted way. This complex process requires instructional design that specifically focuses
on influencing how the interaction between learners is regulated. Kirschner (2013), on the other hand, suggests that pedagogical proposals that do not include sufficient mediation by a tutor will seldom lead to positive results in problem solving and inquiry activities. Gillies (2009) emphasizes that while problem solving activities are highly recommended for ensuring effective learning, explicit instructions and reflection on the argumentation process itself should be provided.

2.2.4. Technology-Supported Scripts

In the last few decades, technology-supported scripts have become increasingly popular as scaffolding for problem solving and collaborative work, as well as for ensuring that the work in the classroom is effective (Jeong, 2012; Miao, 2005; Kirschner, 2013). One branch of the literature concerning technology-supported scripts refers to explicitly incorporating argumentation into the learning process. Providing specific scaffolding for argumentation when working with computer-supported online inquiry activities affects the learner’s consensus-building process. Gijlers et al. (2009) show that consensus-building activities are introduced more effectively when explicit rules for collaboration are provided. Evaluating a peer’s explanations, requesting and providing explanations, and working with statements provided by peers in order to improve ideas lead to a greater level of understanding (Vogel et al., 2016).

Different ways of representing arguments and different types of interaction design are important to the learning outcomes in collaborative argumentative systems (Scheuer et al., 2010). According to Scheuer et al., the way in which arguments are represented should be taken into serious consideration. Scripts that visually guide students when building arguments give rise to more elaborated discourse. Furthermore, the overall structure of the activities in which argumentation takes place is equally important to the learning outcomes.
Noroozi et al. (2012) analyses 108 publications from this field in order to identify the main lines of research that have been developed over the last 15 years, focusing on their respective learning outcomes. The authors identify four main areas of research: student prerequisites, learning environment, processes and activities, and outcomes. Although the general objective of designing and implementing scripts is to improve learning in a specific subject, only 4 (5%) of the publications focus on outcomes, while 28 (31%) combine an analysis of the learning process with the outcomes. Of the articles included in the review, only 4 refer to primary education and none of these focuses on the impact of argumentation on learning. Furthermore, according to Fielding-Wells and Makar (2015), although incorporating argumentation as a tool for learning mathematical concepts has huge potential, it is a concept that is yet to be explored in proper detail.

One area that has not yet been analysed within this field is the effect of explicitly incorporating the construction of arguments in collaborative problem solving activities, as well as its impact on domain-specific learning outcomes (Asterhan & Schwarz, 2016). Constructing arguments is a previous task necessary to engage in argumentation process. This study looks to provide evidence regarding the specific gains of explicitly constructing arguments in primary school lessons within a particular domain. The aim of doing so is to look at how using scripts as scaffolding when developing arguments enhances learning in a collaborative problem solving activity.

2.3. Methodology

2.3.1. Instruments used

According to Kuhn’s (2011) research on argument skills, these skills should be developed continuously and go hand-in-hand with cognitive development from early childhood through to
adulthood. According to this philosophy, between infancy and pre-adolescence, students should be able to explain to others in basic terms what their own point of view is and why they propose a certain idea. Furthermore, one of the transversal skills included in the Chilean curriculum for mathematics (MINEDUC, 2012A) is being able to provide an explanation, i.e. the student’s ability to explain their own thought processes. Therefore, the scaffolding proposed in this article consists of a specific tool with which students can write an argument to evaluate their peers’ responses, applying the subject matter needed to solve a specific problem. The structure of this argument is the most simple one, consisting of a claim and a reason (Voss and Van Dyke, 2001), as it is aimed at fifth grade students (Kuhn, 2011). The aim of this tool is to prompt student reflection (Nückles et al., 2009) and to improve peer interaction when collaborating (Papadopoulos et al., 2014).

The introduction into the classroom of tools such as tablets and smartphones allows for the design of face-to-face activities that promote peer interaction and the construction of shared knowledge (Nussbaum et al., 2009). Geometry is one branch of mathematics that has great potential for being taught through interactive problem solving (Isotani, 2009) and yet this potential has still not been fully explored (Isotani, 2014). In order to study the impact of incorporating the construction of arguments into a collaborative learning activity, an interactive script was designed that explicitly allows students to build an argument. Based on the fifth grade curriculum for Chile, the activities were designed to cover the learning outcomes relating to rotation, translation and reflection.

The basis of the script used in this study was taken from the script used in Collpad (Nussbaum et al., 2009). Collpad is a tool that supports the practice of face-to-face collaboration on open-ended tasks. By doing so, it facilitates group discussion within a constructivist model of knowledge
building, with the teacher playing a key role as moderator. Collpad was initially proposed as a flexible form of technology-supported scaffolding that allows teachers to use open-ended questions within a given subject, without needing a specific script. Although one of the advantages of this flexibility is that the scaffolding can be used with a wide range of activities, it runs the risk of not adequately guiding the interactions that are needed for learning a specific topic (Kirschner, 2013). Furthermore, although Collpad encourages discussion among peers, the way in which they reach an agreement is left to the students. As stated in the introduction, structuring the process of consensus-building through the construction of written arguments would enhance the learning process. With this aim, we propose a variation of Collpad called Collpad 2 (Figure 2-1).
As with Collpad, there are four phases in Collpad 2, as well as a final conclusion (Figure 2-1). At the start of the lesson, the class is randomly divided into teams of three students (Nussbaum et al., 2009). In the first phase, the teacher sets an open-ended task, both verbally and using their device. This task appears independently on each student’s device, and is the same task for the whole class. The following phase involves each student individually solving the task. Each member of the team must answer the problem that has been set independently and using their
own device. To develop their solution, every student is given the same elements. These elements are manipulated using the student’s device. As an example, we show a step-by-step, collaborative solution to an exercise for identifying lines of symmetry, one of the learning outcomes covered during this study, as seen by one of the members of a team. All of the subsequent figures in this section (Figure 2-2 to Figure 2-5) are screenshots from one team member’s tablet from different phases of the process described in Figure 2-1. Figure 2-2 shows the problem that was presented to the class (top) and the elements that the students could use to solve the problem (bottom).

Figure 2-2. Collpad 2, Phase 1. In phase 1, each student is given the same geometric object (upper part) and the same lines (lower part) that have to be identified as the corresponding lines of symmetry.
Once a student has developed their solution, they must wait for their peers to finish. As each student finishes, the other members of the team that have already completed the task can see the other students’ responses on their own device. Finally, once every student in the team has finished the task, the whole team must then confirm that they have seen their partners’ responses. The second phase starts with each student evaluating the solutions given by their peers and providing an argument to support their decision (Phase 2.1, Figure 2-1). This phase is key as it encourages the students to explicitly reflect on the subject matter, as well as on their own understanding of the problem and the possible solutions. In order to provide the solution, students use an argument builder. This allows them to develop pre-written arguments based on the task that is being completed. The argument builder was designed after a pilot study in which students were able to write their arguments in an exercise book. In this pilot study, the students had difficulty building arguments and therefore proper scaffolding was subsequently designed, as recommended by previous research (Scheuer et al., 2010). In this scaffold, students must build their argument by selecting words using a spinning wheel picker (Figure 2-3). In the example shown in Figure 2-3, the student labelled “You” is evaluating Brandon’s response. Within the interface, each student is identified by a colour. The argument in Figure 2-3 is therefore surrounded by the colour blue, which is the colour used to identify Brandon.
Figure 2-3. Collpad 2, Phase 2.1. In phase 2.1, peers co-evaluate their solutions using an argument builder.

In the second part of phase 2 (Phase 2.2, Figure 2-1), each student reads their peers’ assessment plus argument, of their response to the task set by the teacher (Figure 2-4). In the example in Figure 2-4, we can see the display for the student labelled as “You”. This figure shows the comment left by this student for their classmate Alex (which begins with “I said…”), as well as the comment left by Brandon. As students build their arguments and decide to share them using the “Send” button (bottom-right corner, Figure 2-3), the arguments appear on the screen. To assess Brandon’s response, the student must click on “Comment”, which can be found below the response given by the student that has not yet been assessed.
Figure 2-4. Collpad 2, Phase 2.2. In phase 2.2, each student can see the feedback given by the peers who reviewed their solution.

The third phase consists of developing a group response to the task that has been set. Each student in the team can see the same workspace as their peers on their own device. To generate greater interdependency between peers when developing the group response, the elements that are needed to solve the problem are split among the team peers in such a way that each student must participate in order to solve the task (Figure 2-5). Such interdependency is an essential condition for collaborative work (Dillenbourg, 1999). The example in Figure 5 shows that each of the students has been assigned different lines of symmetry, providing different alternatives for solving the problem. Figure 2-5 also shows that the elements that belong to each student are highlighted in the student’s identifying colour. The three students in the team are shown the same screen, but each student can only manipulate the elements that have been assigned to them. Furthermore, the individual responses and the arguments given by each student earlier in the activity can be seen at the bottom of the screen, so that they can be referred to if necessary as an input for the consensus-building process. Finally, once the team finishes and confirms their response, with all three students sliding the button from “Working” to “Done”, the team’s response is sent to the teacher. The team must then wait for all of the other teams to finish.
Figure 2-5. Collpad 2, Phase 3. In phase 3, the team builds a collaborative response to the task. All of the members of the team can see the arguments elaborated by their peers in the previous phase and can therefore use them as an input for the consensus-building process.

As with Collpad, the final phase begins once all of the teams have finished or when the teacher decides it is time to do so. In this phase, the teacher selects some of the teams’ responses, which they see as being representative of the discussion they would like to have with the class. The students can see these responses on their device, while they are also projected onto a shared screen. In this whole-class discussion, the teacher analyses the responses that they selected, highlighting where the team was correct and where they made a mistake. Finally, the teacher
then provides a conclusion to the activity that has been completed. For another example of the script, illustrated with a rotation activity, see Appendix 1.

2.3.2. Experimental Design

A quasi-experimental study was designed involving three groups. The aim of this design was to determine the specific impact of the scaffolding that was provided to help students with their argumentation during the collaborative problem solving activity. To isolate the effect of using technology, the first of these groups (Control Group) did not use technology. They did, however, use a content guide and worksheets that had previously been developed by the research team. Explicit instructions were given in these guides regarding how to interact. Therefore, the same collaborative interaction pattern was orchestrated with each group (See Appendix 2 for an example of these guides). The second group used the Collpad 2 application, without the argument builder (Collpad 2 Group). In other words, this group skipped phase 2 described above and instead moved directly from phase 1 to phase 3. The final group used Collpad 2, featuring the argument builder (Collpad+Arg Group). As described previously, the argument builder was incorporated in Phase 2 of the script for the Collpad+Arg group. Consequently, the teacher guidelines specified that the teacher had to encourage discussion among students and mediate should a conflict arise.

The three groups were given the same set of exercises on symmetry, reflection, translation and rotation (see Appendix 3 for example exercises). They also followed the same orchestration (Roschelle et al, 2013), i.e. the teachers followed a script that contained the same teaching activities, despite working with different technologies (see Appendix 2 for an orchestration example).
Table 2-1. Differences and similarities between groups.

Table 2-1 summarizes the differences between the three groups. As described previously, the differences lie in the technological support that was provided, as well as in the argument builder. This is because the Control group was the only group that did not use tablets, while the Collpad + Arg group was the only group to use the argument builder. All of the groups solved the same geometry problem through face-to-face collaboration, and followed an orchestration script that structured the learning process for it to be as similar as possible for each group.

Each lesson consisted of three sections: introduction, development and closing. In the introduction, the teacher activated previous knowledge with a discussion about what the students knew about the subject, as well as briefly introducing the objectives of the lesson. The development section consisted of two parts. In the first part, the teacher presented the new concept using a PowerPoint presentation and class discussion. The second part consisted of putting the concept into practice by using collaborative problem solving. Each group was given different support when solving the problems, as explained previously. However, the three groups worked collaboratively, alternating between whole class discussion and group work. In the closing section, the teacher highlighted the key concepts from the lesson and gave feedback about the group work.
All of the groups completed their activities over 10 sixty-minute sessions across a period of 4 weeks, with the sessions held instead of the students’ regular maths classes. Following Zurita et al.’s (2005) recommendations, groups of three students were randomly formed at the beginning of each session. The students in each group were seated next to one another in order to facilitate face-to-face collaboration. This also allowed peers to interact verbally and go beyond the interaction script (Zurita & Nussbaum, 2004).

A pre- and post-test was used to measure learning among the three groups. This instrument was designed by the research team and included 20 multiple choice questions on the topics covered during the 10 sessions (see Appendix 4 for sample questions). Cronbach’s alpha was calculated in order to test the internal validity of the test, giving a score of 0.67 for the pre-test and 0.72 for the post-test. According to Bland & Altman (1997), any score over 0.6 is enough to demonstrate the internal validity of a test.

2.3.3. Description of the sample

The study was conducted in a lower-middle class, state-subsidized private school in Santiago de Chile. The sample used in the study consisted of three fifth grade classes, randomly assigned to the three different conditions. The Control Group consisted of 27 students (11 boys and 16 girls), the Collpad 2 Group consisted of 29 students (12 boys and 17 girls), while the Collpad +Arg Group consisted of 23 students (13 boys and 10 girls).

2.4. Analysis and Results

Pre- and post-test results are shown in Table 2-2.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Pre Test Mean (SD)</th>
<th>Post Test Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>27</td>
<td>13.48 (3.2)</td>
<td>15.04 (3.06)</td>
</tr>
</tbody>
</table>
Table 2-2. Pre- and Post-test means and standard deviations for each group.

In order to determine the student learning gain in each group, Cohen’s d was calculated to measure the effect size (Cohen, 1988). This yielded a small effect size (0.49) for the Control Group, a medium effect size (0.7) for the Collpad 2 Group and a large effect size (0.96) for the Collpad + Arg Group.

An analysis of covariance (ANCOVA) was conducted in order to detect differences in learning among the three groups. In this case, the student’s group (Control, Collpad 2 and Collpad + Arg) was taken as the independent variable, while the pre-test score was used as the covariate. According to Keppel and Wickens (2004), a series of statistical checks must be carried out on the data before an ANCOVA can be conducted. To assess the normality of the residuals, the Shapiro-Wilk test was performed using the post-test scores for each group. For the Control Group, the Shapiro-Wilk test returned a p value of 0.43 (>0.05), while for the Collpad 2 Group it was 0.35 (>0.05) and for the Collpad + Arg Group it was 0.0055 (<0.05). This final figure suggests that the results from the ANCOVA should be treated with caution, as the residuals are not normally distributed for the Collpad + Arg Group. Levene’s test was used to test the equality of variances, giving a result of F(2,76) = 1.79, p =0.17 (>0.05). A value of greater than 0.05 suggests that there is equality of variances among the groups being compared (Levene, 1960).

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>29</td>
<td>12.48</td>
<td>14.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.86)</td>
<td>(3.27)</td>
</tr>
<tr>
<td>Collpad 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collpad 2 + Arg</td>
<td>23</td>
<td>14.48</td>
<td>17.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.36)</td>
<td>(2.38)</td>
</tr>
</tbody>
</table>
An analysis of variance (ANOVA) was used to reject the hypothesis that the covariate (i.e. the pre-test score) had an unequal influence on the different groups, taking the student’s group as the independent variable and their post-test score as the dependent variable, as well as including the covariate as an interaction term. The interaction term gave a result of $F(2,73)=2.57$, $p=0.083$ ($>0.05$), which suggests that the result of the pre-test does not have an unequal influence on the groups. Finally, as a requirement for considering the pre-test as a covariate, Pearson’s test was used to verify whether the pre-test scores are correlated with the post-test scores (Keppel & Wickens, 2004). The results of this test revealed a strong correlation (0.65).

Having tested the assumptions for the ANCOVA, we were able to carry out an analysis to detect whether there are any differences in the post-test scores among the groups, controlling for the pre-test score. The results of the ANCOVA (see Table 2-3) revealed significant differences between the groups, with a $F$ value of $F(2,75)=3.63$, $p=0.031$ ($<0.05$), which means that the different group conditions had some effect on learning.

<table>
<thead>
<tr>
<th></th>
<th>Sum squares</th>
<th>of df</th>
<th>Quadratic Mean</th>
<th>F Value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Test</td>
<td>328.7</td>
<td>1</td>
<td>328.7</td>
<td>61.3</td>
<td>$2.31 \times 10^{-11}$ ***</td>
</tr>
<tr>
<td>Group</td>
<td>38.7</td>
<td>2</td>
<td>19.3</td>
<td>3.6</td>
<td>0.031 *</td>
</tr>
<tr>
<td>Residuals</td>
<td>400.1</td>
<td>75</td>
<td>5.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p<.05, ***p<.001

Table 2-3. ANCOVA results.

Corrected means after performing the ANCOVA analysis are shown in table 2-4.

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>Adjusted Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>15.04</td>
<td>14.99</td>
</tr>
<tr>
<td>Collpad 2</td>
<td>14.66</td>
<td>15.21</td>
</tr>
<tr>
<td>Collpad 2 + Arg</td>
<td>17.3</td>
<td>16.66</td>
</tr>
</tbody>
</table>

Table 2-4. Corrected means after performing the ANCOVA.
To specifically determine which groups presented a difference, Tukey’s method was used for pairwise comparisons. The only comparison to reveal significant differences was between the Control Group and the Collpad+Arg Group, with a p value of 0.035(<0.05).

2.5. Discussion

The aim of this study was to look at how using scripts as scaffolding for developing arguments enhances learning in a collaborative problem solving activity. In order to do so, a quasi-experiment was designed involving three groups. These three groups worked collaboratively to solve geometry problems while following a learning script. The study took place over 10 sixty-minute sessions across a period of 4 weeks. To control for the impact of technology, a Control Group completed the activity without using technology. To assess the impact of explicitly integrating scaffolded argumentation, an argument builder was added (Collpad + Arg) to a collaborative problem solving script (Collpad 2).

There were no significant differences in student learning outcomes between the group without technology and the collaborative group without the argument builder. This may be explained by the fact that a similar learning script was used with both groups (Roschelle, 2013) (See Appendix 2). Accordingly, previous literature consistently shows that technology itself does not necessarily lead to better learning outcomes (OECD, 2015).

Significant differences were detected between the group without technology and the group with the built-in argument builder. This allows us to conclude that leading the students to reflect on their processes and outcomes by making them explicitly writing their point of view in the form of an argument has more of an effect on learning than the technological support. This process is very much in line with the need to develop productive learning environments using argumentation (Ibrahim & Harun, 2015), as well as with previous findings about explicitly
writing arguments to develop better understanding of subject matter (Jang, 2007) and to strengthen collaborative work (Papadopoulos, 2013). The results presented above are also in line with the findings from the literature presented in the theoretical framework for this study. Furthermore, they also help isolate the effect of technology, collaboration and argumentation on learning.

The idea that the pedagogical process in the classroom is more important than the technology is something that has been suggested in recent studies (OECD, 2015; Toyama, 2015). These studies make a call to put pedagogy, i.e. the process through which teachers relate with their students in order to achieve learning, as well as the surrounding conditions, at the centre of the education debate. As proposed by Glover (2016), integrating technology can only be effective if the specific needs of each educational context are taken into account.

As limitations to this study, we can highlight the number of students that were involved. The fact that no significant differences were revealed between the two groups that used technology may be due to the small sample size. It therefore remains as future work to expand this research to include larger groups of students so as to have more reliable statistics. Furthermore, having qualitative observations would allow us to understand the argumentation process and therefore establish causal relationships between the different types of scaffolding and the results that were obtained.
3. IS MORE DETAILED FEEDBACK BETTER FOR PROBLEM SOLVING?

3.1. Abstract

For several decades now, there has been considerable debate on the promises and the effectiveness of constructivist methodologies. In response to this, direct instruction has been put forward as an effective alternative. Through this approach, students are explicitly provided with as much information as possible during the learning process. Within this debate, the effectiveness of different degrees and types of feedback becomes increasingly relevant. The present study looks at two types of feedback: Knowledge of Results and Elaborated Feedback. The former consists of showing the student whether or not their answer is correct, while the latter consists of providing information through strategic hints, explanations or examples. A series of interactive problems was designed for tablets to cover a range of topics for fifth grade mathematics. Through a quasi-experimental design, one group of students (n=31) was provided with Elaborated Feedback, while another group (n=33) was provided with Knowledge of Results. Feedback was given to the students as they worked on the interactive problems over 6 sessions. The effectiveness of both types of feedback was then measured using a pre- and post-test. Although Elaborated Feedback helped the students achieve better results during the sessions, the Knowledge of Results group scored higher on the post-test. The results add to the growing debate on the importance of providing increasing levels of information or guidance, in an area that had not previously been explored, i.e. problem solving in primary education.

3.2. Introduction

Education systems across the world are asking how they can transition towards a system based
on developing the skills that are required in order to meet the challenges of an increasingly complex world (OECD, 2015). Different frameworks have been put forward to promote the development of so-called 21st century skills (Reimers & Chung, 2016). Problem solving plays a key role in developing higher-order things skills in all of these proposals (Jonassen, 1997; Chi, 2004; Savery, 2005; MINEDUC, 2012A; Häkkinen et al., 2017). However, although there is a consensus on the need to promote problem solving in the classroom, implementation is not always straightforward (Reimers & Chung, 2016).

The type of problems that are given to students in order to develop these skills is particularly important as it can shape the learning conditions (Jonassen, 1997). According to Jonassen’s (1997) analysis, problems can be classified as either well-structured or ill-structured. Well-structured problems are characterized by having convergent answers and a preferred, prescribed solution process. Ill-structured problems, on the other hand, are characterized by having multiple solutions and/or solution paths. Several authors have suggested that ill-structured problems are better suited to developing critical thinking and other higher-order thinking skills (Jonassen, 1999; Papert, 1993; Chin, 2004). Shin and Jonassen (2002) showed that different skills are developed when solving the two types of problem. Well-structured problems help build knowledge of the topic itself, while ill-structured problems help regulate cognition.

Pedagogical proposals that promote the essential role of problem solving are often underpinned by the constructivist approach. This approach has been widely adopted after being included in many education reforms in recent decades (Reimers & Chung, 2016). Despite the enthusiasm for the constructivist approach, there is considerable debate in the literature with regards to its effectiveness. This debate has been ongoing for several decades (Coben et al., 2010; Evans, M.
A. & Rick, 2014) and can be seen in the main education theories of the 20th century. Piaget (1970) and Dewey (1938) alluded to the need for students to learn from direct experience of the phenomena they are studying. Ausubel (1964) and Skinner (1968), on the other hand, highlighted the fact that conceptual learning can only be achieved through explicit information provided by direct instruction.

Throughout the 21st century, there has been an ongoing debate on the benefits of direct instruction vs. student-centered methods. An interesting example of this is the provocative paper published by Kirschner, Sweller & Clark (2006), who strongly criticize constructivist methods, branding them as minimal guidance approaches. This category includes methodologies such as problem based learning, inquiry based learning and experiential learning. The authors argue that those who promote such methodologies do so without any empirical evidence and without acknowledging recent advances in cognitive science. They also suggest that providing minimal guidance does not work as it overloads the students’ working memory by offering too many stimuli without any structure, thus hindering the formation of long-term memory. Given this, the most suitable approach would be to provide the students with as much guidance as possible, favoring direct, explicit instruction by the teacher.

Kirschner et al.’s paper prompted a series of responses. Hmelo-Silver, Duncan & Chinn (2007) suggest that problem based learning and inquiry based learning are not minimally guided. Instead, they depend on well-designed scaffolding, including the teacher’s actions, social interaction among peers and teaching materials. Furthermore, they also argue that Kirschner et al.’s empirical review is biased. They claim that there is evidence to suggest that these approaches allow students to gain more in-depth knowledge of the subject matter (Mergendoller,
Maxwell & Bellisimo, 2006; Norman, Brooks, Colle & Hatala, 2000), as well as developing skills that are otherwise difficult to address through direct instruction (Hmelo, 1998; Hmelo & Lin, 2000; Gallagher, Stepien & Rosenthal, 1992). Similarly, Schmidt, Loyens, Van Gog & Paas (2007) suggest that problem based learning is not minimally guided as it involves a system of scaffolding. This scaffolding consists of explicit skill development, the design of increasingly complex tasks, peer discussion and a tutor. They also indicate that single-response questions are often used to measure the effectiveness of such approaches, whereas problem based learning encourages students to develop open-ended responses. In this sense, the authors suggest that the wrong tools are being used to measure the true benefits of problem based learning.

In turn, Deanna Kuhn (2007) suggests that Kirschner et al. also ignore important aspects that underlie the issue of choosing a certain pedagogical approach over another. In this sense, Kuhn accuses the authors of ignoring the real objectives of education. Furthermore, she also highlights the lack of attention paid by the authors to contextualized practice and its effects on motivation. She argues that the focus of the methods criticized by Kirschner et al. is to provide students with additional context and motivation. Finally, she suggests that the only way to prepare for the real world is to develop complex skills through complex situations.

Sweller, Kirschner & Clark (2007) answered their critics in a subsequent paper, reaffirming the need for students to be given as much guidance as possible and making a call to rigorously investigate different aspects of student instruction.

A meta-analysis conducted by Alfieri, Brooks, Aldrich & Tenenbaum (2011) looks to weigh up the evidence on the effectiveness of different instructional approaches. Their study reveals that
explicit instruction leads to better results than unguided, discovery based learning. However, enhanced discovery learning is more effective than any other method. The findings from this analysis suggest that not guiding students at all is not effective, which is not the case with certain types of feedback, worked examples and other types of scaffolding.

There is evidence on how to support the learning process during problem solving from the field of computer assisted learning (Kulik & Fletcher, 2015). The most important element of a computer system when it comes to guiding students is feedback. Studying the effectiveness of different types of feedback and in different educational contexts is therefore crucial (Goldin, Narciss, Foltz & Bauer, 2017).

The effectiveness of feedback in learning is currently being studied in different fields, such as professional development among technical professionals (Toader & Lungu, 2015), early literacy (Wood, Grant, Gottardo, Savage & Evans, 2017; Patchan & Puranik, 2016), vocabulary acquisition (Frishkoff, Collins-Thompson, Hodges & Crossley, 2016), formative assessment (Timmers, Walraven & Veldkamp, 2015; Shute & Rahimi, 2017; Faber, Luyten & Visscher, 2017) and adaptive learning environments (Heffernan et al., 2016). Despite the importance of feedback in instructional design (Hattie, 2007), there is little consensus on its effectiveness and how it should be implemented in computer systems. Van der Kleij, Feskens & Eggen (2015) detected this mismatch and conducted a meta-analysis in order to clarify the issue. According to Shute (2008), the most common types of feedback can be classified into three categories according to the type of information that is given to the students. These categories include Knowledge of Results, Knowledge of Correct Response and Elaborated Feedback. Knowledge of Results consists of showing the students whether or not their answer was correct. Knowledge of
Correct Response consists of explicitly showing the students which is the correct answer, while Elaborated Feedback consists of providing students with information through strategic hints, explanations or examples. The conclusion from Van der Kleij et al.’s (2015) meta-analysis is the more elaborated the feedback, the greater the impact on learning. In other words, in terms of the effect size of the interventions that were reviewed, Elaborated Feedback is more effective than Knowledge of Correct Response, which in turn is more effective than Knowledge of Results. The authors note that their meta-analysis focuses mainly on higher education and, to a lesser extent, secondary education. They also note that there is very little research in this area in primary education. Furthermore, the results are based on post-tests that are taken immediately after short interventions, leading the authors to call for more empirical studies, especially in an educational context. Recent studies have shown that the effectiveness of feedback may even vary for different types of problem within the same subject (Chase & Klahr, 2017). It is worth noting that none of the studies that compare different types of feedback within the context of higher-order thinking skills focus on problem solving in primary education.

Within this context, Emily Fyfe (2016) recently conducted a series of empirical studies looking at the effect of feedback in real-life educational settings. Fyfe & Rittle-Johnson (2016) carried out a study with primary school students, focusing on problem solving in arithmetic. From this experience, they conclude that feedback can have positive and negative effects, depending on the students’ prior knowledge. The authors explain the positive effect on students without prior knowledge by arguing that feedback encourages students to pay attention, engage with the task and develop different strategies. In the same study, however, students with greater knowledge of problem solving strategies performed worse. The authors explain this result by suggesting that
encouraging students to look for new strategies may lead to cognitive overload and cause confusion. In another experimental study, Fyfe (2016B) obtains similar results with secondary school students within the context of problem solving in algebra. She concludes that different types of feedback help students with little prior knowledge, but that there is no effect on students with no prior knowledge. Her study does not reveal any significant differences between different types of feedback. The author therefore recommends designing experiments in order to study the effectiveness of different types of feedback, including feedback that adapts and changes based on the students’ answers. In a third experimental study on feedback, Fyfe & Rittle-Johnson (2017) look into the effects of feedback immediately after an intervention, as well as a week later. The results of this experiment suggest that immediate feedback helps students to perform better during practice. However, students who did not receive any feedback performed better on a post-test measuring knowledge retention. The authors therefore conclude that certain students may be better off without receiving any feedback, especially those with more prior knowledge.

Fyfe’s studies call for a more in-depth investigation into the effects of feedback. They also call into question the results from Van der Kleij et al.’s (2015) meta-analysis, which concludes that giving students more detailed information leads to improved learning. Although there are recent studies which suggest that giving feedback is more beneficial than not giving feedback (Basu, Biswas & Kinnebrew, 2017), the discussion regarding giving more or less detailed feedback is yet to be resolved. There is even less evidence on the benefits of giving feedback to students in primary school (Schaeffer, Margulieux, Chen & Catrambone, 2016).

Given this lack of evidence, particularly within the context of problem solving, our research question asks the following: Is more detailed feedback better for problem solving? In particular,
the present study aims to compare the impact on learning in problem solving between a system of Elaborated Feedback and a system based on Knowledge of Results, two types of feedback that provide very different levels of guidance (Van der Kleij, Feskens & Eggen, 2015). Our study will analyze this impact both immediately after an intervention, as well as on a subsequent post-test.

3.3. Methodology

3.3.1. Instruments used

A series of interactive problems was designed to compare the effect of different types of feedback on learning in problem solving. As the specific aim of the study is to compare Elaborated Feedback with Knowledge of Results, a scaffold based on each of these systems was also designed, as well as a test to measure their impact. The present section provides details of the instruments that were designed and the methodology that was adopted.

3.3.1.1. Interactive problems

Recently, personal mobile devices (particularly tablets) have drawn considerable attention and enthusiasm from promoters of pedagogical innovation. This is because of their growing presence, potential for interactivity, functionality and ergonomics (Hung, Sun & Yu, 2015; Patten, Sánchez & Tangney, 2006; Haßler, Major & Hennessy, 2016).

For the present study, a series of interactive problems was designed through a process of Design Based Research (Reeves, 2006). This involved an iterative design that was tested on pilot groups throughout the implementation. The aim of these tests was to ensure that the problems were sufficiently challenging and at an appropriate difficulty level for the chosen age group (Hamari
et al., 2016). They also ensured that the time needed to solve the problems was compatible with the time available in a real classroom setting, that the instructions were easy to follow and the tools were easy to use. Finally, this process also allowed the researchers to test whether or not the feedback that was designed helped the students solve the problems. As well as testing the design on pilot groups, the proposal was also validated by the teacher of the final experimental groups. As a result of this process, it was decided that three exercises with elaborated feedback was a good number for a class of 90 minutes. The initial tests revealed that the time taken to solve the problems varied significantly. It was therefore decided that students who could successfully complete the exercises with elaborated feedback should complete a total of eight additional exercises. Furthermore, a joint decision was made with the teacher to conduct the study in six sessions over a period of six weeks.

The problems were created using the programming platform Unity (Technology, 2016) for tablets using the Android operating system.

The topics covered by the problems were defined based on the fifth-grade mathematics curriculum (MINEDUC, 2012A). The research team chose a set of topics from different strands so as to design challenging, non-routine problems that had different possible solution paths and were aligned with the curriculum. Each session focused on a different learning objective and covered the topics that are shown in Table 3-1, below.

<table>
<thead>
<tr>
<th>Session</th>
<th>Strand</th>
<th>Learning Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Numbers and</td>
<td>Counting strategies using two-dimensional</td>
</tr>
</tbody>
</table>
The problems that were designed can be found in Appendix 5.

### 3.3.1.2. A proposal for Elaborated Feedback

To study the effect of Elaborated Feedback on learning, a scaffold was designed that mediated the students' interaction in the problem-solving process. According to Zheng (2016), the theoretical foundation of scaffolds is to provide the students with guidance as and when they need it in order to improve their skill level.

Kirschner, Sweller & Clark (2006) urge their readers to bear in mind that student-centered learning methods are not effective if they do not provide sufficient guidance. According to Van Meeuwen (2013), systems must be designed that provide students with detailed information
based on their individual needs. Considering this, a scaffold was designed with different levels of feedback depending on the student’s level of achievement for each problem. The system classifies the student into one of three levels based on the level of feedback they require: autonomous, guided and directed. Students at the autonomous level do not require feedback as it is the level assigned when they do not make any mistakes. At the guided level the students are given a hint as they are expected to be able to complete the exercise without explicit instruction. Finally, at the directed level students are given direct instruction as they are not able to complete the exercise using only hints.

The messages that were designed for each of the sessions can be found in Appendix 6. Figure 3-1 shows how the system works.
The system reacts to the mistakes made by the students, with the level of detail in the feedback increasing if the students are not able to arrive at the correct answer (Figure 3-1). The continuous lines in the figure demonstrate the flow for when the student gives the correct answer, while the dotted lines demonstrate the flow for when the student makes a mistake. At the beginning of the program, the students are shown a message (M1), inviting them to solve the first problem (Type 1, Version 1). If the student completes the exercise correctly, they are congratulated (M2) and move on to the next problem. If the student makes a mistake they are given a hint (M1.1) and must repeat the exercise (Type 1, Version 1). If they make another mistake, they are given more specific instructions as to how to solve the problem (M1.2) and must repeat the exercise once more (Type 1, Version 1). If they continue to make mistakes, they are given direct instructions again (M1.3). At both the guided and directed levels, if the student gets the correct answer they are given another exercise of the same type, but a different version (Type 1, Version 2). The aim of this is to ensure that they can solve the problem without any help, with the students invited to do so through a motivational message (M1.4). If the student makes a mistake on this exercise, they are given a hint (M1.5) and must return to Version 1 of the exercise. Once the student is capable of completing the exercise without any feedback, they continue on to the next exercise.

The complete flow for each session with the experimental group that worked with Elaborated Feedback consisted of repeating the cycle described above with three problems of increasing levels of difficulty (Type 1, Type 2 and Type 3). Each problem focused on the same learning objective and covered the same topic. Upon completing the three problems, the students then continue with 8 further variations (Figure 3-2).
Should the students manage to complete the three exercises (Types 1, 2 and 3) with Elaborated Feedback, they then work on up to 8 additional exercises; in this case with only feedback regarding Knowledge of Results. This system allows all information entered in the tablets to be collected and subsequently analyzed in a log file (e.g. number of correct and incorrect answers, time taken, choice of tools for solving each exercise, etc.)

With the Knowledge of Results group, the students were presented with a linear sequence of eleven problems. If they made a mistake, they were told that their answer was incorrect and they were invited to try again. If they got the answer right, they continued to the next problem.

The information obtained from the log files of both systems allowed the researchers to assess the immediate students’ performance.
3.3.1.3. Pre- and Post-test

The pre- and post-test that was designed by the research team contained 8 problems that were similar to those used in the classroom sessions, with an open-ended response (see Appendix 7). The students were first asked to solve the problem and then to explain the problem-solving strategy that they adopted. The students were awarded two points for their explanation and two points for getting the correct answer. The objective of the test was therefore to measure the students’ ability to transfer the knowledge they had acquired during the sessions.

Cronbach’s alpha was calculated in order to determine the internal validity of the test. As Cronbach’s alpha depends on the sample, it was calculated for each measurement that was taken. For the pre-test, Cronbach’s alpha for the Knowledge of Results group was 0.7 and for the Elaborated Feedback group it was 0.78. For the post-test, Cronbach’s alpha as 0.78 and 0.76, respectively. According to George & Mallery (2003), a Cronbach’s alpha of more than 0.7 indicates internal validity.

3.3.2. Experimental Design

A quasi-experiment was designed in order to determine the effect of different types of feedback on learning in problem solving. The experiment involved two groups of fifth-grade students from a lower-middle class voucher school in Santiago, Chile. The school’s results on national standardized tests are in line with the national average. The Knowledge of Results group contained 33 students (13 girls and 20 boys), while the Elaborated Feedback group contained 31 students (9 girls and 22 boys). The same teacher led the sessions for both groups. This teacher was also the regular classroom teacher for both groups.
One of the groups received Elaborated Feedback via the system described in the previous section. The other group received Knowledge of Results, i.e. they were only told whether their answer was correct or incorrect. If their answer was incorrect, the students had to try again, while if it was correct they were congratulated and given a new problem to solve.

The decision as to which group would receive Elaborated Feedback and which would receive Knowledge of Results was made at random. Both groups worked for six sessions on solving the interactive problems presented above.

At the start of each session, the teacher gave a brief introduction to the class using a presentation prepared jointly with the research team. Through this presentation, the students briefly reviewed the content that they would need in order to solve the problems, as well as going over behavior management (e.g. don’t hit the tablets, work conscientiously, ask in case of difficulties etc.) and being shown the functionality of the system. Following this, during the class the teacher intervened to answer the students’ technical questions and to mediate in case of frustration or misbehavior. During this part of the session the students were allowed to interact with each other and with the teacher in case of technical difficulties. Once all of the students had finished the exercises, or when the time ran out, the teacher briefly talked with the group about the strategies that they used to solve the problems. This procedure was followed in the same way with both groups.

The sessions were conducted during the students’ regular mathematics classes and lasted for 90 minutes. The sessions, as well as the pre- and post-test, were held on a weekly basis. Therefore, the intervention lasted for a total of 8 weeks.
The data that was gathered using the tablets in each session was then analyzed in order to measure the immediate effectiveness of the feedback system. A pre-test was applied a week before the sessions began, with a post-test a week after they ended. The results of these tests were then used to measure the impact of both types of feedback.

3.4. Results and analysis

The results from the pre-test and post-test for both groups are detailed below.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Pre-test Mean (SD)</th>
<th>Post-test Mean (SD)</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge of Results</td>
<td>33</td>
<td>17.84 (4.54)</td>
<td>24.27 (4.43)</td>
<td>10.28</td>
<td>&lt; 0.00001*</td>
</tr>
<tr>
<td>Elaborated Feedback</td>
<td>31</td>
<td>18.87 (4.97)</td>
<td>23.03 (4.39)</td>
<td>5.51</td>
<td>&lt; 0.00001*</td>
</tr>
</tbody>
</table>

*p<0.05

Table 3-2. Pre-Post-test descriptive

In both cases, the intervention had a significant impact. Cohen’s d was calculated in order to determine the effect size for each group (Morris & DeShon, 2002). The effect size for the Knowledge of Results group was \( d = 1.43 \), which, according to Sawilowsky (2009) is very large. For the Elaborated Feedback, the effect size was \( d = 0.88 \), which indicates a large effect size according to Cohen (1988).
An analysis of covariance (ANCOVA) was conducted in order to determine whether there were any significant differences in the groups’ performance on the post-test. For this analysis, the dependent variable was the result on the post-test and the independent variable was the type of feedback received. The students’ scores on the pre-test was also used as a co-variable. According to Keppel & Wickens (2004), the residuals must be normally distributed in each group in order to conduct an ANCOVA. They also suggest that the variances should be equal, that the co-variable should influence both groups equally and that there should be a significant correlation between the co-variable and the independent variable.

The Shapiro-Wilk test was used to check the distribution of the residuals, both on the pre-test as well as the post-test. The results for the pre-test were $p = 0.13 (>0.5)$ for the Elaborated Feedback group and $p = 0.0083 (<0.05)$ for the Knowledge of Results group. The results for the post-test were $p = 0.57 (>0.05)$ and $p = 0.66 (>0.05)$, respectively. The null hypothesis for this test can therefore be rejected in each case except for the pre-test for the Knowledge of Results group. This suggests that the results should be interpreted with caution. The equality of variances was verified using Bartlett’s test. The result of this test was 0.96 (>0.05), indicating that the variances are homogenous. The lack of interaction between the co-variable (i.e. the result on the pre-test) and the student’s group was verified using an ANOVA, with type of feedback as the independent variable and the co-variable as the interaction term. The interaction term returned $F(1, 60) = 2.57, p = 0.347 (>0.05)$, i.e. not significant. We can therefore rule out any interaction between the result on the pre-test and the student’s group. Finally, the correlation between the co-variable and the independent variable is between moderate and strong, $R=0.58$, with a significant p-value of $3 \times 10^{-7}(<.05)$. It is therefore reasonable to consider the results of the pre-
test as a co-variable.

These results mean that an ANCOVA could be carried out, with the results shown in Table 3-3, below.

Table 3-3, ANCOVA

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Quadratic Mean</th>
<th>F value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Test</td>
<td>427.5</td>
<td>1</td>
<td>427.5</td>
<td>34.66</td>
<td>1.8*10^{-07} ***</td>
</tr>
<tr>
<td>Group</td>
<td>52.5</td>
<td>1</td>
<td>52.5</td>
<td>4.257</td>
<td>0.0434 *</td>
</tr>
<tr>
<td>Residuals</td>
<td>752.2</td>
<td>61</td>
<td>12.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p<.05, ***p<.001

There are significant differences between the post-test scores if we control for the results of the pre-test. The adjusted means from the ANCOVA are shown in Table 3-4, below.

Table 3-4, adjusted means

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>Adjusted Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge of Results</td>
<td>24.27</td>
<td>24.55</td>
</tr>
<tr>
<td>Elaborated Feedback</td>
<td>23.03</td>
<td>22.73</td>
</tr>
</tbody>
</table>

The results from the ANCOVA (Table 3-3) and the adjusted means (Table 3-4) reveal that the Knowledge of Results group performed significantly better on the post-test.

According to some authors (Timmers & Veldkamp, 2011; Van der Kleij et al., 2012), one
important issue regarding feedback is that students do not always pay attention to the feedback that is given. A comparative analysis was carried out for the effectiveness of the feedback (i.e. the number of correct answers as a percentage of the total attempts for each session). Doing so allows the immediate effectiveness of the feedback to be studied. The results of this analysis can be found in Table 3-5.

<table>
<thead>
<tr>
<th>Session</th>
<th>Elaborated Feedback Effectivity Mean(SD)</th>
<th>Knowledge of Results Effectivity Mean (SD)</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.65 (0.2)</td>
<td>0.54 (0.25)</td>
<td>1.87</td>
<td>0.033*</td>
</tr>
<tr>
<td>2</td>
<td>0.64 (0.2)</td>
<td>0.62 (0.19)</td>
<td>0.2</td>
<td>0.41</td>
</tr>
<tr>
<td>3</td>
<td>0.53 (0.2)</td>
<td>0.3 (0.21)</td>
<td>3.75</td>
<td>0.0002*</td>
</tr>
<tr>
<td>4</td>
<td>0.46 (0.25)</td>
<td>0.47 (0.22)</td>
<td>-0.2</td>
<td>0.408</td>
</tr>
<tr>
<td>5</td>
<td>0.41 (0.1)</td>
<td>0.21 (0.1)</td>
<td>7.78</td>
<td>0.00001*</td>
</tr>
<tr>
<td>6</td>
<td>0.32 (0.09)</td>
<td>0.18 (0.1)</td>
<td>6.13</td>
<td>0.00001*</td>
</tr>
</tbody>
</table>

* significant at p<0.05

Table 3-5, Comparing the immediate effectiveness for arriving at the correct answer

In four of the six sessions (sessions 1, 3, 5 and 6), the level of effectiveness was significantly higher for the Elaborated Feedback group (Table 3-5). This suggests that, at least in the immediate, short term, the Elaborated Feedback system that was designed allowed students to be more efficient when solving the problems.
3.5. Discussion and Conclusions

There is little empirical evidence on the impact of providing primary school students with more or less guidance during the learning process when solving problems. Therefore, the aim of the present study was to determine the impact of two types of feedback in this context: Elaborated Feedback and Knowledge of Results. As a system of Elaborated Feedback provides students with more guidance than a system based on Knowledge of Results, comparing the two allows us to answer the research question “Is more detailed feedback better for problem solving?”

In order to answer the research question, a quasi-experiment was designed, including a pre- and post-test. After six classroom sessions, spread over a period of six weeks, the results consistently show that Elaborated Feedback allows students to solve problems more efficiently. However, the results from the post-test suggest that students who received less guidance (i.e. the Knowledge of Results group) learned more. It is worth noting that the Elaborated Feedback appears not to have had an effect on the group in two of the six sessions (Table 3-5, sessions 2 and 4). We should point out that there were certain peculiarities in both of these sessions that may explain this result. The scores for the Knowledge of Results group in session 2 were particularly good, in fact they were the best scores across the six sessions. This may suggest that the Feedback was not really needed, with both groups performing similarly. The ineffectiveness of the feedback in session 4, on the other hand, may be due to the fact that the strategy that was suggested was difficult for the students who received feedback to understand. This is because the strategy involved more steps than the strategies for the other sessions (see Appendix 5).

This result is consistent with the empirical evidence found by Fyfe (2017), who revealed that not
providing feedback may be beneficial. According to different studies (Rittle-Johnson, 2006; Siegler & Shipley, 1995), discovering new procedures for solving problems is a key source of cognitive change and may be an important predictor of future performance. More broadly, these results are in line with the findings from Dean & Kuhn (2007), who replicated an experiment showing that direct instruction leads to improved learning when compared with discovery-based methods. When replicating the experiment, the authors carried out a delayed post-test and showed that, in the long-term, the discovery-based group achieved better results.

The results of the present study are in the same line as those that question the vision of Kirschner et al. (2006), who advocate giving students as much guidance as possible. To support this position, the authors refer to cognitive load theory. However, subsequent studies, such as Kalyuga & Singh (2015) recommend revisiting cognitive load theory for more complex learning objectives that go beyond acquiring domain-specific conceptual knowledge.

One branch of research which may help explain our results is so-called Productive Failure (Kapur, 2010). Kapur suggests that mistakes are an essential part of deeper learning. This is because they force students to face knowledge that they have not yet acquired and question for themselves how they might improve. In the present study, the Elaborated Feedback group received direct and immediate feedback if they made a mistake, unlike the Knowledge of Results group, who were able to follow the process described by Kapur.

Another interesting finding from the present study is that the effect size for both groups was either large or very large. It is therefore interesting to see how beneficial the interactive problems designed for this study may be when helping students learn how to tackle problem solving,
regardless of the type of feedback they receive.

It remains as future work to expand this study to include a larger number of participants. Doing so would allow for a more detailed study of the effects of the feedback on different sub-groups of students, as has been recommended by previous investigations (Fyfe, 2016). It would also be important to replicate this same experiment with other types of problems and also in other subjects as the results are not necessary transferable to other areas. Furthermore, different systems of feedback could also be designed in order to allow for greater levels of personalization based on each student’s individual actions.
4. IMPLEMENTING CRITICAL THINKING FROM A TEACHER’S PERSPECTIVE

4.1. Abstract

Studies on critical thinking have often overlooked the work done by teachers to develop this skill in the classroom. However, studying critical thinking from the teacher’s perspective is key to closing the gap between theory and practice. This study looks to characterize the work done by Spanish-speaking teachers in Latin America when implementing critical thinking in the classroom. This is achieved by analysing the topics chosen by the teachers, the activities they propose, and how they link these activities to the development of critical thinking. The results show that teachers primarily try to develop their students’ critical thinking skills by integrating them into their subjects. Furthermore, they do so by using topics that help the students understand the world better, as well as introducing them to different subject-specific practices. These results suggest that there is a mismatch between educational practice and existing research, which tends to advocate the specific and explicit teaching of critical thinking, whether as a separate subject or through a cross-curriculum approach.

4.2. Introduction

Different education systems have highlighted the importance of citizens acquiring the necessary skills to participate in an ever-changing and increasingly-complex world (Pellegrino & Hilton, 2012). This includes critical thinking, which is thought to strengthen democracies and allow citizens to actively participate in an economy that requires increasing levels of preparation (Behar-Horenstein & Niu, 2011). Furthermore, mastering critical thinking is a better predictor of successful life decisions than other factors such as intelligence (Butler, Pentoney, & Bong, 2017;
Several issues have been addressed by the research into critical thinking over the last few decades. This includes how to define, measure and develop the skill, as well as the effectiveness of different strategies for teaching it (Larsson, 2017). Despite the wealth of research, there is still little evidence on what teachers are effectively doing in the classroom in order to teach this skill (Abrami et al., 2014; Larsson, 2017). This is especially true in schools settings, even though it has been proven that critical thinking can be developed from a young age (Kuhn, 1999).

Understanding educational phenomena from everyday teaching practice can help bridge the gaps between research, public policy and continuing professional development (Farley-Ripple et al., 2018; Vanderlinde & van Braak, 2010; McIntyre, 2005). Given its importance, this study aims to reduce the gap between research and teaching practice when it comes to critical thinking. This is done by exploring the work that teachers are doing to develop critical thinking in the classroom. Our research has a practical focus and is guided by ongoing discussions in the literature. We look at the topics teachers choose to teach critical thinking, the activities they propose for their students and how these activities relate to the development of this skill. Furthermore, we also look at how these practices vary according to the students’ age, as well as the subject that is being taught.

4.3. Literature review

4.3.1. Definitions of critical thinking

Given the variety of definitions for critical thinking and the lack of consensus among experts,
previous authors have proposed different ways of classifying these definitions. Lai (2011) suggests that the definitions should be grouped according to the author’s field, e.g. psychology, philosophy or education.

According to Lai (2011), definitions from the field of psychology tend to refer to cognitive skills. In this sense, critical thinking is understood to be a process. As such, the definitions therefore focus on the mental activities required when using this skill. One example of this is the definition proposed by Dwyer, Hogan, & Stewart (2014), who define critical thinking as “a metacognitive process that, through purposeful, reflective judgement, increases the chances of producing a logical conclusion to an argument or solution to a problem” (p. 43).

Definitions from the field of philosophy have their roots in ancient Greece and Socratic philosophy, both of which are still valid to this day. This approach focuses more on the end result of critical thinking, rather than on the process itself. Two of the most frequently cited definitions from this category include Ennis (1985), who considers critical thinking to be “reflective and reasonable thinking that is focused on deciding what to believe or do”, and Paul’s (2009), who views it as “disciplined, self-directed thinking that exemplifies the perfections of thinking appropriate to a particular mode or domain of thought”.

Finally, in the field of education, critical thinking is used interchangeably with the concept of higher order thinking, from Bloom’s taxonomy (Anderson et al., 2001). According to Bloom’s taxonomy, cognitive skills can be classified according to their level of complexity. In this sense, higher-order thinking skills therefore refer to the levels of analysis, synthesis and evaluation.

Barnett (1997) acknowledges the difficulty of defining the concept of critical thinking, arguing
that it depends on how the skill is used. He therefore identifies at least four different ways of using critical thinking: as disciplinary competence, as practical knowledge, as political engagement, and as a form of strategic thinking. This range of definitions, together with the multidimensional nature of the proposed constructs, ensures that critical thinking is a difficult concept to operationalize (Bensley et al., 2016). As a result, it has been suggested that instead of discussing what critical thinking means in theory it is more important to understand what it refers to in practice (Davies & Barnett, 2015; Moore, 2013). Moore (2013) suggests that research into critical thinking has tended to define the skill in abstract terms, separating it from its practical uses. Davies and Barnett (2015) add that critical thinking is often reduced to a series of mental processes that take place on an individual level, rather than looking at it within the context of social interactions. In the following section, we will therefore look at how critical thinking is implemented in an educational setting.

4.3.2. Implementing critical thinking in an educational setting

Regardless of its definition, several different strategies have been proposed for teaching critical thinking in the classroom. Ennis (1989) provided a classification that is still applicable today (Abrami et al., 2014), dividing these teaching strategies into three groups: general, infusion and immersion.

The general approach suggests that critical thinking is a cross-curricular skill that requires specific knowledge on how it works. The teaching of critical thinking must therefore focus on explicitly teaching its guiding principles, as well as putting it into practice through exercises that promote its use. Pioneering studies into critical thinking focused on this type of intervention
Infusion strategies also suggest explicitly teaching the principles and practices of critical thinking, albeit integrated into another subject. Robert Swartz (Swartz & Parks, 1994) has produced plenty of material for integrating critical thinking into key areas of the curriculum, as well as suggesting how to select the most suitable topics for doing so. Alan, Bensley & Spero (2014) worked with a class of undergraduate psychology students to prove the effectiveness of explicitly teaching different methods for developing metacognition and analysing arguments, both of which they consider to be essential components of critical thinking. Finally, McLaughlin & McGill (2017) proposed teaching a school-level history class how to identify pseudoscientific information, understanding critical thinking to be the ability to question proposals based on evidence.

The third group of strategies, referred to as immersion, suggest that critical thinking can be developed by teaching subjects rigorously and inviting students to question and engage in deep thought. However, they do not believe in the need to explicitly outline the rules for critical thinking. Authors who adhere to this approach suggest involving students in rigorous thinking, an exchange of ideas, or civic engagement (Huber & Kuncel, 2016).

In their meta-analysis, Abrami et al. (2008) conclude that the most effective strategies are those that explicitly teach critical thinking, while tying them to a specific subject. Despite the wealth of literature recommending that critical thinking be taught explicitly, there is little evidence on the transferability of such knowledge and skills to different contexts or domains (Pellegrino & Hilton, 2012). There has therefore been growing interest over recent years in designing strategies
for specific subjects, such as psychology (Stuple et al., 2017), healthcare (Carvalho et al., 2017), and the humanities (McLaughlin & McGill, 2017). Furthermore, in a school setting, there are even fewer examples of how to integrate the teaching of critical thinking into different subjects. In addition to the study by Swartz (1994), one exception to this is the work by Cargas, Williams, & Rosenberg (2017), who propose designing a rubric to specify achievement criteria based on critical thinking standards for use in different subjects. Given this research gap, the present study will focus on teaching practices in a school setting.

There are several different strategies for implementing and developing critical thinking in the classroom. These can be classified into four categories (Abrami et al., 2014). The first of these, individual study, includes strategies where students must work on their own on the proposed activities. The second, dialogue, is characterized by an emphasis on discussion. The third, authentic or anchored instruction, refers to the selection of authentic problems or situations that are of interest to the students. Finally, mentoring, refers to strategies that bring together a subject matter expert with novices. Abrami et al. (2014) suggest that the best results are obtained by combining dialogue with authentic or anchored instruction. However, there are few studies on this in a school setting.

4.3.3. Critical thinking in practice

The aforementioned definitions, classifications and strategies have been used to design a series of interventions, as well as to study their impact (Abrami et al., 2014). This has provided an evidence base on how to effectively develop this skill. However, there is little research into the work done by teachers in the classroom, other than the interventions designed by academics
(Abrami et al., 2014; Moore 2013). It is also unclear how in-service teachers implement critical thinking in the classroom (Davies & Barnett, 2015). In order for research to be useful to educators, it must focus on the teachers’ practices (Farley-Ripple et al., 2018), as well as on understanding the teaching and learning practices involved in critical thinking (Vanderlinde & van Braak, 2010; McIntyre, 2005).

Among the studies that do focus on critical thinking from a teacher’s perspective, some are based on higher education, while others focus on school settings. The studies in higher education conclude that what is understood by critical thinking largely depends on the cultural context (Chen, 2017). Similarly, albeit in a school setting, Howe (2004) compares the beliefs held by Canadian and Japanese teachers regarding critical thinking, concluding that the conceptualization of this skill varies between cultures. Within the field of healthcare, where research into critical thinking has a proud tradition (Carvalho et al., 2017), one outstanding study is Huang, Lindell, Jaffe, & Sullivan (2016), who look at the what, how and why of teaching critical thinking in health-related degree programs in higher education. The results of this study suggest that the lecturers who were interviewed focus on teaching “mental habits”, such as the use of higher order thinking skills or metacognition. They also teach critical thinking by rigorously implementing the principles of clinical practice, doing so to ensure that their graduates go on to become better healthcare professionals. Finally, on a school level, one study reveals that teachers in Jordan do not know what critical thinking is, despite the need for students to develop this skill forming part of the public agenda (Bataineh, 2009). Teachers in the USA, on the other hand, highlight the need to develop content for teaching critical thinking skills (Reynolds, 2016).

This wide range of definitions, classifications and strategies for teaching critical thinking
suggests that many of the debates in the literature are still ongoing. Despite there being some level of agreement on how important and beneficial it would be to address these issues from the perspective of teaching practices, there are very few studies which do so. It is therefore hugely important to study the development of these skills among school-age students (Reymers & Chung, 2016) and from the perspective of teaching practices. In this sense, our first research question asks “What are teachers doing to implement critical thinking in the classroom?”. More specifically, our study looks to answer this question by looking at which topics teachers use with their students, the activities they expect them to carry out, and how these activities relate to the development of critical thinking. Furthermore, the study will also look at how much these practices depend on the age of the students and the subjects in which they are being implemented.

4.4. Methodology

4.4.1. Participants

Convenience sampling was used to select the participants from a database of teachers enrolled on the online course “Towards a constructivist approach in the classroom”\(^1\). This course was delivered on the Coursera platform and was aimed at Spanish-speaking teachers. Furthermore, the course was designed for teachers who are interested in developing constructivist learning environments. It covers topics such as skill development, classroom culture and integrating technology in the classroom. An invitation to participate in this study was sent to all 29,216 participants on the course. Appendix 9 shows the demographics of the database to which the

\(^{1}\) https://es.coursera.org/learn/aulaconstructivista
A total of 380 people answered the survey in full, over a period of four months. Responses from participants who taught in higher education were not considered (88). Nor were responses from participants whose answers did not provide the information that was requested (14). Therefore, a total of 278 responses were analysed. Table 4-1 shows the demographics of the participants in this study.

<table>
<thead>
<tr>
<th>Age of the students</th>
<th>N (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 to 13 years</td>
<td>104 (37.4%)</td>
</tr>
<tr>
<td>14 to 18 years</td>
<td>174 (62.58%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Subject area¹</th>
<th>N (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics</td>
<td>38 (13.4%)</td>
</tr>
<tr>
<td>Natural Sciences</td>
<td>85 (30.6%)</td>
</tr>
<tr>
<td>Social Sciences</td>
<td>57 (20.5%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age of the participants</th>
<th>N (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-24</td>
<td>17 (6.1%)</td>
</tr>
<tr>
<td>25-34</td>
<td>46 (16.5%)</td>
</tr>
<tr>
<td>35-44</td>
<td>73 (25.2%)</td>
</tr>
<tr>
<td>45-54</td>
<td>94 (32.8%)</td>
</tr>
<tr>
<td>55-64</td>
<td>41 (14.7%)</td>
</tr>
<tr>
<td>&gt; 65</td>
<td>7 (2.5%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gender</th>
<th>N (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masculine</td>
<td>176 (63.3%)</td>
</tr>
<tr>
<td>Feminine</td>
<td>95 (34.2%)</td>
</tr>
<tr>
<td>Other</td>
<td>7 (2.5%)</td>
</tr>
</tbody>
</table>

---

¹ Appendix 8 includes a description of the subjects comprising each area
### Table 4.1. Participants’ demographics

<table>
<thead>
<tr>
<th>Participant’s country</th>
<th>N</th>
<th>(Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chile</td>
<td>58</td>
<td>(20.9%)</td>
</tr>
<tr>
<td>Mexico</td>
<td>57</td>
<td>(20.5%)</td>
</tr>
<tr>
<td>Colombia</td>
<td>27</td>
<td>(9.7%)</td>
</tr>
<tr>
<td>Ecuador</td>
<td>27</td>
<td>(9.7%)</td>
</tr>
<tr>
<td>Peru</td>
<td>24</td>
<td>(9.6%)</td>
</tr>
<tr>
<td>Guatemala</td>
<td>6</td>
<td>(2.2%)</td>
</tr>
<tr>
<td>Honduras</td>
<td>6</td>
<td>(2.2%)</td>
</tr>
<tr>
<td>El Salvador</td>
<td>6</td>
<td>(2.2%)</td>
</tr>
<tr>
<td>Dominican Republic</td>
<td>6</td>
<td>(2.2%)</td>
</tr>
<tr>
<td>Venezuela</td>
<td>6</td>
<td>(2.2%)</td>
</tr>
<tr>
<td>Other</td>
<td>34</td>
<td>(12.2%)</td>
</tr>
</tbody>
</table>

**4.4.2. Procedures**

An exploratory study was conducted following a mixed methods approach (Creswell, 2014). Twining, Rachelle, Nussbaum & Tsai (2016) recommend adopting a qualitative approach when exploring phenomena that have not been studied before and that require an interpretative and inductive focus, which is the case here. Using this approach, an online survey was designed to include both closed and open-ended questions. The open-ended questions were designed to gather information on the teachers’ practices, while the closed-ended questions were designed to gather information on the participants’ demographics. The survey was sent to the participants
enrolled on a MOOC (Massive Online Open Course), a description of which can be found in section 3.1.

The responses to each of the open-ended questions were analysed using an inductive methodology based on emerging categories (Glaser & Strauss, 2017) and a technique for analysing eclectic content (Saldaña, 2015). Emerging categories allow different phenomena to be understood through situated analysis (Glaser & Strauss, 2017), which is the aim of the present study. In general terms, the categorization used corresponds to a process of structural analysis (Guest et al., 2012), where the answers to analytical questions are sought from within a corpus. The first, exploratory phase of analysis involved a process of open coding (Corbin & Strauss, 2008), where the responses were broken down into units of interest in order to compare and contrast them. The approach that was adopted during the open coding phase was referred to as *in vivo*. This approach looks to respect the terms used by the respondents and understand the practices of particular groups of interest (Charmaz, 2006). Following this, a process of subcoding (Gibbs, 2007) was carried out in order to conceptually group together the codes that were generated during the first phase. For the second round of analysis, a process of *focused coding* was conducted (Charmaz, 2006). This technique consists of grouping together different concepts based on semantics, with the aim of producing a series of categories to comprise a taxonomy.

Pair coding was used to ensure the rigorous nature and reflexivity of the coding process (Twining, Rachelle, Nussbaum, & Tsai, 2016). In this case, the pair consisted of the lead researcher, whose research interests focus on strategies for developing critical thinking, and a research assistant, who had no knowledge of the literature on critical thinking but did have previous experience in qualitative research. Meetings were held during each phase of the coding
process, during which the coding process was discussed, the results were compared, and decisions were made on how to proceed. These decisions were made by reviewing the researchers’ notes from their individual work, containing their doubts, reflections and clarifications on the coding process. Each phase was then iterated until there was 100% agreement on the codes that were produced and the classifications that were applied. Furthermore, the categories were then validated by another researcher, who is an expert in critical thinking.

With regards to the closed-ended questions, these were used to gather information on the participants’ demographics, such as their country of residence and gender, as well as the subject they teach and the age of their students. Descriptive analysis was then carried out using this information. During this process, the frequency of each response was studied, as well as looking at how these varied with the subject taught and the age of the students. Finally, the relationships between the responses to the three open-ended questions were also analysed. In order to explore the relationships between the different categories, these were visualized using the R package ‘ggalluvial’, while the frequency was counted using a program in Python. A chi-squared test (McHugh, 2013) was used to see whether the differences in the frequency of responses for each category was significant when separating by subject or student age.

4.4.3. Instrument design

In order to understand what the participating teachers do to develop critical thinking among their students, an online survey was designed to include both closed and open-ended questions. Open-ended questions are considered appropriate for studies that look to produce a wide range of
information. This is because they allow the topics of interest to come from the participants themselves (Reja, Manfreda & Vehovar, 2003). The information on the participants’ demographics was obtained through a series of closed-ended questions, which are more appropriate for gathering accurate information.

Given that the main aim of the present study is to understand how critical thinking is used in the classroom, rather than to focus on theoretical definitions, the teachers were not explicitly asked for a definition of critical thinking (Moore, 2013). In order to understand the teachers’ practices, they were asked to think of an activity that they had used in the classroom to develop critical thinking. They were then asked three questions about this activity.

Firstly, to determine whether the teachers incorporate critical thinking into their own subject or teach the skill explicitly (Abrami, 2008), the participants were asked the following question: “Which specific question or problem have you found to be useful for developing your students’ critical thinking skills?”. Using responses to this question, we can see how teachers put into practice their idea of critical thinking.

While the first question helps identify the topics used by the teachers, it does not necessarily allow us to know what it is that the students do as part of the activity. Simply being exposed to a question or problem will not lead to the development of critical thinking. Instead, the students must do an activity in order to answer the question or solve the problem (Moore, 2013). To explore this idea in more detail, the teachers were also asked the following question: “What did the students do to answer the question or solve the problem?”. This question allows us to go beyond simple topics and understand which actions the teachers feel help their students develop
critical thinking.

To understand how the teachers think critical thinking should be implemented in the classroom, they were then asked a third question. This question asked the teachers to explicitly link the activity that they had described with the development of critical thinking. In this sense, the question asked the following: “Why do you think that the activity described in the previous question is useful for developing your students’ critical thinking?”.

The aim of these three questions is to provide an overview of what teachers are doing to develop their students’ critical thinking. Furthermore, considering the importance given by the literature to the subject taught by the teachers (Abrami, 2014), as well as the relevance of the students’ age (Kuhn, 1999), the teachers were also asked for the subject that they teach, the age of their students, their own gender and their country of residence.

A pilot study was conducted with a small group (N= 15) of people with classroom experience to ensure that the survey provided the information that was required to answer the research questions. The participants in this pilot study were also selected through convenience sampling. Once the results of the pilot had been analysed, confirming that the responses would allow for the kind of analysis proposed in this study, the survey was then sent out to the participants enrolled on the MOOC “Towards a constructivist approach in the classroom”.

4.5. Results and analysis

4.5.1. Creating categories

4.5.1.1. What are the questions or problems about?
Based on the responses to the question “Which specific question or problem have you found to be useful when developing your students’ critical thinking skills?”, our aim was to discover which topics teachers use to develop their students’ critical thinking. To obtain this information, we asked the following analytical question: “What are the questions or problems about?”. During the first phase of coding, the fragment of the response in which the teacher refers to the topic of the question or problem was rewritten in the same terms used by the participants. This was done through a process of in vivo coding (Charmaz, 2006). To demonstrate the coding process, we will use the response given by a high-school natural sciences teacher. This teacher’s response to the first question was “Talking about the consumption of psychoactive substances by producing a short film”. The result from the first phase of coding was therefore “consumption of psychoactive substances”.

Having analysed all of the responses, the second phase of coding then took place. This consisted of developing a list of concepts. In this sense, the concepts attempt to group the topics together under a more abstract phrase (Gibbs, 2007). In order to develop these concepts, a meeting was held to analyse the researchers’ notes and propose a list of possible concepts. The concepts which covered the largest number of responses were then chosen. For the example response given above, the corresponding topic was “issues that concern the students”. Following this, in a second phase of analysis (Charmaz, 2006) these concepts were then grouped into categories. In this case, we realized that there were a lot of questions that covered a range of issues. This included local issues, global issues and also hypothetical issues. These were all grouped together in the category labelled as “Issues”. Table 4-2 shows the categories that were developed during the coding process.
<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Examples</th>
<th>N (278)</th>
</tr>
</thead>
</table>
| Core concepts                  | The topics in this category are inherent to the subject that is being taught. This category includes the core topics of a subject, as well as any activities that require students to master a subject-specific skill. | 1. Can everything that we observe be measured?  
2. What is art?  
3. Could life have started through spontaneous generation?                                                                                                                                      | 115 (41.4%) |
| Issues                         | This category groups together topics that refer to real world issues, whether true or hypothetical. This includes local, national and global issues, as well as personal and hypothetical issues. | 1. What chance does our country have of implementing clean technologies?  
2. What arguments do you have in favour of decriminalizing the consumption of drugs?  
3. Do social networks decide for us?                                                                                                                                       | 83 (29.9%) |
| Metacognition                  | These topics relate to the students’ mental processes. They include the learning itself, as well as the students’ thoughts and behaviour, both in and outside of school. | 1. What do I know? What do I want to learn? What did I learn?  
2. How could you change the process in order to get a different result?  
3. What makes you say that?                                                                                                                                                   | 36 (12.9%) |
| Usefulness of the acquired knowledge | The questions in this category refer explicitly to how the topics that are being covered relate to everyday life, as well as linking theory with practice. | 1. What’s the point of me learning this?  
2. How does learning about biology help with the economic and environmental development of this country?  
3. How can you relate what | 30 (10.8%) |
Table 4-2. Topics chosen by the teachers in order to develop their students’ critical thinking

| Personal interests | These topics focus on issues that are relevant to the students’ long-term futures, as well as to their own interests, opinions or beliefs. | 1. What’s your goal in life and what are you doing to achieve it?  
2. What more would you like to learn about what we studied?  
3. What do I most like to do and enjoy doing? | 13 (5%) |

4.5.1.2. What do the students have to do?

Based on responses to the question “What did the students do to answer the question or solve the problem?”, we were able to determine what the students had to do in class. The analysis focused on the main verbs that were used in these responses. This is because such verbs tend to describe the actions that were carried out by the students. To guide the in vivo coding process, the following question was answered: “What do the students have to do?”. For the first phase of the analysis, the section of the response containing the main verb was extracted or paraphrased. It is worth noting that in several cases there was more than one main verb. In these cases, the responses were assigned two categories through a process of simultaneous or concurrent coding (Miles & Huberman, 1994). In the case of the example participant mentioned previously, their response to this question was the following: “The students met each week in order to find out where people consumed [drugs] at school and spoke with some of their classmates in order to understand their perception of psychoactive drugs. Using this information, they wrote a script and put together a series of scenes and reflections.” The result of the in vivo coding for this
response was “Following some inquiries, the students made a short film.” Having compared this and other codes obtained during this phase of the study, the concepts “Create an audio-visual product” and “Make inquiries” were suggested as umbrella terms. Following the second round of coding, the categories that emerged from this and similar responses were “Create” and “Inquire”. Table 4-3 shows the categories that were generated by analysing the responses to the question “What did the students do to answer the question or solve the problem?”

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Examples</th>
<th>N (311)</th>
</tr>
</thead>
</table>
| Analyse  | Detailed review of a topic. Includes in-depth reading and critical analysis of cultural objects, such as works of art or audio-visual materials. | 1. They observed and looked for everyday outdoor objects throughout the city and started to describe old buildings, such as the church and the municipal library.  
2. They engaged in critical/analytical reading of a text.  
3. They analysed different works of art. | 84 (27%) |
| Inquire  | Carrying out a full-scale or mini research project. This category groups together different ways of applying the scientific method and using different means to search for information. | 1. They defined a hypothesis based on their experience and then tested this hypothesis with an experiment.  
2. They made a list of what they knew and didn’t know about the topic. They then researched what they didn’t know using different sources, analysed the information and gave an opinion.  
3. They researched in books and on the internet and then asked people who were involved. | 58 (18.6%) |
| Create   | Creating a product, whether building something physical or developing an original conclusion at the end of a process. | 1. They wrote a script and then put together a series of scenes and reflections.  
2. They wrote a short story or piece of creative writing. | 49 (15.8%) |
| Argue | Forming or exchanging arguments. Includes debates, discussions and analysing arguments. | 1. They had a debate on a topic.  
2. They had a group discussion.  
3. They looked at possible arguments and the strength of the reasoning behind them. This starts with a brainstorm and becomes more and more complex as the arguments start to run out. | 45 (14.5%) |
|---|---|---|---|
| Express | Oral or written expression. Usually involves answering a question orally or in writing. | 1. Several students gave their opinion on the story, making suggestions as to what they would have done in the characters’ position.  
2. In a group class, the students gave their opinions to the questions that were asked.  
3. They listened to the statement and then raised their hand to give an opinion. | 30 (9.6%) |
| Reflect | Introspective process of deep thought. Thinking carefully about a topic and considering different points of view. | 1. When reading the text, the students questioned it based on their own reality.  
2. The students reflect at the start of the class using a question prompt.  
3. They reflected on how they might solve a problem from different angles or in different situations. | 29 (9.3%) |
| Collaborate | The focus is on pair or group work, where priority is given to the exchange of ideas or working together on a solution. | 1. They worked in groups of 5, talking about their families’ current economic difficulties and how they hoped to help.  
2. They worked in groups of 4, with each student giving an answer, then they had to make an outline using the 4 | 12 (3.9%) |
Table 4-3. Activities that the students had to do in order to answer the questions or solve the problems posed by the teachers

<table>
<thead>
<tr>
<th>Apply</th>
<th>1. They read several times, collected data and then turned the data into equations.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2. Based on the concept of fractions, they looked for equivalencies, applying these concepts to their own lives.</td>
</tr>
<tr>
<td></td>
<td>3. They used an abacus to practice additions.</td>
</tr>
<tr>
<td>4.5.1.3. How does the activity develop the students’ critical thinking?</td>
<td></td>
</tr>
</tbody>
</table>
| Responses to the question “How do you think that the activity described in your response to the previous question helps your students develop their critical thinking?” were used to identify how the teachers justified their decisions. During this analysis, we noticed that the teachers did not directly address how the activities developed critical thinking. Instead, they tended to describe the effect that the activities had on their students. We therefore took the main verb used in the teachers’ responses as their justification for using the activity to develop critical thinking. These verbs were also used to generate the codes, concepts and categories for subsequent analysis. Continuing with the example described above, in response to this third question, the participant in question answered “Because they answered their own questions about the use of psychoactive substances while at the same time setting themselves the task of producing something that would allow their classmates to reflect on the issue”. The first round of coding produced the following: “Because the activity led the students to answer their own questions, and they produced...
something for others to reflect upon”. The category to come from this type of response was “Appropriate”. Table 4-4 shows the categories that were defined based on responses to the question “How do you think that the activity described in your response to the previous question helps your students develop their critical thinking?”

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Examples</th>
<th>N (321)</th>
</tr>
</thead>
</table>
| Understand               | Refers to how, at the end of the process, the students have improved their understanding of a phenomenon or concept, enriched their view by incorporating other perspectives, or become aware of an aspect of reality that they had not previously considered. | 1. Because when they start the experiment they realize that there are several, interrelated variables.  
2. Because, although it’s an everyday activity, they are not aware of how much water is consumed in their homes, nor whether or not it is wasted. By analysing the situation, they become more aware of this situation.  
3. Because they listen to and analyse several points of view and possible explanations for the cause of the problem.                                                                                                                                                                                                                                                                       | 86      |
| Develop cognitive skills | Refers to the students putting into practice one or more cognitive skills, i.e. higher order thinking skills according to Bloom’s taxonomy.                                                                 | 1. It’s useful because, by analysing the situation, they have to comprehend, assess and judge it.  
2. Because it undoubtedly requires them to apply different levels [of thought], from basic knowledge through to analysis.  
3. Because they don’t just memorize. Instead, they have to relate what they’ve learnt to real life. In this sense, they take the time to read, analyse, draw conclusions, ask questions, clarify doubts and exchange points of view, all of which helps them to be more creative.                                                                                                                                                                                                                       | 69      |
| Reflect                  | Refers to the students having engaged in a process of deep, introspective and meditative thought.                                                                                                              | 1. Because it encourages them to think about things in more detail and analyse all of the issues surrounding them.  
2. Because any activity that makes the...                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 64      |

(26.8%)  
(21.5%)  
(19.9%)
| **Appropriate** | Focuses on the importance of the students playing a leading role in the process. | 1. Because it makes the students reflect on and search for something themselves, without there being a right answer. The aim is for each student to give a justified answer, based on what they found.  
2. Because they can build their own knowledge.  
3. Because it allows them to give an explanation based on their own criteria. | 54  
(16.8%) |
| **Develop social skills** | Reveals the importance of putting into practice the skills that are required to work with others or contribute more to society. | 1. As feelings are subjective, when working on this topic the students have to be respectful and empathetic, as well as being mindful when giving their opinion. They also have to learn to contribute at the right time and not just to say any old thing. The students are therefore forced to think about what they say and to reflect. They learn to listen and to develop their opinion, based on the context.  
2. Because that way they participate or contribute to society as humans and agents of change.  
3. Because it teaches them to respect each other’s opinion and opens their minds by exposing them to several different responses. | 20  
(6.2%) |
| **Argue** | Suggests that the process of argumentation is key to developing critical thinking. | 1. Because it allows the students to debate, analyse and put forward different points of view  
2. Because it leads them to back up their thoughts or opinions with evidence.  
3. Because it develops their reasoning skills. | 16  
(5%) |
| **Apply** | Focuses on the | 1. Because they transfer their knowledge to | 12 |
knowledge | importance of applying knowledge to real life.  
---|---
1. | everyday life.  
2. | Because it allows them to link the topics covered in class to their own context and/or issues.  
3. | Because they don’t just acquire information; they learn how to apply it, too.  
(3.7%)  

Table 4-4. Reasons given by the teachers to explain how their activities develop the students’ critical thinking

4.5.2. Comparing subjects

There is an ongoing discussion in the literature regarding the importance of incorporating critical thinking into each subject, as opposed to teaching it as a separate subject (Abrami et al., 2008; Ennis, 1989). We therefore analysed whether the topics, activities and teachers’ reasons varied depending on the subject.

4.5.2.1. Comparing topics by subject

<table>
<thead>
<tr>
<th>Categories</th>
<th>Mathematics (N=38)</th>
<th>Natural Sciences (N=83)</th>
<th>Social Sciences (N=39)</th>
<th>Humanities (N=85)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core concepts</td>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>Issues</td>
<td>16</td>
<td>42.1</td>
<td>36</td>
<td>43.4</td>
</tr>
<tr>
<td>Metacognition</td>
<td>6</td>
<td>15.8</td>
<td>28</td>
<td>33.7</td>
</tr>
<tr>
<td>Usefulness of the acquired knowledge</td>
<td>10</td>
<td>26.3</td>
<td>7</td>
<td>8.4</td>
</tr>
<tr>
<td>Personal interests</td>
<td>4</td>
<td>10.5</td>
<td>11</td>
<td>13.3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5.3</td>
<td>1</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4-5. Comparing topics by subject

Table 4-5 shows a comparison of the topics used to teach critical thinking in each subject. A chi-squared test was used to see whether there were any significant differences in the distribution of the responses across the different categories for each subject. The results of the test were $X^2 = 18.387$, df = 12, p-value = 0.1044. This shows that the differences in the distribution of responses are not significant (p>0.05), therefore suggesting that the topics chosen by the teachers do not depend on the subject they teach. However, the results do show that the most common category for each subject (with more than 40% of responses) is “Core concepts”. The four remaining categories each have a much lower share of responses. Although there are no significant differences, it is interesting to note that there a greater number of responses for metacognition in mathematics than in other subjects.

4.5.2.2. Comparing student activities by subject

<table>
<thead>
<tr>
<th>Categories</th>
<th>Mathematics (N=59)</th>
<th>Natural Sciences (N=93)</th>
<th>Social Sciences (N=60)</th>
<th>Humanities (N=89)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>Analyse</td>
<td>14</td>
<td>25</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Inquire</td>
<td>6</td>
<td>10.7</td>
<td>34</td>
<td>36.6</td>
</tr>
<tr>
<td>Create</td>
<td>26</td>
<td>46.4</td>
<td>11</td>
<td>11.8</td>
</tr>
<tr>
<td>Argue</td>
<td>1</td>
<td>1.8</td>
<td>12</td>
<td>12.9</td>
</tr>
<tr>
<td>Express</td>
<td>4</td>
<td>7.1</td>
<td>6</td>
<td>6.5</td>
</tr>
<tr>
<td>Reflect</td>
<td>4</td>
<td>7.1</td>
<td>11</td>
<td>11.8</td>
</tr>
<tr>
<td>Collaborate</td>
<td>1</td>
<td>1.8</td>
<td>5</td>
<td>5.4</td>
</tr>
</tbody>
</table>
Table 4-6. Comparing student activities by subject

Table 4-6 shows the kinds of activities done by the students in each subject. A chi-squared test in this case revealed significant differences in the distribution of the responses (X-squared = 76.388, df = 21, p-value = 3.212e-08, (p > 0.05)). This means that the student activities reported by the teachers vary, depending on the subject that they teach. The most notable difference is in mathematics, where the majority of responses fall within the category ‘Create’. In natural sciences, however, the most common category is ‘Inquire’. The distribution in social sciences is much more balanced, while in humanities there is more of an emphasis on activities where the students have to Analyse.

4.5.2.3. Comparing how the activities develop critical thinking by subject

<table>
<thead>
<tr>
<th>Categories</th>
<th>Mathematics (N=38)</th>
<th>Natural Sciences (N=99)</th>
<th>Social Sciences (N=55)</th>
<th>Humanities (N=96)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understand</td>
<td>N 18.4%</td>
<td>N 29.3%</td>
<td>N 27.3%</td>
<td>N 29.2%</td>
</tr>
<tr>
<td>Appropriate</td>
<td>6 15.8%</td>
<td>22 22.2%</td>
<td>9 16.4%</td>
<td>12 12.5%</td>
</tr>
<tr>
<td>Argue</td>
<td>0 0%</td>
<td>1 1%</td>
<td>5 9.1%</td>
<td>6 6.3%</td>
</tr>
<tr>
<td>Reflect</td>
<td>7</td>
<td>18.4</td>
<td>16</td>
<td>16.2</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>----</td>
<td>------</td>
<td>-----</td>
<td>------</td>
</tr>
<tr>
<td>Develop cognitive skills</td>
<td>12</td>
<td>31.6</td>
<td>26</td>
<td>26.3</td>
</tr>
<tr>
<td>Develop social skills</td>
<td>4</td>
<td>10.5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Apply knowledge</td>
<td>2</td>
<td>5.3</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 4-7. Comparing teacher reasons by subject

Table 4-7 shows a comparison of the reasons given to explain how an activity develops critical thinking across different subjects. In this case, the results of the chi-squared test reveal that there are no statistically significant differences between subjects ($X^2 = 24.167$, df = 15, p-value = 0.0623, (p>0.05)). Although there are some differences in the distribution of the responses, especially when comparing mathematics with the other subjects, these are not statistically significant.

4.5.3. Comparing by student age

4.5.3.1. Comparing topics by student age

<table>
<thead>
<tr>
<th></th>
<th>7-13 years</th>
<th>14-18 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>N %</td>
<td>N %</td>
</tr>
<tr>
<td>Metacognition</td>
<td>19 18.3</td>
<td>17  9.8</td>
</tr>
<tr>
<td>Usefulness of the acquired knowledge</td>
<td>6  5.8</td>
<td>24 13.8</td>
</tr>
<tr>
<td>Core concepts</td>
<td>38 36.5</td>
<td>71 40.8</td>
</tr>
</tbody>
</table>
Table 4-8. Comparing topics by student age

Table 4-8 shows a comparison of the topics used with students of different ages. Although Metacognition is more prevalent among primary school students and Usefulness of the acquired knowledge is more frequent among high-school students, the chi-squared test reveals that these differences are not significant ($X^2$ = 8.377, df = 4, p-value = 0.0787, (p>0.05)). This result suggests that the kind of topics used to teach critical thinking does not vary based on the age of the students.

4.5.3.2. Comparing student activities by age

Table 4-9. Comparing activities by student age
Table 4-9 shows the kinds of activities done by students of different ages. In this case, the results of the chi-squared test reveal that the differences are statistically significant (X-squared = 15.938, df = 7, p-value = 0.02569 (p<0.05)). The most noticeable differences are the categories *Inquire* and *Reason*, which are both more frequent with older students, while *Analyse* is more common with younger students.

### 4.5.3.3. Comparing how the activities develop critical thinking by student age

<table>
<thead>
<tr>
<th>Categories</th>
<th>7 – 13 years</th>
<th>14-18 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understand</td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>19.8</td>
</tr>
<tr>
<td>Appropriate</td>
<td>14</td>
<td>13.9</td>
</tr>
<tr>
<td>Argue</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Reflect</td>
<td>17</td>
<td>16.8</td>
</tr>
<tr>
<td>Develop cognitive skills</td>
<td>30</td>
<td>29.7</td>
</tr>
<tr>
<td>Develop social skills</td>
<td>14</td>
<td>13.9</td>
</tr>
<tr>
<td>Apply knowledge</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

*Table 4-10. Comparing teacher reasons by student age*

Finally, Table 4-10 shows a comparison of the reasons given to explain how an activity develops critical thinking for students of different ages. The results of the chi-squared test reveal that the differences are also significant (X-squared = 18.677, df = 6, p-value = 0.004745 (p<0.05)). The most noticeable differences are the categories *Understand* and *Appropriate*, which are more frequent with older students, and *Develop cognitive and social skills*, which are more common
with younger students.

4.5.4. Relationships between categories

Descriptive analysis was used to give an overview of how the topics covered relate to the activities. This was done by counting the frequency with which the categories were connected to one another by the respondents. These relationships are shown in the following graphs.

![Relationships between responses](image)

**Figure 4-2. Relationships between responses**

Figures 4-1 to 4-5 reveal the relationships between the categories developed for this study. The responses to the questions were labelled as *Topics* (i.e. what the question/problem is about), *Activities* (i.e. what the students have to do), and *Reasons* (i.e. how the activity develops*.
critical thinking). There are more noticeable relationships between Activities and Reasons, with strong links between Analyse and Understand (N=27), as well as between Inquire and Understand (N=21), Appropriate (N=17), Reflect (N=13) and Develop cognitive skills (N=15). Similarly, there is also a strong link between Create and Develop cognitive skills (N=15).
Figure 4-2. Relationships between responses in Social Sciences

Figure 4-3. Relationships between responses in Mathematics

Figure 4-4. Relationships between responses in Humanities

Figure 4-5. Relationships between responses in Natural Sciences.
When breaking the information down by subject (Figures 2-5), we can also see some differences. In Mathematics (Figure 4-2), there is a strong link between Metacognition and Analysis (N=6), which is less prevalent in Social Sciences (Figure 4-2) and absent from the other subjects. In Natural Sciences (Figure 4-5), there is a noticeable relationship between Core concepts and Inquire (N=27), as well as between Inquire and Understand (N=11), Appropriate (N=10), Reflect (N=10) and Develop cognitive skills (N=12). In both Humanities and Social Sciences there is a strong link between Analyse and Understand (N=12 and N=5, respectively), though the link between Analyse and Develop cognitive skills in Social Sciences is stronger (N=10). In the case of Humanities, there are also noticeable links between Analyse and Create with Reflect (N=8 and N=6, respectively).

4.6. Discussion

Based on these results, we will now look at how what the teachers say they do to promote critical thinking relates to the literature.

Firstly, we will look at the topics used by the teachers to develop critical thinking. The categories to emerge from responses to the question “What are the problems or activities about?” were Metacognition, Usefulness of the acquired knowledge, Core concepts, Issues and Personal interests. The most common category from the participants’ responses was Core concepts, which accounted for more than 40% of responses. It is interesting to note that this differs from the recommendations made by researchers in the area critical thinking, who recommend teaching critical thinking explicitly (Abrami et al., 2008; Marin
even when integrating it into other subjects. The responses classified within this category do not address critical thinking itself. Instead, they address core concepts within each subject. The second most common category was Issues. This category is similar to what Abrami et al. (2014) refer to as authentic or anchored instruction.

Given that Core concepts and Issues account for 70% of responses, we can conclude that teachers mainly opt for the kind of strategies that Ennis (1989) refers to as immersion. These strategies have been promoted by frameworks that are frequently used within initial teacher training and continuing professional development, such as Understanding by Design (Wiggins & McTighe, 2005). Furthermore, it is also consistent with the approach adopted by the national curriculum in two of the countries involved in this study, accounting for 41.4% of the responses that were analysed (see Bellei and Morawietz (2016) for the case of Chile and Cárdenas (2016) for the case of Mexico). Although critical thinking is not included as a topic on the national curriculum in Chile, it does appear as a cross-curricular skill in all programs and recommendations are made to integrate into every subject (MINEDUC, 2012A; MINEDUC,2012B, MINEDUC,2012C). Some studies even suggest that the development of critical thinking depends more on the school culture and interactions between the relevant actors than on instructional design itself (Huber & Kuncel, 2016; Tsui (2001).

The third most common category is Metacognition. Metacognition has been widely acknowledged in the literature as being important to the development of critical thinking
(Facione, 1990; Dwyer et al., 2014). Finally, *Usefulness of the acquired knowledge* may look to link the topic to the student’s interests, which is also the case with *Personal interests*. Taking students’ interests into account, as well as their need for the content to be meaningful, are both necessary conditions for learning and is in line with recent studies on motivation (Priniski, Hecht & Harackiewicz, 2018). Furthermore, teachers of different subjects and with students of different ages all follow similar trends when it comes to the topics they use to implement critical thinking (Tables 4-5 & 4-8).

With regards to student activities, the categories to emerge were *Analyse, Inquire, Argument, Express, Create, Reflect, Collaborate* and *Apply*. The most common category is *Analyse* (27% of responses). Analysis is considered a key sub-skill within critical thinking by many of the definitions (Facione, 1990; Dwyer, 2014; Lai, 2011). The second most common category is *Inquire* (18.6%). This highlights the importance that teachers attach to having their students engage in research and knowledge construction. The relationship between critical thinking and scientific thinking has been addressed by the literature (Forawi, 2016), with evidence of strong links between the two. The main elements of critical thinking coincide with the standards of scientific thinking, such as establishing relationships between evidence and explanations, conducting research and thinking logically in order to make inferences from unstructured problems (Forawi, 2016; Kuhn, 2008). *Inquire* is followed by *Create* (15.8%), which is the highest-order skill according to the hierarchy of skills developed by Anderson et al. (2001), based on Bloom’s taxonomy. Although closely linked to critical thinking and essential for solving problems, inquiry is considered different to critical thinking (Wechsler et al., 2018). *Inquire* is, in turn,
followed by *Reason* (14.5%), which, like analysis, is an important sub-skill in different operationalizations of critical thinking (Shehab & Nussbaum, 2015; Kuhn, 2017). The following category is *Reflect* (9.3%), which coincides with definitions that emphasize reflecting thinking, i.e. questioning one’s own points of view and assumptions when questioning any evidence that is presented (King & Kitchener, 2004). The next category is *Collaborate* (3.9%), which, although suitable for developing critical thinking (Espey, 2018), does not appear to be so important for teachers. Finally, *Apply* (1.3%) is even less frequent among responses, which is in line with the thinking that application is not usually considered a higher-order skill (Anderson et al., 2001). The majority of categories to emerge from the teachers’ responses are higher-order thinking skills that appear in Bloom’s taxonomy (Anderson et al., 2001), which is widely used in the world of education (Lai, 2001).

Significant differences can be found when comparing student activities across different subjects (Table 6). This finding is in line with the trend seen at a topic-level, where the teachers suggest they focus on *Core concepts* within their subject. In this sense, natural science teachers refer mainly to activities where the students are required to *Inquire* (36%). Inquiry is key to scientific practice (Bailin, 2002; Forawi, 2016), while the emphasis in mathematics is on activities where the students must *Appropriate* the content (46%). This category includes activities where students have to develop their own response, which is common in problem solving in mathematics. Furthermore, in social sciences, *Create* and *Analyse* are the most important categories. Within this subject in particular, the category *Create* refers to suggesting solutions to real-world problems. The predominant category in
humanities is Analyse, which may be explained by the fact that this subject often involves analysing texts and other cultural objects. There are also significant differences when comparing the activities done by students of different ages (Table 4-9). In this sense, we can see that younger students are required to analyse more, while older students have to inquire and reason. These differences may be due to the students’ level of cognitive development (Kuhn, 1999).

When analysing how the teachers link these activities to the development of critical thinking, the following categories emerge: Understand, Appropriate, Argue, Reflect, Develop cognitive skills, Develop social skills and Apply (Table 4-4). These verbs reveal the way in which teachers believe that their activities develop critical thinking. The main category in this case is Understand (26.8% of responses). This category groups together responses that refer to the students developing an improved understanding of a given topic. This is in line with frameworks such as Understanding by Design (Wiggins & McTighe, 2005), which refer to the concept of mastery (Belenky & Nokes-Malach, 2013), i.e. mastering a concept to allow for deep thought. The second most common category, Develop cognitive skills (21.5%), is closer to the definitions found in psychology (Lai, 2011). The third category, Reflect (19.9%), is similar to King & Kichtener’s (2007) position, who refer to reflective thinking as a way of understanding reality by analysing the epistemology itself. This is followed by Appropriate (16.8%), which has often been the focus of the new maker movement (Holbert & Wilensky, 2018), with an emphasis on students engaging in authentic work by producing artefacts. The next category is Develop social skills (6.2%), which groups together more attitudinal aspects (Facione, 1990) and
highlights the relationships between students, as well as their relationship with society. Reymers & Chung (2016) suggest that this element (which they refer to as Interpersonal skills) is generally underdeveloped on a curricular level and has been poorly implemented across the world. The category Argue (5%) is less commonly cited by teachers as justification for how their activities develop critical thinking. This differs to those who suggest that there is an equivalence between critical thinking and reasoning (Shehab & Nussbaum, 2015). The category Apply (3.2%), where the aim is the transfer of knowledge, is referenced less by the teachers than it is in the literature (Halpern, 1998). When comparing by subject, we can see that there are no significant differences in terms of the reasons given by the teachers (Table 7). However, when comparing by age, there are significant differences (Table 10). This may be due again to the students’ level of development (Kuhn, 1999).

Finally, when looking at the links between the teachers’ responses, we can see that they use a range of activities to cover the same topics and also provide a range of reasons when explaining how these activities develop critical thinking (Figures 4-1 to 4-5). Nevertheless, when analysing these links by subject, certain interesting trends do start to emerge. For example, there are stronger links between Metacognition and Analyse/Understand in mathematics, while in natural sciences there are strong links between Core concepts and Inquire. Furthermore, Analysis is linked to the concept of Understand in social sciences, while in humanities it is linked to Reflect. Teachers therefore tend to select activities that strengthen typical practices within their subject (Jones, 2015). In this sense, metacognition has been closely linked to mathematical thinking (Schoenfeld, 2016), while inquiry is
central to science (Forawi, 2016). In humanities, on the other hand, it is the students’ ability to analyse and reflect that plays a leading role (MINEDUC, 2012B), while in social sciences it is more about trying to understand social reality (MINEDUC, 2012D). This finding is in line with Jones (2015), who suggests that the way of looking at critical thinking depends heavily on the traditions, conventions and knowledge of each subject.

4.7. Conclusions

As highlighted in the introduction, studies on critical thinking have often overlooked the work done by teachers to develop this skill. However, studying critical thinking from the teacher’s perspective is key to bridging the gap between theory and practice. Initial training and continuing professional development both require a knowledge of what teachers are doing in the classroom if they are to contribute towards improving teaching processes (Farley-Ripple et al., 2018). This study therefore looked to characterize the work done by Spanish-speaking teachers to implement this skill. This was done by analysing the topics chosen by the teachers, the activities their students had to carry out, and the way in which they linked these activities to the development of critical thinking.

In terms of the topics used, the majority of teachers chose topics that related to the core concepts within their subject, as well as to real-world issues. The most common activities required the students to analyse, inquire and come up with solutions. The main reasons given by the teachers to justify their activities were that they encouraged the students to have a better understanding of reality or of subject-specific concepts, to develop cognitive skills, and to reflect on their thinking. When comparing subjects, we can see that there are
differences in the kind of activities the students do. This is also the case when comparing student ages.

Teachers mainly try to develop their students’ critical thinking by integrating it into their own subject. They do so by using topics that help the students understand the world from the perspective of the subject, as well as familiarizing them with subject-specific practices. This is in line with frameworks such as Understanding by Design (Wiggins & McTighe, 2005), the gold standard for Project-Based Learning (Larmer et al., 2015). It is also in line with suggestions made by several authors, who believe that critical thinking must be situated within a particular subject (Willingham, 2008; Jones, 2015; Moore, 2015). This is because it is built on the conventions, methodologies and knowledge specific to each subject. This approach differs from the recommendations made by the literature on critical thinking, which advocates for the specific and explicit teaching of critical thinking (Abrami et al., 2008), whether as a separate subject or integrated into other disciplines.

These results suggest that there is a mismatch between research and practice in education, while posing challenges for both (Farley-Ripple et al., 2018). In this sense, researchers must position their studies within the same context in which learning takes place. They must also ask questions that are relevant to teachers and be capable of answering these in a way that makes sense to educators. Teachers, on the other hand, must find the time and space to implement continuing professional development initiatives that are in line with findings from the research.

There are a series of limitations to this study. Firstly, the sample only included Spanish-
speaking teachers from across Latin America. However, it was not representative of this population as the survey was only sent to participants on a particular MOOC. The participants therefore had access to the internet, a set of certain digital skills and the time needed to take part in the study, which is not necessarily the case for most teachers across Latin America. Furthermore, the study was based on a system of self-reporting and therefore may not be a true reflection of what the teachers actually do in the classroom. In order to address this issue, future studies should look include in-depth interviews, as well as classroom observations. Replicating this study in other parts of the world would also allow us to see whether the results are applicable to other contexts. As such, a more in-depth study including classroom observations may help expand on the conclusions provided by the current study.
5. CONCLUSIONS AND FUTURE WORK

The overarching research question of the present thesis was: How can Critical Thinking be integrated into the classroom? To address this question, a model that identifies different actors and their relationships was proposed. Chapter 2 and Chapter 3 situate this question in the teaching and learning of mathematics, specifically in problem solving. Chapter 2 studies the scaffolding of argumentation in collaborative problem solving. Chapter 3 addresses the issue of the level of guidance that should be delivered in problem solving. Chapter 4 addresses the problem from the perspective of teachers’ practices. Below is a summary of the objectives and main findings of this thesis.

At the beginning of the research process, a design approach was followed. From this approach, a previously designed scaffold for collaborative problem solving was enriched with explicit argumentation. In order to study its benefits for learning problem solving, a quasi-experiment was developed to compare three collaborative problem solving situations: without technology, with technology and with technology and explicit argumentation. The results showed that only the group with explicit argumentation performed significantly better. This result covers a gap because of the absence of previous studies aimed at primary. On the other side, it reinforces the importance of explicitly embedding skills related to Critical Thinking in domain specific practices. Secondly, and also from the design approach, a scaffold with different levels of guidance was implemented and tested. The objective of this study was to explore if more or less detailed
feedback is better for learning in an interactive problem solving scenario. The results of this study show that, even though more detailed feedback is better immediately, for long term learning is better to give less detailed feedback. This result may be counterintuitive but is aligned with literature that shows if students are engaged with the learning process, they can benefit from their mistakes as they discover the results by their own means. After these two studies, a more comprehensive perspective was taken. With the objective of contributing further to closing the gap between research and implementation, the perspective of teachers was taken into account in the third study, shown in Chapter 4. In this study teachers were asked to describe what do they do in their everyday practice to incorporate Critical Thinking in their classrooms. The results show that teachers implement critical thinking mostly as an integrated part of their disciplines, resembling critical thinking with mastering the practices of each discipline.
The results can be summarized answering the overarching question: For integrating critical thinking in problem solving, explicit argumentation and less detailed feedback should be implemented. On the other hand, critical thinking must be integrated by practices of each discipline. Figure 5-1 summarizes these findings as recommendations in the different levels of the proposed model. Overall, the presented results contribute with evidence about specific practices that can be integrated by teachers to implement student centered methodologies, aimed to develop 21st century competences through the enforcement of agency.

Future work should consider the limitations of the presented studies. It would be important to test if the findings presented in Chapters 2 and 3 are applicable to other subjects, students of different ages, or even different subject matter in mathematics. On the other hand, repeating the same experiments with a larger number of students would be important to confirm the results. Furthermore, rigorous qualitative observations would be useful to understand with more details the learning process. Regarding the study presented in Chapter 4, it would be important to deepen the results by directly observing teachers in classroom settings.

Finally, it is important to add that for fostering the integration of Critical Thinking, it is paramount to include into the presented model aspects about teachers’ Professional Development and school level changes. Without relating the presented findings with research and practice on these areas it is difficult that the proposed recommendations are actually implemented in a sustainable way in schools.
REFERENCES


Fielding-Wells, J, and Makar, J. (2015). If it doesn’t have an apex it’s not a pyramid: argumentation as a bridge to mathematical reasoning. The 39th Conference of the International Group for the Psychology of Mathematics Education.


APPENDICES

Appendix 1: Rotation Script

Figure 2-6. Rotation example, phase 1.

Figure 2-7. Rotation example, phase 2.1.
Figure 2-8. Rotation example, phase 2.2.
## Appendix 2: Orchestration Lesson 1

The following is the orchestration for the preparation and the start of Lesson 1:

### Preparation prior to the start of the lesson

<table>
<thead>
<tr>
<th>Stage</th>
<th>Teacher guidelines</th>
<th>Resources needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control group</td>
<td><strong>(10 min, including the start)</strong></td>
<td>• Teacher laptop. • Projector.</td>
</tr>
<tr>
<td>Experimental group</td>
<td><strong>(20 min, including the start)</strong></td>
<td>• Teacher laptop. • Teacher tablet. • 3 routers. • One tablet per student. • Signs with group numbers (1 to 11).</td>
</tr>
</tbody>
</table>

### Start (10 minutes)

- **Contingency Group**: Start the lesson by explaining to your students that they will start with a new topic within the subject of Geometry, called *Lines of Symmetry*. Indicate to them that the objective of this lesson is for them to understand and identify lines of symmetry in 2D figures. To do this, ask your students the following questions and set them the following activities:
  1. What are 2D figures? Give some examples.
  2. To give them an intuitive idea about the concept of lines of symmetry, mention some examples of lines of symmetry we may find in our surroundings, for example of a door, of a table, etc. Then, ask in which other elements of our surroundings we could draw an imaginary line that would divide it into two equal halves.

- As your students start to participate, write their comments on the whiteboard. Then invite them to actively participate in the PowerPoint presentation on the topic of "Lines of Symmetry in 2D figures". To make the introduction to the lesson more engaging, explain to them that they will be introduced to new concepts in the lesson. During the PowerPoint presentation, explain to your students the different stages in the lesson:
  1. **Introduction**: The teacher will introduce the topic of *Lines of Symmetry*.
  2. **Explanatory**: 2D figures and their properties will be explained.
  3. **Exercises**: Students will be given exercises to practice the concepts learned.

- After the presentation, students will have the opportunity to ask questions and participate in a group discussion.
Appendix 3. Example exercises

Figure 2-9. Reflection

Figure 2-10. Rotation
Figure 2-11. Symmetry

Figure 2-12. Translation
Appendix 4. Pre- and post-test sample questions

The following are sample questions of the pre- and post-test.

1. How was quadrangle 1 translated to obtain quadrangle 2?

A. 2 squares up and 3 squares left.
B. 2 squares up and 3 squares right.
C. 3 squares left and 2 squares up.
D. 3 squares right and 2 squares down.

2. In which of the following butterfly images a symmetry line was traced?

A.  
B.  
C.  
D.  

3. Which of the following figures represents a rotation of this figure?

A.  
B.  
C.  
D.  

?
Appendix 5: Interactive Problems

Examples of exercises used in each session are presented below.

Session 1

Figure 3. Session 1 problem.

Question: How many tokens fit on the board? In the box at the right students are required to write their answers with the texts: Your response, and Type your answer here.

Figure 3 shows the Type 1, Version 1 problem. Version 2 includes a board with different sized tokens. The students were able to add or remove tokens, measure with a ruler and use a calculator.

Type 2 exercises had a limited number of tokens.

Type 3 exercises featured tokens that could neither be removed nor added.

The 8 following exercises were all different variations of the above.
Session 2
Figure 3-4. Session 2 problem.

Question: How many trees are in the picture? In the box at the right students are required to write their answers with the texts: Your response, and Type your answer here.
The figure shown above is the Type 1, Version 1 problem. Version 2 was the same, but with a different picture and a different number of objects. The students were able to use the calculator. Type 2 exercises included objects contained within other objects. For example, apples on the trees. Type 3 exercises allowed the students to choose different groups from the menu:
Figure 3-5. Session 2 type 3 problem.

Question: How many fish are there in total?

The 8 following exercises were all different variations of the above.
Session 3
Figure 3-6. Session 3 problem.

Question: How many seconds will it take for 100 goats to pass by?
Figure 6 corresponds to the Type 1, Version 1 problem. Version 2 involved a comet that appeared from a star-lit sky and passed by at a different interval than the one used in Type 1, Version 1. The students could use the calculator, as well as pausing or resetting the timer.
Type 2 exercises involved a tank of water that was being filled in stages.
Type 3 exercises involved a tank of water that was being filled continuously.
The 8 following exercises were all different variations of the above.
Session 4
Figure 3-7. Session 4 problem.

Question: How many cubes are there in total?

Figure 7 corresponds to the Type 1, Version 1 problem. The distribution in Version 2 was different, although it used a similar number of cubes. Type 2 and 3 exercises were similar, only using more cubes each time. The students could rotate the figure by 360°, press a button on the menu to separate and then join the cubes back together in the original figure, as well as use a calculator. The 8 following exercises were all different variations of the above.
Session 5
Figure 3-8. Session 5 problem.

Question: Calculate the area of the shape

Figure 8 above corresponds to the Type 1, Version 1 problem. Version 2 was similar, but used a different shape. The students could use the calculator, as well as adding or taking away blocks (which was the unit of measurement).
Type 2 exercises were similar, but students had to calculate the perimeter.
Type 3 exercises required students to build a shape whose area and perimeter satisfied certain given values.
The 8 following exercises were all different variations of the above.
Instruction: Draw the final position of the shape. Actions: The rotation is done from the square marked ‘O’. Move 7 spaces down. Move 6 spaces left. Move 3 spaces up.

Figure 9 corresponds to the Type 1, Version 1 problem. Version 2 involved another shape that started in a different position, while the instructions were also different. The students could add or remove blocks in order to draw the final position of the shape. Type 2 exercises included rotations around a given axis. Type 3 exercises required students to type instructions so that the shape would end up in the indicated position. The 8 following exercises were all different variations of the above.
Appendix 6: Feedback Messages

Below are all of the messages given to students in the Elaborated Feedback group during sessions 1 and 2. For sessions 2 to 6, only the messages for the Type 1 exercises are included.

Session 1
Type 1 Exercise
Message 1: Welcome to today’s session. The challenge for today is to calculate how many square tokens can fit on a rectangular board.
Message 1.1: Can you fill the board with tokens?
Message 1.2: One strategy for completing this challenge is to fill the board and then count how many tokens fit.
Message 1.3: One strategy for completing this challenge is to fill the board and then count one-by-one how many tokens fit.
Message 1.4: Well done! Now solve the next problem by applying what you’ve just learned.
Message 1.5: Can you fill the board with tokens?
Message 2: Well done! Now you have to solve the following problem with a limited number of tokens.

Type 2 Exercise
Message 2.1: We’ll only give you one clue: width by height.
Message 2.2: Count how many tokens fit from top to bottom and how many fit from side to side, then multiply the two numbers.
Message 2.3: Count how many tokens fit from top to bottom and how many fit from side to side, then multiply the two numbers.
Message 2.4: Well done! Now solve the next problem by applying what you’ve just learned.
Message 2.5: We’ll only give you one clue: width by height.
Message 3: Well done! Now you have to solve the next problem, where you won’t be able to add or remove the tokens.

Type 3 Exercise
Message 3.1: Would it be helpful to measure the width of the squares and the board?
Message 3.2: Measure the height of each token, count how many tokens fit from top to bottom, then do the same but from side to side. Multiply the two numbers.
Message 3.3: Measure the height of each token, count how many tokens fit from top to bottom, then do the same but from side to side. Multiply the two numbers.
Message 3.4: Well done! Now solve the next problem by applying what you’ve just learned.
Message 3.5: Would it be helpful to measure the width of the squares and the board?
Message 4: Congratulations! Now put into practice what you’ve learned by solving some new problems.
Session 2

Type 1 Exercise
Message 1: Welcome to today’s session. Today’s challenge is about counting in groups.
Message 1.1: Would it be helpful to count how many trees and how many groups of trees there are?
Message 1.2: Count the number of trees, the number of groups of trees and use the calculator to multiply the two numbers.
Message 1.3: Count the number of trees, the number of groups of trees and use the calculator to multiply the two numbers.
Message 1.4: Well done! Now solve the next problem by applying what you’ve just learned.
Message 1.5: Would it be helpful to count how many trees and how many groups of trees there are?
Message 2: Well done! Can you solve the next problem?

Type 2 Exercise
Message 2.1: Would it be helpful to count the number of petals, the number of flowers in each group and the number of groups of flowers?
Message 2.2: Count the number of petals on each flower, the number of flowers in each group and the number of groups of flowers, then multiply the three numbers.
Message 2.3: Count the number of petals on each flower, the number of flowers in each group and the number of groups of flowers, then multiply the three numbers.
Message 2.4: Well done! Now solve the next problem by applying what you’ve just learned.
Message 2.5: Would it be helpful to count the number of petals, the number of flowers in each group and the number of groups of flowers?
Message 3: Well done! Can you solve the next problem?

Type 3 Exercise
Message 3.1: Would it be helpful to count the number of fish per group and count how many groups there are?
Message 3.2: Count the number of fish in each group and the number of groups, then multiply the two numbers.
Message 3.3: Count the number of fish in each group and the number of groups, then multiply the two numbers.
Message 3.4: Well done! Now solve the next problem by applying what you’ve just learned.
Message 3.5: Would it be helpful to count the number of fish per group and count how many groups there are?
Message 4: Congratulations! Now put into practice what you’ve learned by solving some new problems.

Session 3
Type 1 Exercise
Message 1: Welcome to today’s game. The challenge for today is to use patterns in order to predict what will happen in the future.
Message 1.1: How long does it take for each goat to pass by? This information might help you.
Message 1.2: Measure the time it takes for the goat to pass by and then multiply it by the total number of goats that have to pass by.
Message 1.3: Measure the time it takes for the goat to pass by and then multiply it by the total number of goats that have to pass by.
Message 1.4: Well done! Now solve the next problem by applying what you’ve just learned.
Message 1.5: How long does it take for each goat to pass by? This information might help you.

Session 4
Type 1 Exercise
Message 1: Welcome to today’s game. The challenge for today is to use strategies to count with 3D figures.
Message 1.1: How many cubes are there in each layer? It might help to count layer by layer.
Message 1.2: Count the number of cubes in the first layer, then add the cubes in the second layer.
Message 1.3: Count the number of cubes in the first layer, then add the cubes in the second layer.
Message 1.4: Well done! Now solve the next problem by applying what you’ve just learned.
Message 1.5: How many cubes are there in each layer? It might help to count layer by layer.
Message 2: Well done! Can you solve the next problem?

Session 5
Type 1 Exercise
Message 1: Welcome to today’s game. The challenge for today is to use strategies to calculate area and perimeter.
Message 1.1: Can you break the shape up into several rectangles?
Message 1.2: Divide the shape into several rectangles. Then calculate the area of each rectangle by multiplying the width by the height. Then add up the three areas in order to calculate the total area.
Message 1.3: Divide the shape into several rectangles. Then calculate the area of each rectangle by multiplying the width by the height. Then add up the three areas in order to calculate the total area.
Message 1.4: Well done! Now solve the next problem by applying what you’ve just learned.
Message 1.5: Can you break the shape up into several rectangles?
Message 2: Well done! Can you solve the next problem?

Session 6
Type 1 Exercise
Message 1: Welcome to today’s game. The challenge for today is to translate and rotate shapes.
Message 1.1: Choose one block in the shape. Can you work out where it will end up?
Message 1.2: Add up the movements to the right and subtract any movements to the left. Do the same with the movements up and down and that way you’ll get the final position.
Message 1.3: Add up the movements to the right and subtract any movements to the left. Do the same with the movements up and down and that way you’ll get the final position.
Message 1.4: Well done! Now solve the next problem by applying what you’ve just learned.
Message 1.5: Choose one block in the shape. Can you work out where it will end up?
Message 2: Well done! Can you solve the next problem?
Appendix 7: Pre- and Post-Test
Below are the exercises that were included on the pre- and post-test.

**Problem 1**
How many tiles like the one below are needed to cover the whole floor?
Figure 3-10.

Answer:
What strategy did you use to solve the problem? Explain step by step how you arrived at your solution.
**Problem 2**
How many flower petals are there in the picture below?
Figure 3-11.

Answer:
What strategy did you use to solve the problem? Explain step by step how you arrived at your solution.
**Problem 3**
Every 5 seconds, the water in the tank increases by 1 meter. How long will it take for the tank to fill up? (The lines on the tank are 1 meter apart)
Figure 3-12.

Answer:
What strategy did you use to solve the problem? Explain step by step how you arrived at your solution.

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**Problem 4**
How many fingers are there in your class?
If you like, you can use the space below to draw a picture and help you come up with an answer:
Answer:
What strategy did you use to solve the problem? Explain step by step how you arrived at your solution.
**Problem 5**
How many boxes are stacked in the pile below? Note: there are no empty spaces without a box.
Figure 3-13.

Answer:
What strategy did you use to solve the problem? Explain step by step how you arrived at your solution.

**Problem 6**
Using only isometric transformations (reflections, rotations and translations), how would you create the shape on the right using the pieces on the left?
Figure 3-14.
Problem 7
What is the area and perimeter of the shape below?
Figure 3-15.

Answer:
What strategy did you use to solve the problem? Explain step by step how you arrived at your solution.

Problem 8
How many cubes like the one below would be needed to build a chair like the one you’re sitting on?
Figure 3-16.
Answer:
What strategy did you use to solve the problem? Explain step by step how you arrived at your solution.
## Appendix 8: MOOC Demographics

<table>
<thead>
<tr>
<th>Participant Countries</th>
<th>Ages</th>
</tr>
</thead>
</table>
| Chile                 | 31%    | 18-24 9.6%  
| Mexico                | 25%    | 25-34 43%  
| Colombia              | 10%    | 35-44 24%  
| Spain                 | 6%     | 45-54 7.40% 
| Peru                  | 6%     | 55-64 14.60% 
| Ecuador               | 4%     | > 65 0.40%  
| Argentina             | 3%     |  
| Others                | <3%    | Sex  
|                       |        | Male 43%  
|                       |        | Female 56% |
## Appendix 9: Aggregation of subjects in areas

<table>
<thead>
<tr>
<th>Subject selected by the participant</th>
<th>Subject area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language Arts, Foreign Languages, Philosophy, Ethics, Art, Music and Religion.</td>
<td>Humanities</td>
</tr>
<tr>
<td>Physics, Chemistry, Biology, Natural Sciences, Technology, ICT</td>
<td>Natural Sciences</td>
</tr>
<tr>
<td>History, Social Sciences, Economics, Citizenship</td>
<td>Social Sciences</td>
</tr>
<tr>
<td>Mathematics</td>
<td>Mathematics</td>
</tr>
<tr>
<td>Guidance, Cross-Curricular Skills</td>
<td>Other</td>
</tr>
</tbody>
</table>