CYPRUS UNIVERSITY OF TECHNOLOGY

FACULTY OF FINE AND APPLIED ARTS

Doctoral Dissertation

COLLABORATIVE KNOWLEDGE CONSTRUCTION AND METACOGNITION VIA EDUCATIONAL ROBOTICS

Chrysanthos Socratous

Limassol, April 2022

CYPRUS UNIVERSITY OF TECHNOLOGY
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ABSTRACT

The purpose of this study was to explore how Educational Robotics (ER) can support students' development of metacognitive thinking as a key element for collaborative knowledge construction in Computer-Supported Collaborative Learning (CSCL) settings. The work adopts a Design-based Research (DBR) methodology, to address the development of metacognitive skills via ER while documenting design principles for successful implementations, based on collected evidence of cycles of work. The study consists of three sequential cycles in real classroom settings in primary education. The first cycle explored the use of ER in supporting collaborative knowledge construction as well as the mediating role of ER in supporting students' group metacognitive processes. The second cycle investigated the potential added value of ER in promoting students' metacognitive thinking and mathematical problem-solving. In the third cycle, the study examined how different ER learning design approaches could influence student learning. The third cycle presented differences between a structured and an unstructured ER curriculum in supporting students' learning.

Overall, findings from this dissertation provide an in-depth understanding of how ER can be used in real classroom settings for facilitating metacognitive thinking as a key element for collaborative knowledge construction. Moreover, through the analysis of different curriculum structures, the dissertation provides evidence that ER is a useful metacognitive medium whose learning benefits can be maximized through a structured curriculum design using pre-designed tasks, in combination with guided experimentation at the beginning of each session. This study is one of very few, adopting a design-based research methodology, to address the development of metacognitive skills via ER, therefore, it contributes to the scarce literature on the use of ER as tools for promoting metacognitive thinking and collaborative knowledge construction. The results of this study contribute significantly to the research conducted in the design and implementation of these interventions. Implementation of research can build on this project's elements and ground the use of ER as a metacognitive tool. The dissertation concludes with practical guidelines and implications for educators who wish to incorporate these into their curricula towards the goal of increasing metacognition and collaborative knowledge construction.

Keywords: educational robotics, computer supported collaborative learning, metacognition, collaborative knowledge construction, problem-solving, classroom, primary education, designed-based research

Περίληψη

Σκοπός της μελέτης ήταν να διερευνήσει πώς η εκπαιδευτική ρομποτική μπορεί να υποστηρίξει την ανάπτυξη της μεταγνωστικής σκέψης των μαθητών ως βασικό στοιχείο για τη συνεργατική οικοδόμηση της γνώσης σε περιβάλλοντα συνεργατικής μάθησης υποστηριζόμενη από υπολογιστή. Η εργασία υιοθετεί μια μεθοδολογία έρευνας βασισμένη στον σχεδιασμό για την διερεύνηση μεταγνωστικών δεξιοτήτων μέσω της χρήσης εργαλείων εκπαιδευτικής ρομποτικής, ενώ τεκμηριώνει τις αρχές σχεδιασμού για επιτυχημένες υλοποιήσεις, με βάση τα συλλεγμένα στοιχεία των κύκλων εργασίας. Η μελέτη αποτελείται από τρεις διαδοχικούς κύκλους σε πραγματικές τάξεις στην πρωτοβάθμια εκπαίδευση. Ο πρώτος κύκλος διερεύνησε τη χρήση της εκπαιδευτικής ρομποτικής για την υποστήριξη της συνεργατικής οικοδόμησης της γνώσης καθώς και τον διαμεσολαβητικό της ρόλο στην υποστήριξη συνεργατικών μεταγνωστικών δεξιοτήτων. Ο δεύτερος κύκλος διερεύνησε την αξία της εκπαιδευτικής ρομποτικής στην προώθηση των μεταγνωστικών δεξιοτήτων και της επίλυσης μαθηματικών προβλημάτων. Στον τρίτο κύκλο, η μελέτη εξέτασε πώς διαφορετικές προσεγγίσεις σχεδιασμού θα μπορούσαν να επηρεάσουν τη μάθηση. Ο τρίτος κύκλος παρουσίασε διαφορές μεταξύ ενός δομημένου και ενός μη δομημένου προγράμματος σπουδών εκπαιδευτικής ρομποτικής για την υποστήριξη της μάθησης.

Συνολικά, τα ευρήματα της διατριβής παρέχουν μια εις βάθος κατανόηση του τρόπου με τον οποίο η εκπαιδευτική ρομποτική μπορεί να χρησιμοποιηθεί σε πραγματικές συνθήκες τάξης για τη διευκόλυνση της μεταγνωστικής σκέψης ως βασικό στοιχείο για την συνεργατική οικοδόμηση της γνώσης. Επιπλέον, μέσω της ανάλυσης ενός δομημένου και ενός μη δομημένου προγράμματος σπουδών, η διατριβή παρέχει στοιχεία για τη χρησιμότητα της εκπαιδευτικής ρομποτικής ως ένα μεταγνωστικό εργαλείο του οποίου τα μαθησιακά οφέλη μπορούν να μεγιστοποιηθούν μέσω ενός συνδυασμού δομημένου και μη δομημένου προγράμματος σπουδών. Η μελέτη αυτή είναι μία από τις λίγες που υιοθετούν μια ερευνητική μεθοδολογία βασισμένη στον σχεδιασμό με σκοπό την ανάπτυξη μεταγνωστικών δεξιοτήτων μέσω της χρήσης της εκπαιδευτικής ρομποτικής, επομένως, συμβάλλει στη σπάνια βιβλιογραφία σχετικά με τη χρήση της ως εργαλείο για την προώθηση της μεταγνωστικής σκέψης και της συνεργατικής οικοδόμησης της γνώσης. Τα αποτελέσματα της μελέτης συμβάλλουν σημαντικά στην έρευνα που διεξάγεται στο σχεδιασμό και την υλοποίηση αυτών των παρεμβάσεων. Άλλοι ερευνητές μπορούν να βασιστούν στα στοιχεία αυτού του έργου και να θεμελιώσουν τη χρήση της εκπαιδευτικής ρομποτικής ως μεταγνωστικό εργαλείο. Η διατριβή ολοκληρώνεται με πρακτικές οδηγίες και προεκτάσεις για εκπαιδευτικούς που επιθυμούν να τις ενσωματώσουν στα προγράμματα σπουδών τους με στόχο την αύξηση των μεταγνωστικών δεξιοτήτων και της συνεργατικής οικοδόμησης της γνώσης.

Λέξεις κλειδιά: εκπαιδευτική ρομποτική, συνεργατική μάθηση υποστηριζόμενη από υπολογιστή, μεταγνώση, συνεργατική οικοδόμηση της γνώσης, επίλυση προβλήματος, πρωτοβάθμια εκπαίδευση, έρευνα βασισμένη στον σχεδιασμό.

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LIST OF ABBREVIATIONS

CSCL:	Computer Supported Collaborative Learning
ER:	Educational Robotics
MAI:	Metacognitive Awareness Inventory
STEM:	Science, Technology, Engineering, Mathematics
CORDTRA:	Chronologically-Oriented Representations of Discourse and Tool-related Activity
VisA:	Visualization and Accuracy Instrument
M:	Mean
N:	Number
SD:	Standard Deviation

Introduction

Robotics has been endorsed as an educational tool by many researchers (Petre & Price, 2004, p. 147). Many researchers argue that robotics is motivating for students since it is concrete and complex, and it is pedagogically valuable because it allows students to use and extend their knowledge to diagnose and fix problems. ER is now considered a powerful teaching and learning tool that enables students to put their ideas into practice by creating a mechanical artifact and controlling it with a simple and easy-to-use programming environment (Alimisis, 2009). ER is seen as an interdisciplinary activity, which is mainly based on STEM and contributes notable benefits at all levels of education (Rogers & Portsmore, 2004). Over the past decade, it has attracted researchers and teachers' interest for supporting learning and developing students' cognitive and social skills (Alimisis, 2013). ER is introduced to many learning environments as a teaching and learning tool (Eguchi, 2014), which transforms classrooms into dynamic learning spaces that support students: (a) in the development of higher-order thinking skills, (b) in the creation of multiple representations of understanding of the subject (Jonassen, 2000), (c) in constructive communication and cooperation among them and (d) in the development of their learning by solving complex authentic problems (Gura, 2007; Blanchard et al., 2010; Çalik et al., 2014, 2015).

ER enables students to implement abstract design ideas, reflect on these ideas, and directly observe the results of this effort (Druin & Hendler, 2000). In this way, students go from the stage of "learning about technology," which predominates the educational systems, to the stage of "learning with technology" (Carbonaro et al., 2004). ER activities promote problem-solving as they focus on researching and analyzing complex real-world problems (Torp & Sage, 2002). By designing and programming a robot to do even a simple task, students' creativity and problem-solving skills are enhanced (Tappert, 2002). An important aspect of ER is their gamification, as an essential factor in motivating students, especially in primary education (Atmatzidou et al., 2008).

Prior to 2012, no systematic reviews of robotics in education had been published (Benitti, 2012). In her report, Benitti noted the lack of rigorous quantitative research on ER. Only ten of the 70 articles found, discussed the effectiveness of ER as a teaching tool employed quantitative methods. However, a methodological flaw was found in 40% of the studies that used experimental designs. All except one of the studies used LEGO robotics in the educational activities. Most of these activities were not integrated into classroom activities; they were done in after-school or summer camp programs. In general, the results of the studies showed learning gains with the use of robotics, but there were cases where there was no significant increase in student learning. Many studies focused on self-directed learning experiences that significantly increased learning in STEM areas. However, some of the studies reported nonsignificant increases, and it was impossible to isolate the variables that contributed to the success due to methodological challenges. Thinking skills, science process skills, problem-solving and social interaction/ teamwork skills were the common focus of the studies, but the results were mixed. Therefore, ER seems to be a relevant tool for improving learning. However, the assertion needs to be supported with empirical evidence to discover how to use robotics to develop specific skills.

More recent reviews or single studies show that the use of robots in education is growing, yet some of the same trends continue and more obstacles pertain. Many robotics programs described in the literature for school children ages 6 through 17 typically have taken place in robotics competitions (Sklar et al., 2007), after school programs (Barker & Ansorge, 2007), robotics summer camps (Williams et al., 2007), or regular classrooms (Rogers & Portsmore, 2004). These programs usually consisted of one or multiple robotics challenges that required the students to work in groups to design and program the robot to meet certain goals, such as having the robots play soccer or dance or transport items along a path with obstacles. A general structure of the design and teaching and learning process in these programs is missing. Indeed, a few researchers have pointed out the need to explore appropriate educational models and practices for robotics activities to create a fruitful learning environment for students (Williams & Prejean, 2010; Eteokleous-Grigoriou & Psomas, 2013). Karim et al. (2015) pointed out that even though robotics has been widely used, most activities are short-termed and developed informally through extra-curricular activities. The explanation is primarily associated with the time-consuming unintuitive overwhelming design process which requires excellent inventory and project management skills. Consequently, teachers’ control over the classroom is reduced, which worsens due to the absence of formally structured curricula linking traditional and robot-based education.

1.1 Skills development via ER

Current research has focused on the learning benefits of ER activities relevant mainly to cognitive skills such as problem-solving, programming, and critical thinking. Benitti (2012), in her review, stresses that the results in the area of skills development are inaccurate and suggests the need for elaborated assessment tools as a necessity for this exploration. Overall, empirical evidence in the area presents a positive picture on problem-solving (Chambers et al., 2008; Castledine & Chalmers, 2011), sequencing skills (Kazakoff et al., 2013), creativity (Sullivan, 2011) programming and computational thinking (Bers et al., 2014; Atmatzidou & Demetriadis, 2016) and language skills (Sugimoto, 2011; Chen et al., 2011). In addition, although collaboration and teamwork skills are reported peripherally in the literature, some studies support the assumption that the application of ER proved to be a highly motivating activity for the students, fostering collaboration among them (Mitnik et al., 2009; Ardito et al., 2014).

Existing literature regarding the use of ER to teach math and science concepts suggests that robotics are valuable tools to increase learning in specific concept areas. ER activities to teach mathematics concepts were first introduced in the 80s by Papert, who used the LOGO platform to teach geometry. Robots helped his students see the relationships between programming, mathematics, and robot movement. After many years, Walker and Burleson (2012) reproduced Papert’s results using the iRobot Create in drawing two-dimensional geometric primitives and advanced complex shapes. Other studies reported that ER significantly helped in improving students' skills with fractions, ratios, decimals, and coordinate estimation (Nugent et al., 2008; Nugent et al., 2009; Rogers & Portsmore, 2004; Barker & Ansorge, 2007). ER has also been used in science education to examine the relationship between distance, time, speed, and velocity in the general topic of kinematics (Mitnik et al., 2008; Mikropoulos & Bellou, 2013; Mitnik et al., 2009). Studies also showed that robots helped students in the construction and interpretation of graphs relating to kinematics variables such as time, speed, and acceleration (Mitnik et al., 2008; Alimisis & Boulougaris, 2014). Furthermore, there seems to be a direct relationship between robotics and Technology and Engineering, as robots are technological tools and products of Engineering and Technology. However, the correlation to the other two areas of Science and Mathematics might not be clear (Stergiopoulou et al., 2017). The use of ER to teach STEM concepts is not a new idea; in fact, the literature on this subject covers a wide array of topics from elementary to graduate education. However, much work remains to be done to assess their effectiveness.

1.2 Metacognitive skills

Metacognition has been defined as "one's knowledge concerning one's own cognitive processes, or anything related to them." Metacognitive skills help individuals process and retain information through self-recognition and reflection. Metacognitive skills allow someone to organize and evaluate his/her thought process related to learning and problem-solving. Therefore, having well-developed metacognitive thinking skills is associated with improved learning. Metacognitive skills typically start developing during childhood and allow individuals to learn different school subjects. These skills continue to grow and evolve throughout the teenage years and into adulthood as individuals move from educational to professional settings.

Metacognitive skills typically fit into three distinct categories of the learning process (a) planning, (b) monitoring, and (c) evaluation. The first phase of metacognition, the planning phase, asks individuals to question what they want to learn, what existing knowledge they can use to help them learn, what they need to focus on to learn and what time frame they have to achieve comprehension. The monitoring phase occurs throughout the learning process. During this phase, individuals ask questions relating to how well they are retaining information, whether to slow or quicken the pace at which they learn depending on the subject's difficulty and whether they need to seek additional guidance to help them learn. The evaluation phase is the final phase during the metacognitive process. During this phase, individuals evaluate their learning ability during the monitoring phase. They question whether what they learned could help them in other areas, determine weak areas where they need to complete additional work, and reflect on what they should have done differently to maximize their learning experience.

Metacognitive skills are essential because they help individuals understand their learning processes and how they learn effectively. In addition, metacognitive skills help people learn information quickly and retain information for their educational development. This is because they understand the methods, they need to use to educate themselves and overcome potential learning barriers. Generally, we do not know what we are doing when we do it, but it is very hard to improve a process that we are engaged in if we do not have a sense of what we are doing in the moment. If one aim of schooling is to prepare children to be lifelong learners, then it is important to help students become aware of themselves as learners and to take control of their own activities. The vast majority of students spontaneously pick up metacognitive knowledge and skills to a certain extent from their parents, their peers, and especially from their teachers (Jaleel, 2016). However, students show a considerable variation in their metacognitive ability (Muijs & Bokhove, 2020). Learners often show an increase in self-confidence when they build metacognitive skills. Self-efficacy improves motivation as well as learning success.

1.3 Identifying the problem

To thrive in the 'fourth industrial revolution' will require humans to be able to adapt and to do so quickly. We will need a ‘tool kit’ of learning strategies to make fast improvements. To choose the right tool we will need to be able to reflect on what’s working for us and what isn’t. This metacognitive skill is crucial for future proofing students beyond the school gates. It also has significant benefits for grade attainment, behaviour, and well-being in the classroom (Kuhn, 2021). Reflecting on our own thoughts is how we gain insight into our feelings, needs, and behaviors, and how we learn, manage, and adapt to new experiences, challenges, and emotional setbacks. It’s the running conversation we have in our heads, mentally sounding ourselves out and making plans. Teaching (and training) students to use it proactively to overcome obstacles can be a powerful tool for life. More and more studies continue to report that students who are taught to use metacognitive strategies early on are more resilient and more successful, both in and out of school (Jacobson, 2020).

In case of absence of metacognition, the problems are many, as documented in the research by Dunning et al. (2003). They found that “people tend to be blissfully unaware of their incompetence, lacking insight about deficiencies in their intellectual and social skills." They identified this pattern across domains, from test-taking, writing grammatically, thinking logically, to recognizing humor and problem-solving skills. They elaborate that if people lack the skills to produce correct answers, they are also cursed with an inability to know when their answers, or anyone else's, are right or wrong. The study documented that increased metacognitive abilities to learn specific (and correct) skills, how to recognize them, and how to practice them is needed in every context. Taking such research reports into account, it becomes immediately relevant to invest on exploring tools for supporting the development of skills such as metacognition.

ER is an innovative teaching tool that actively engages students in the learning process and aims to enhance and develop higher order thinking skills (Blanchard et al., 2010). Several studies report that ER activities have positive effects on the level of collaboration between students, the development of critical thinking and problem-solving skills (Petre & Price, 2004; Norton et al., 2007; Castledine & Chalmers, 2011), cognition and computational thinking (e.g., La Paglia et al., 2010; Benitti, 2012). At the same time, despite robotics' rapid acceleration in the 1990s (after it has emerged from Seymour Papert's work in the 1980's), ER is still not the outstanding tool expected to be. In fact, ER technology has had a slow adoption by schools and educators. Few schools use robotics regularly, as part of their curriculum. ER activities are often occasional and are done as fun, extracurricular activities. In many of the initiatives reported in the literature, the chosen robotic platform is the consistent (Lego) and the topics taught via ER are around STEM ideas, but not necessarily linked to the curriculum.

1.4 Identifying the research gap

Unfortunately, the benefits of ER activities or complete programs remain largely undocumented. While there is a substantial amount of published literature about ER, most publications focus on descriptions of implementations of programs (Benitti, 2012), and evidence of learning tends to be anecdotal (Silk & Schunn, 2008). With respect to quantitative studies on ER, many suffer from small sample sizes, use instruments that have not undergone validity checks, and conduct interventions of limited duration

(Barker & Ansorge, 2007; Laughlin, 2013; Nugent et al., 2008; Wolfgang et al., 2003). Few studies have used experimental designs with comparison or control groups; however, their picture is unclear as to how the groups have received comparable lessons. Some studies used multiple sites, but did not coordinate the curriculum, making it uncertain whether the groups received comparable lessons (Hussain et al., 2006; Lindh & Holgersson, 2007). Furthermore, most of the studies conducted their evaluation within a few months of the intervention. Given these issues, it is difficult to conclude whether ER activities or complete robotics programs deliver meaningful benefits for their participants.

Overall, there are virtually no studies dealing with the complexity of real-life settings when ER activities are integrated into the curriculum. Robotics alone is not enough to change students' thinking and lead to high learning outcomes (Alimisis, 2013). Robotics tasks should be supported by an appropriate teaching framework that will give them the necessary added value to significantly improve and enhance their teaching (Papert, 1993; Eteokleous-Grigoriou & Psomas, 2013). Limited research has been conducted to determine the best practices and strategies for designing and implementing ER activities. To date, the evidence suggests that the development of technology skills stemming from participation in ER activities depends on the implementation approach. Notably, there seems to be a connection between the type of ER approach implemented within an educational setting and the impact on technology skills development (Eguchi, 2014; Nugent et al., 2008). For example, evidence suggests that ER classes and projects could positively impact technology skills development (Nugent et al., 2014), although the same cannot be said about ER competitions. There is indeed a huge gap in research that systematically designs and changes the learning environment over time, collecting evidence of the various changes toward the documentation of conceptual models or design principles that can facilitate a successful integration of ER. The present work does exactly this. By adopting the Design-Based Research (DBR) methodology, it addresses the development of metacognitive skills via ER while it documents design principles for successful ER implementations, based on collected evidence for cycles of work.

1.5 Research design and research questions

The overarching goal of this work was to explore how ER can support students' development of metacognitive thinking as a key element of collaborative knowledge construction. In an effort to implement theoretically designed learning environments in real-world classrooms, this dissertation employed Design-Based Research methodology (Brown, 1992; Collins, 1992; Design-based Research Collective, 2003; Barab, 2006; Reeves, 2006). DBR deals with the complexity of real-life settings by systematically designing and changing the learning environment over time, collecting evidence of the various changes which recursively feed into future designs (Brown, 1992; Collins, 1992; Barab, 2006). The research questions are investigated in three phases work which is organized as follows:

(1) identification and analysis of the problems in the use of ER in real contexts

(2) reviewing of the literature on the use of ER technologies in education for promoting various skills

(3) enactment of ER activities in three CSCL settings for promoting students' metacognitive thinking as a key element of collaborative knowledge construction

(4) examining the intervention holistically, with an eye to claiming success through a set of instructional design elements that generate "heuristics for those interested in enacting innovations in their own local contexts" (Design-Based Research Collective, 2003, p. 6).

The theoretical understanding is considered the final step of a DBR study, resulting in conceptual models or design principles that can facilitate a successful solution. Figure 1 presents the stages of this DBR and communicates how each of the stages operates with one another, in order to inform conceptual models or design principles and strengthen the design of our interventions.

All the interventions were conducted in real classroom environments in elementary schools in Cyprus. The Lego Mindstorms EV3 toolkit was used. The content for the activities came from (a) the national curriculum on mathematics and science education, and (b) the EV3 STEM problem-solving curriculum.

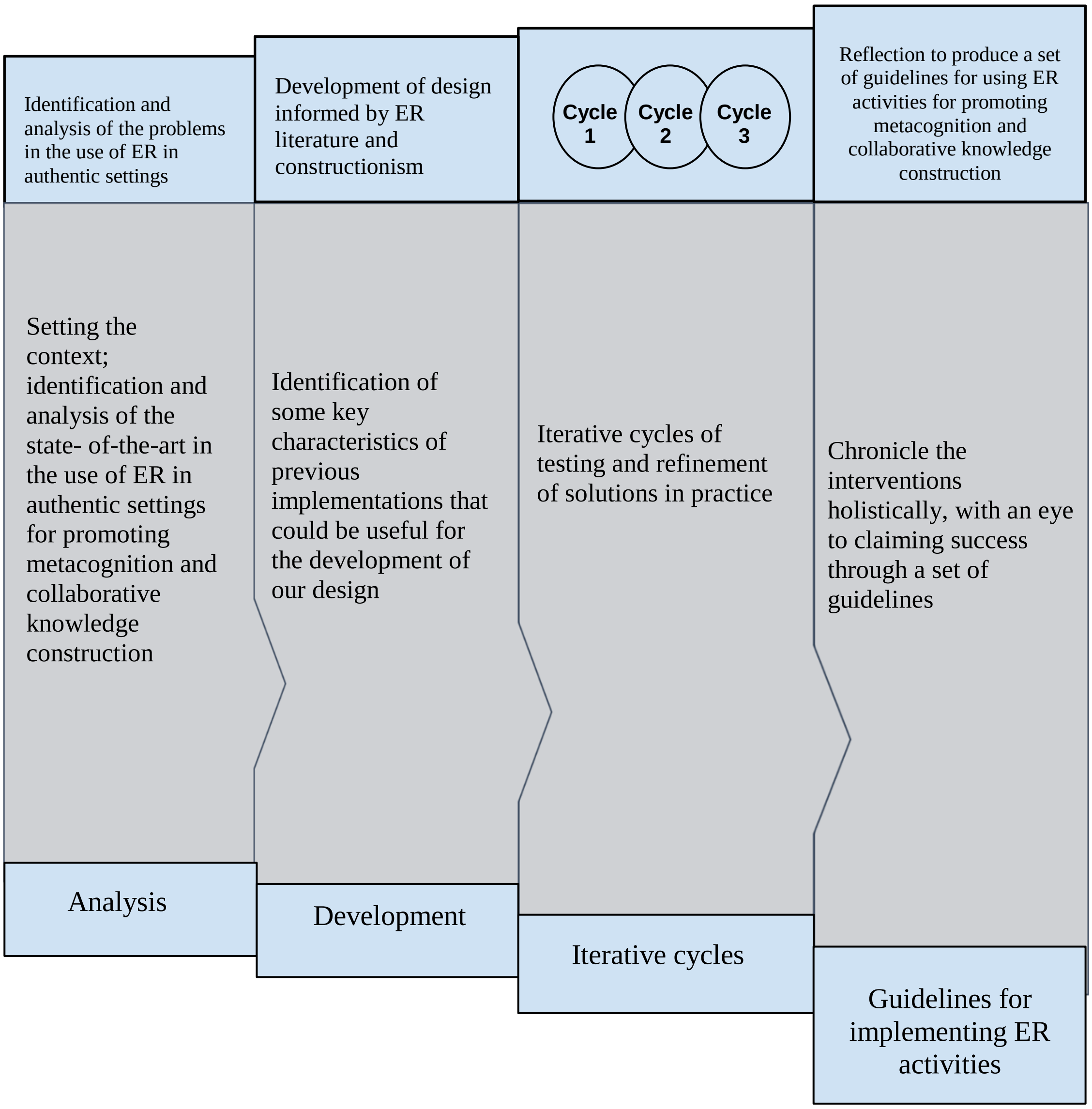


Figure 1: The stages of this DBR (adopted from Reeves, 2006).

In sum, the DBR cycles and research questions (RQs) addressed are summarised below. Figure 2 is a schematic representation of the research questions used in the three cycles of the investigation aimed at the overarching goal to explore how ER can support students’ development of metacognitive thinking as a key element of collaborative knowledge construction.

- DBR Cycle 1 explored the use of ER in supporting collaborative knowledge construction and group metacognition in addition to providing insights into classroom practice and students' interaction with the technology and their peers.

- DBR Cycle 2 extended our understanding of the added value of ER in promoting students' metacognitive thinking and mathematical problem-solving at an individual level of analysis.
- In DBR Cycle 3, the study examined how different ER learning design approaches could influence student learning. Namely, this cycle presented differences between a structured and an unstructured ER curriculum in supporting students' learning.

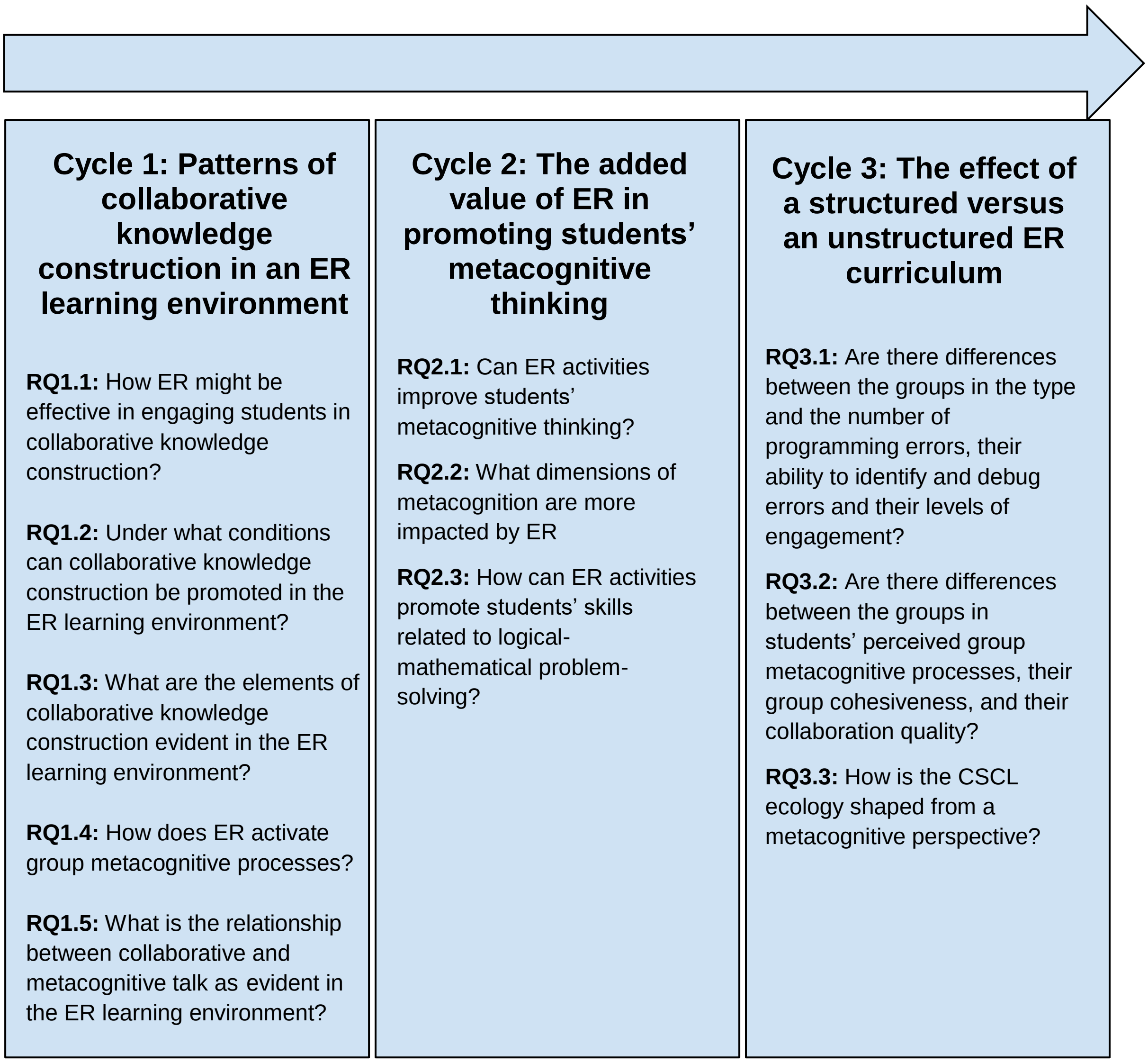


Figure 2: DBR cycles and RQs of the study

1.6 The importance of this work

ER appears to be a promising tool for investigation in education. Although quite some work has been done in the area, there are still many unanswered questions. Namely, more research is needed to confirm that ER can be beneficial for learning.

If one aim of schooling is to prepare children to be lifelong learners, then it is important to help students become aware of themselves as learners and to take control of their own activities. By gaining metacognitive awareness, students can become aware of themselves as learners and are conscious of what they learn and why and how to use the information they learn. Students' ability to reflect on their problem-solving strategies is essential; their metacognitive beliefs, decisions, and actions can be determinants of learning success or failure (Garofalo & Lester, 1985). An important contribution of this work is the presentation of empirical findings on how ER can promote students' metacognitive thinking.

The study further contributes to the growing body of research applying sociocultural theories to understand learning. Namely, a contribution of this work is the consideration of ER in the direction of metacognitive thinking as a social practice, by presenting empirical findings on how ER can support (group) metacognition in CSCL settings.

This research further attempts to understand and define appropriate ER activities that can promote students' metacognitive thinking as a key element of collaborative knowledge construction in CSCL settings. While ER has great potential to assist in teaching, learning gains are not guaranteed with a simple application of robotics; there are several factors that can determine the outcome (Benitti, 2012). One such factor is the level of structure that educators adopt in their activities; there is very little work focused on the level of structure and guidance that educators should adopt in their ER activities. A contribution of the present work is the holistic and details presentation of the learning environment, including activities, structures, and processes for the enactment of students' metacognitive thinking through an authentic classroom learning experience.

Overall, this research provides educators, researchers, and practitioners with a better understanding of the possibilities of using robotics technologies in educational contexts, leading to new perspectives of its use. A set of guiding principles for classroom integration, including classroom practice and teaching method are documented for educators while an agenda for future research aims to guide future researchers in the field. The work is one of very few, adopting a design-based research methodology, to address the development of metacognitive skills via ER while documenting design principles for successful ER implementations, based on collected evidence for cycles of work.

1.7 Structure of the dissertation

This dissertation is structured in eight chapters, in addition to this introduction. The structure is the result of the Design-Based Research (DBR) methodology adopted in this work and elaborated in the third chapter. In summary,

- Chapter 1: Introduction
- Chapter 2: Conceptual framework. This chapter introduces the relevant scientific paradigms that underpin the emerging area of ER and the specific variables explored in the dissertation. This chapter brings together a number of related concepts under a conceptual framework that guides the work in this dissertation.
- Chapter 3: Review of the Literature. This chapter examines the development in the field of robotics in education based on the results of recent empirical research conducted in the field.
- Chapter 4: Research Methodology. This chapter details the DBR methodology, and the different phases of data collection and analysis involved in this dissertation. In this chapter, DBR is defined along with its features and justification of its appropriation for its use.
- Chapter 5: DBR Cycle 1. Exploring patterns of collaborative knowledge construction in an ER learning environment.
- Chapter 6: DBR Cycle 2. Documenting the added value of ER in promoting students' metacognitive thinking.
- Chapter 7: DBR Cycle 3. Understanding the effect of a structured versus an unstructured ER curriculum on students' learning outcomes.
- Chapter 8: Discussion. This chapter discusses the findings of the different phases of this research, taking into account results from all previous chapters. Insights for researcher and practitioners and direction for future research are presented.

2 Conceptual framework

This dissertation aims to present a holist understanding of the use of ER in educational settings, by drawing on current learning theories, knowledge on the design of learning environment, and conceptual and operational definitions of key variables related to metacognition and knowledge construction. The conceptual framework of the study presented in Figure 3 and elaborated below.

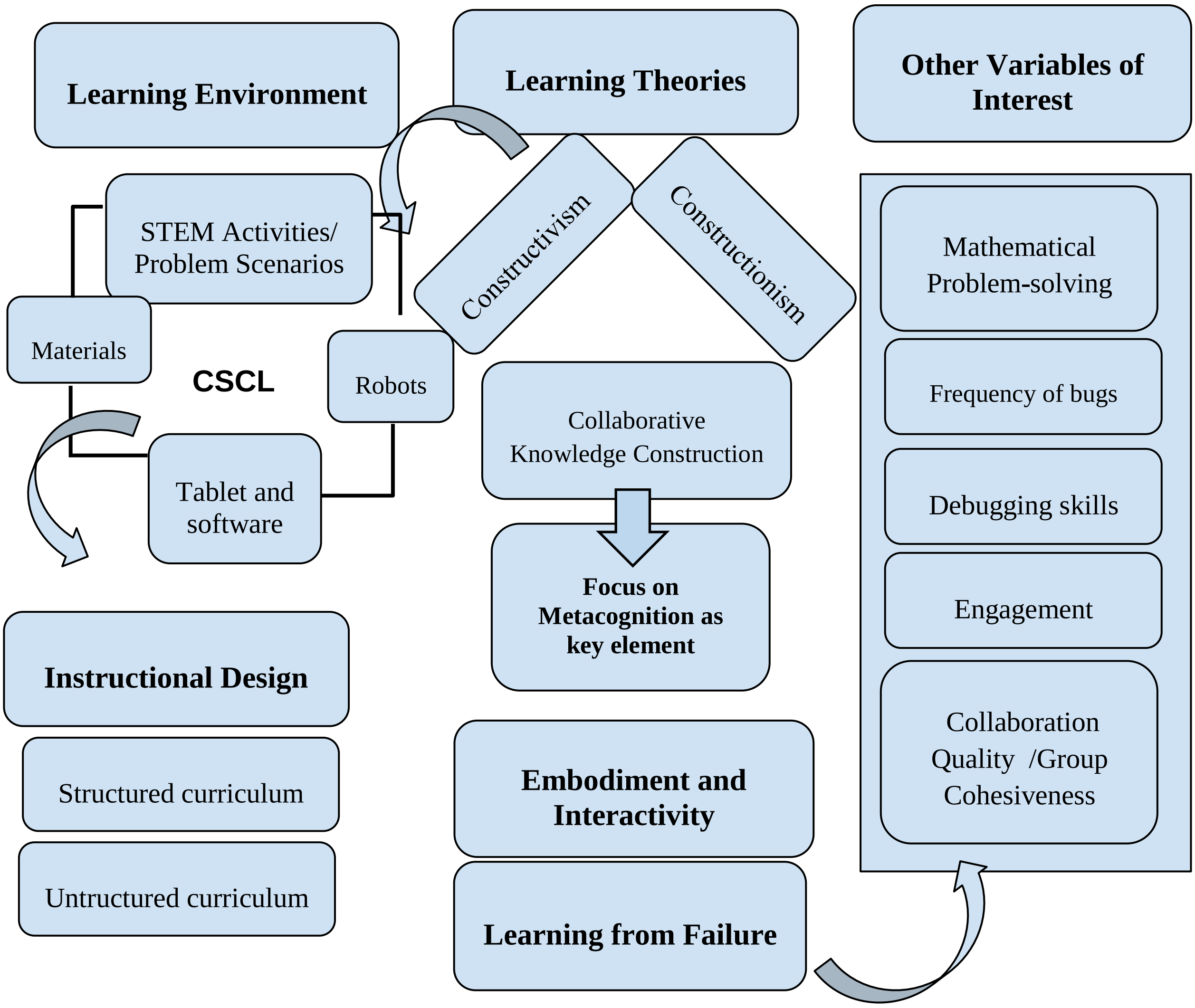


Figure 3: Conceptual framework of the study

2.1 Constructivism

Piaget's constructivism is based on the belief that the learner must actively build knowledge and skills (Huitt, 2003) and is focused on how children make meaning in relation to the interaction between their experiences and their ideas. The world is not just sitting out there waiting to be uncovered but gets progressively shaped and transformed through the child's personal experience (Ackermann, 2001). Social constructivism scholars, strongly influenced by Vygotsky's (1978) work, emphasize more on the social dimension noting that knowledge is first constructed in a social context and is then appropriated by individuals (Bruning et al., 1999). Individuals make meanings through the interactions with each other and with the environment they live in. Knowledge is thus a product of humans and is socially and culturally constructed (Prawat & Floden, 1994). According to this approach, the learning environment should provide authentic activities integrated into real-world problems, to encourage expression and personal involvement in the learning process and support social interaction.

2.2 Constructionism

Constructionism and its ideas can be traced backward to the constructivist education ideas of Jean Piaget. Papert stated "the fundamental principle of constructivism is that we learn better by doing and we learn even more if we combine our doing with talking and thinking about what we have done" (Papert, 1999, p. VI). Papert (1999) also clarified that there exists a difference between constructivism and constructionism. He stated that constructionism goes beyond the "learning by doing" philosophy of constructivism and should be thought of as "learning by making." The opposition is definite, but constructionism involves not only teaching of concepts but also determining what children of the future demand to know to carry on with creating new ideas and technology.

While constructionism is an extension of Piaget's constructivism, the former focuses on new technologies and on the significance of making them aid the learning process (Ioannou & Makridou, 2018). Constructionism adds to the constructivist perspective the idea of artifact construction through the assistance of digital media and computer-based technologies. Constructionism also highlights how children are involved in a conversation about artifacts, and how these conversations promote self-directed learning and finally make easier the construction of new knowledge. In other words, it emphasizes on the importance of an artifact with which the students are engaged with, and on the idea that computers can be used as a tool for applying knowledge and exploring new ideas (Papert, 2000). This artifact should be shared and visible to the world.

2.3 Computer supported collaborative learning

Computer Supported Collaborative Learning (CSCL) is a pedagogical approach where learning occurs through social interaction using a computer. This kind of learning can be described by the sharing and construction of knowledge among students working with technology as their primary mean of communication or as a shared resource (Stahl et al., 2006). The central notion of CSCL is that knowledge building is achieved through interaction with others.

The field draws heavily from several learning theories (i.e., distributed cognition, problem-based learning, group cognition, cognitive apprenticeship, and situated learning) that highlight that knowledge is the outcome of students interacting with each other, sharing, and building knowledge as a group. CSCL has roots in constructivist and social cognitivist learning theories (Resta & Laferrière, 2007). Therefore, the origins of collaborative epistemology as linked to CSCL can be found in Vygotsky's social learning theory, with the zone of proximal development and the internalization theory.

In CSCL, cooperation though different from collaboration, contributes to the success of a team in CSCL. The difference can be stated as: cooperative learning focuses on the effects of group interaction on individual learning, while collaborative learning is more about the cognitive processes at the group unit of analysis. In the late 1980s and early 1990s, Scardamalia and Bereiter's work (Scardamalia & Bereiter, 1994) have led to the addition of some other vital notions to CSCL such as knowledge-building communities and knowledge-building discourse.

An ER learning environment can potentially contribute to knowledge-building processes. Given the fact that students engage in a design and construction process, the constructionism approach allows for immediate and ongoing feedback and encourages collaboration and sharing (Chambers et al., 2007). Knowledge-building is, therefore, formed through a dual pathway, through interaction with the artifact and interaction with peers. The use of ER, as tangible learning objects, allows enriching the learning experience by providing instant feedback and subsequent reflection, achieving full immersion of students into the robot-centered collaborative learning environment. ER technologies are fully compatible with the nature of collocated CSCL by providing a way to infuse real-world experiences to the CSCL setting through the hands-on nature of collaborative activities. The literature shows that while most ER interventions take place in CSCL settings, they do not tend to rely on a CSCL framework.

2.4 Collaborative knowledge construction

In the last 20 years, researchers have seriously studied learning in small groups, and the nature of cooperation and interaction have turned into a focal issue for research on learning in social settings. Essential to collaborative learning is knowledge construction where the collaborative learning aims at co-constructing knowledge upon sharing information in groups for solving given tasks (Alavi & Dufner, 2005). The idea of joint construction of knowledge, which is based on a constructionist framework, allows learners to experience a greater level of understanding (Kafai & Resnick, 1996) because they must construct their own knowledge to learn the truth (Tam, 2000). The creation of new ideas and understandings lies at the heart of knowledge construction. Students by focusing on the process of creating ideas and carefully considering their value, they can become more skilled at thinking critically and creatively. The process of collaborative knowledge construction encourages students to investigate deeper about a subject so that can reach their highest potential level of development. The development of new understanding is coming as a combination of prior knowledge and skills with new experiences. New ideas or understandings can be considered any idea or understanding is new to them. When students generate new ideas, we should be interested in the process by which they generate these ideas and not on how important these ideas are. Oksanen et al. (2017) trying to determine the concept of knowledge construction gives the following definition: “Knowledge construction is a collaborative process which aims to produce new understanding or knowledge which exceeds something that anyone alone could not achieve. It is also essential that knowledge construction is based on each other's' ideas and thoughts." The principal points of this definition are the aspect of the generation of new ideas and understandings, and the aspect of collaboration.

2.5 Metacognition

According to Larkin (2006), there is not a general definition of the concept of metacognition and its composition in the literature. Despite not having a broad definition, there are features and dimensions of metacognition that are consistently referred across the field. For example, researchers widely agree that metacognition can be divided into a knowledge dimension and a skill dimension: "knowledge of cognition" and "regulation of cognition." These dimensions of metacognition are described and used to guide this study. For the purpose of this study, metacognition is defined as the understanding, awareness, and control of one's cognitive processes (Baker, 2011). Researchers also disagree with the most proper approaches to measure metacognition due to various and inconsistent definitions. In an effort to understand both the nature and the operation of metacognition, researchers proposed various definitions, such as:

- "one's knowledge concerning one's own cognitive processes and products, or anything related to them" (Flavell, 1976, p. 232).
- "knowledge about executive control systems" and the "evaluation (of) cognitive states such as self-appraisal and self-management" (Brown et al., 1994).
- "knowledge and awareness of one's own cognitive processes" (Mayer, 2003).
- "involves an awareness of the mental processes and strategies required for the performance of any cognitive endeavor. This knowledge is manifested in the form of strategic control of the processes necessary for successful performance" (Schmitt & Newby, 1986)
- "thinking about thinking or a person's cognition about cognition" (Wellman, 1985, p.1).
- metacognition and reflection are considered in educational psychology texts to be concerned with the process of monitoring, regulating, and controlling an individual's thinking about their thinking. It is useful to consider reflection as the verb of the process of thinking about thinking whereas metacognition is the adjective used to describe the awareness of thinking (Daniels, 2002).

According to Steinbach (2008), in recent years, many words synonymous with metacognition have been used. Some researchers use the word self-management for metacognition (O'Neil & Spielberger, 1979) while others prefer the word metamentation (Bogdan, 2000). Furthermore, Veenman, et al. (2006) state some different terms used in the relevant literature in connection with metacognition, such as metacognitive beliefs, executive skills, meta-components, and judgments of learning.

2.5.1 Precursors to metacognition

Flavell is recognized as a foundation researcher in metacognition. However, his work was rooted in Piaget's theory of cognitive development (Inhelder & Piaget, 1958). Piaget suggested a stage theory of cognitive development for children at specific ages, originating an apparent reference to a concept similar to metacognition when he proposed the formal operational stage of cognitive development. He suggested that children in this stage should advance from a concrete understanding of the world to be able to think with more abstract terms. To achieve this, children should be able to make and test hypotheses and think of possible results in problem situations, which supposes the use of metacognition. In other words, Piaget proposed that to enter this stage, a child should have to acquire the capacity to think on its own thoughts, making, in this way, one of the first references to the concept of metacognition.

Vygotsky emphasized the distinction between the spontaneous development of a concept and the development of a scientific concept. He claimed that the first is developed through everyday life, while the second through formal education. As he noted, "the conscious use of concepts simultaneously implies that concepts can be controlled voluntarily" (Vygotsky, 1986, p174). This idea is close to the concept of metacognition, where children know what they know and when they should be applied. Indeed, the concept of metacognition was already in the theories of Vygotsky and Piaget; however, in the area of cognitive psychology, empirical evidence led to a definition and exploration of metacognition.

2.5.2 Dimensions of metacognition

When Flavell first conceptualized metacognition, he thought that it consisted of two central dimensions, with a third dimension added later. The two original dimensions, according to Flavell (Flavell, 1979), were "metacognitive knowledge" and "metacognitive regulation." The third dimension was added later and termed "metacognitive experiences." In his model, metacognitive knowledge refers to the knowledge or beliefs an individual holds. He divided metacognitive knowledge into person, task, and strategy sub-categories. Person category refers to the knowledge of oneself cognitive processing, the task category includes the knowledge of what a task requires, and the strategy involves the knowledge of strategies that are available to achieve the goal. Although Flavell acknowledged "metacognitive experience" as the third dimension of metacognition, he highlighted the importance and study of the other two dimensions. The third dimension in Flavell's model, metacognitive experiences, involved the control and regulation of one's cognitive processes and was described as 'items of metacognitive knowledge that have entered consciousness' (Flavell 1979, p. 908). For instance, during the problem-solving process, a child may remember a previous problem that was related. These metacognitive experiences may lead the learners to revise their goals and strategies. Adding on Flavell's (1979) model of metacognition, Efklides (2002; 2008) viewed metacognition as having three main dimensions: metacognitive knowledge, metacognitive skills, and metacognitive experiences. All three dimensions were deemed to be crucial for successful learning (Efklides, 2002; 2008).

The three dimensions of metacognition, as described earlier, are not entirely separated; there are overlapping features across them. Elements and information from each other are not only interdependent but also consistently enhance each other and are used to inform the learning process. For instance, metacognitive regulation can borrow information from metacognitive experience. When someone has a feeling of uncertainty, then he can revise the strategies used (Papleontiou-Louca, 2003).

Metacognitive knowledge includes three types of categories that may be related (person, task, and strategies). It can be described as the thoughts and beliefs of someone about his own cognitive capabilities. Flavell extended this category by adding the thoughts and beliefs about the cognitive processes of others. According to Brown (1987), metacognitive knowledge is the metacognitive dimension that may develop later than the other two.

The main alternative in the literature on Flavel's model is Brown's model (1987), which, as opposed to Flavell's model, was created to be used in an educational context. Like Flavell's model, Brown proposed that metacognition is composed of two interacting dimensions: knowledge of cognition and regulation of cognition. In Brown's model, metacognitive knowledge was revised and broken down into three categories which, however, are directly related to the initial categories as proposed by Flavell. These categories, as proposed by Brown (1987), are (a) declarative, (b) procedural, and (c) conditional knowledge.

Declarative knowledge is knowledge about things (Figure 4); it is fact-based and objective knowledge. It is what people know about themselves as learners. Procedural knowledge is the knowledge about how to do things, how to perform tasks. It includes knowledge about procedures and strategies that are used to execute actions to solve a problem. Conditional knowledge is the knowledge of why and when to do things, why, and when to use a particular strategy. It has to do with the steps that can be taken to learn, the understanding and application of strategies to enhance learning (Schunk & Zimmerman, 1994, 1998).

Regulation of cognition indicates an individual's actions or mental activities to control their own cognition and includes three types of control: planning, monitoring, and evaluating (Cooper & Sandi-Urena, 2009). Planning refers to goal setting, activating previous knowledge, determining time, choosing suitable strategies, and predicting possible learning outcomes. The monitoring dimension comprises the self-testing skills to control and check the progress of one's learning (Schraw & Moshman, 1995). It can be used to identify problems and to modify learning behavior when needed (Desoete, 2008). The development of monitoring skills is slow in children and needs precise instruction to develop (Glenberg et al., 1987). Evaluation relates to reviewing the outcome and procedures of one's learning, considering the goals (Schraw & Moshman, 1995).

Flavell (1979) explained metacognitive experiences as “any conscious cognitive or affective experience that accompany or pertain to any intellectual enterprise” (p. 906). Flavell (1987) highlighted the value of teaching students how to interpret these affective experiences. Affective experience, as part of metacognitive experiences, is essential because if a person has the feeling that a task is difficult to solve, this feeling may trigger metacognitive reflection and changes in goals or strategies (Papaleontiou-Louca, 2008). Later, Efklides (2001) identified different categories of metacognitive experiences: feeling of familiarity, feeling of confidence, difficulty, feeling of satisfaction, estimate of solution correctness, and effort expenditure. She also joined Flavell (1979) in linking metacognitive experiences to triggering metacognitive knowledge.

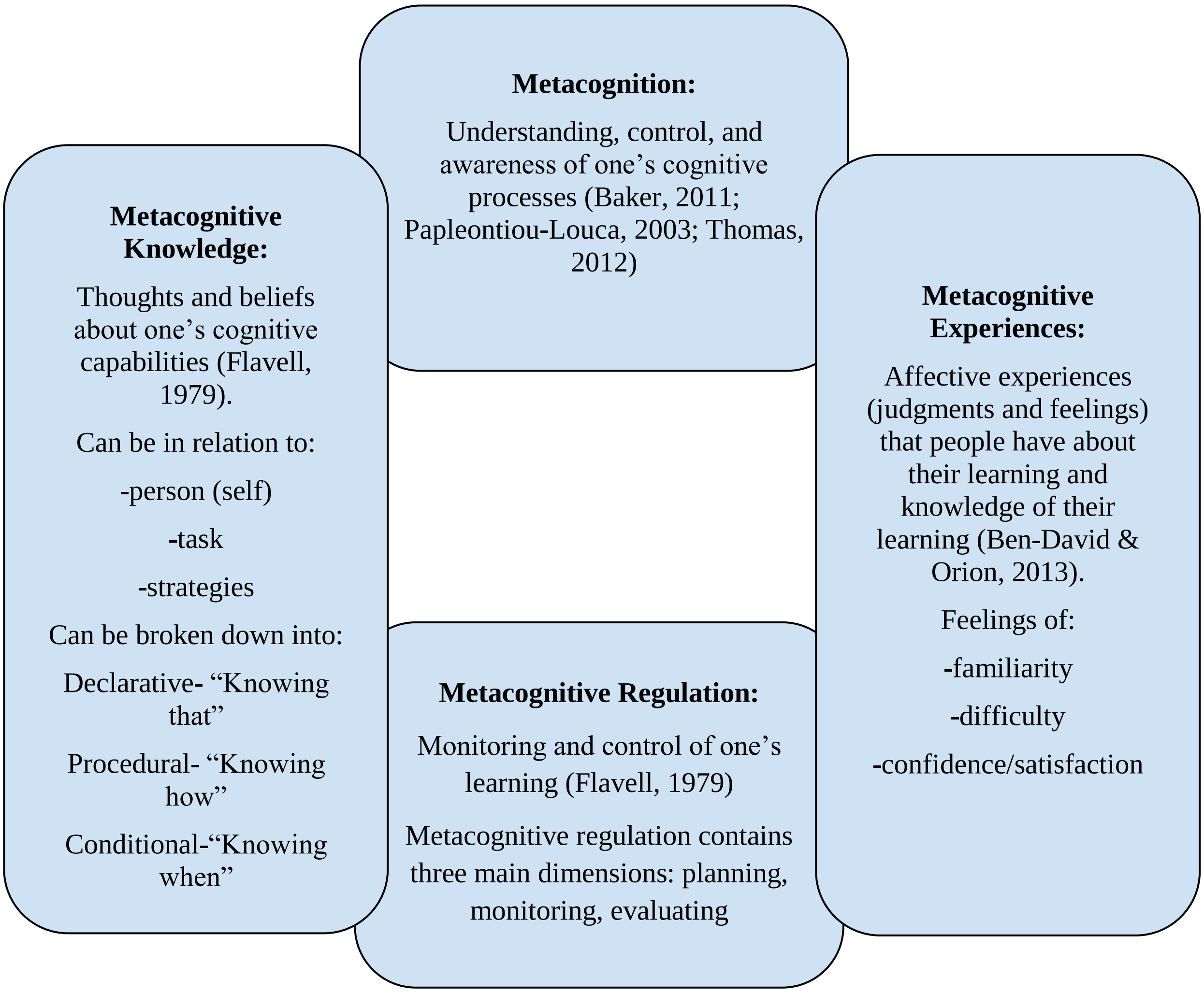


Figure 4: Dimensions of metacognition

2.6 Metacognition of group processes in CSCL environments

Research has shown that metacognition can be performed at an individual level; it has been mostly studied as an individual process thus neglecting the role of social regulated behavior during collaborative activities (Zion et al., 2015). The processes of individual metacognition are well established, and there is a debate around moving the emphasis from the individual to the collective aspect. The collective knowledge management processes and how information is managed and controlled by the group during knowledge building should be analyzed (Järvelä et al., 2015). While the development of regulated learning skills in CSCL activities was considered (Järvelä et al., 2015), there are few contributions and tools to the metacognition of group dynamics and group awareness.

Over the last three decades, several researchers have recognized the role of social interaction in mediating and sharing metacognitive knowledge (Brown et al., 1983; Paris & Winograd, 1990). Group metacognition is a component of a broader educational view of promoting self-regulation and refers to the capacity to reflect on the cognitive skills of the group during group work (Biasutti & Frate, 2018). In other words, group metacognition is about group members thinking of the way the group processes information and the expectations they have about how the group performs the tasks (Hinsz, 2004). This kind of thinking includes the extent to which group members are informed about their abilities in choosing and arranging information, as well as their skills in planning, monitoring, and evaluating aspects of their collaborative work (Biasutti & Fratte, 2018).

Shared metacognition is manifested in different disciplines. Mead (1934) described how argumentation with a generalized other affects thinking. However, he largely ignored the use of cognition, whereas Vygotsky's (1978) alike ideas were affected the cognitive development theories. Similar ideas are manifested in the area of transactive memory research. Transactive memory research is considered a distinct area from metacognition and explores how knowledge is spread among group members and how successful mutual knowledge is used.

Furthermore, within the field of social psychology, the information processing model supports the idea that socially shared metacognition refers to members' knowledge of what other group members know. According to Tindale and Kameda (2000), the degree of sharedness among group members is linked to group performance. In addition, Mathieu et al. (2000) described the role of shared cognition in team effectiveness, claiming that it is not only the overlap of knowledge among team members that is predictive of team outcomes but also the synergy of the knowledge organizations.

The significance of general cognitive characteristics during collaborative learning has been investigated in many research fields but has rarely been extensively applied in metacognitive research. Several words such as team cognition, shared cognition, group awareness and transactive memory have often been used for highlighting the value of group knowledge and collective mental constructs. In group cognition, shared knowledge is constructed effectively when members can collectively process information and follow communication approaches that support fair rates of information sharing across members (Grand et al., 2016).

In social learning situations, metacognitive awareness is required to understand individual and others cognition, to interpret the situational data, and make effective control decisions (Nelson et al., 1998). Group awareness can be considered as another critical factor for team effectiveness. Various conceptualizations have been proposed for this construct, including behavioral, social, and cognitive awareness (Bodemer & Dehler, 2011). Behavioral awareness relates to the students' activities, while social awareness refers to the consciousness of others' presence and the participation of group members. Cognitive awareness is related to the knowledge of members of the group.

Regulated learning is another concept related to metacognition. According to Hadwin and Oshige (2011), there are three types of regulation in collaborative tasks: (a) self-regulated learning in which students take control of their own cognition, (b) coregulated learning where students' self-regulatory processes are supported by other team members, technologies and contextual aspects, and (c) socially shared regulation of learning where group members work together to regulate their collective cognition. Regulated learning is guided by metacognition and involves the regulatory dimensions of metacognition, such as planning, monitoring, and evaluating.

Previous work in the area of regulated learning in CSCL settings has shown that it is crucial to stimulate students' metacognitive thinking and adapt their actions to the particular cognitive challenge (Järvelä et al., 2015). In CSCL, students have to plan collectively, formulate collaboration strategies, monitor and track the group work and evaluate the outcome of their efforts. These actions are recognized as essential aspects for the advancement of group cohesion and the development of effective learning (Järvelä et al., 2015) as students become conscious of their abilities as learners and are able to assess and regulate their cognition.

Research on metacognition in small groups is scarce; what research has been carried out has produced conflicting results (Goos et al., 2002). For example, Goos and Galbraith (1996) showed that students' interactions could support or block metacognitive decisions depending on the students' capacity in assigning metacognitive roles. Stacey (1992) demonstrated that students' problem-solving performance decreased when they worked in groups. Due to the lack of monitoring and evaluation processes, the correct solution had been dismissed. Previous studies in the area of metacognition in collaborative settings have proposed that metacognition is socially shared (Iiskala et al., 2004) and appears through social discourse (Lin, 2001), with members of a group serving as external regulators (Azevedo, 2005). Additionally, Jermann (2004) demonstrated that students are able to not only regulate their own activity but also control how their teammates operate.

2.7 ER and constructionism

Most scholarship cites cognitive constructivism as the theoretical framework that undergirds the teaching and study of ER. There is evidence that Papert's constructionism, which highlights the importance of a public demonstration, is a more relevant model (Papert & Harrel, 1991). Indeed, the foundations of ER lie in Papert's ideas that children can learn mathematics in a more meaningful way when working with computers and the LOGO programming language (Papert, 1980). Papert (1980), observed the potential of computers in education and noted the issue of mixing old instructional methodologies with new technologies. He believed that the dissociated model of learning math was problematic as was saying that people cannot do math just because they do not get the way it is taught in school; they just need to find a different route to get there. Therefore, Papert proposed the use of new technologies, such as computers and robots to change the nature of learning at school (Julià & Antolí, 2016).

He developed the LOGO programming language and explained that LOGO is something more than just a programming language and a learning environment. He emphasized that learning is more than merely getting right or wrong answers; learning is about life and making things work. For example, in the LOGO environment, when a child had a question, the instructor was not to give the child the answer but rather encourage the child to "play Turtle" and act it out. He suggested that this taught the child a method rather than an isolated program. Turtle geometry could develop a mathematics (learning) strategy (i.e., making sense of something in order to learn it) and syntonic learning (i.e., acting things out) could make the learning process concrete.

ER can be considered as an extension of LOGO and turtle graphics involving the construction and programming of physical objects. Children interact with robots as a physical object (although the programming is happening digitally) and employ their knowledge and skills to solve real-world problems. Having its foundations on theories of Piaget, Papert and Vygotsky, ER aims to develop students' higher-order thinking skills through discovery, problem-solving and collaboration (Blanchard et al., 2010; Gura, 2007) in an attractive, engaging and gamefull learning environment.

There are, however, criticisms of constructionism and constructivism. Studying a programming project with elementary school aged students in a constructivist setting, Bruckman et al. (2013) found that while some students mastered the material, the majority of students learned little with large amounts of time off task. Other researchers note that while constructivism is a good cognitive model of learning, it has been difficult to translate into useful instructional practices. Gordon (2009) highlights misuses that have led to poor implementations, while Windschitl (1999) discusses inadequate teacher training, and the difficulties in creating a constructivist culture in the classroom. One practice that draws particular criticism is pure discovery learning, where students are left in a low guidance environment where they are supposed to discover and construct understanding by themselves. Mayer (2004) states that without sufficient guidance students learn inefficiently and sometimes construct the wrong conceptions. Studying children working in Logo, Kurland and Pea (1985) found that the students created the wrong mental model for recursion. Citing empirical studies and cognition theories, Lehrer (1986) similarly calls for more guided learning.

2.8 Productive failure

Structuring problem-solving activities to boost student performance is a fundamental theoretical and design issue in education (Tobias & Duffy, 2009). Structuring may take various forms, such as structuring the problem itself, offering scaffolding, prompts, metacognitive support, and scripting, as well as providing tools, resources, and content. Empirical work has shown that students tend to benefit from such support when engaged in complex problem-solving. Researchers have therefore focused on various techniques for structuring activities to help students achieve performance success. Kapur (2008), on the other hand, espouses the concept of productive failure, which is grounded on the position that engaging students to try, and even fail, to solve complex problems can, under certain conditions, be productive for developing a deeper understanding of a concept. Kapur's idea was to intentionally design failure in ways that are actually productive for learning. Though such a process may initially cause a failure to generate "canonical solutions" (i.e., correct solutions; see Kapur, 2008), it has a hidden efficacy in that it prepares students to see and learn from a suitable instructional intervention later on; this can consolidate student-generated solutions into canonical solutions. The notion that students can learn from their own failed problem-solving efforts is now empirically grounded. A recent meta-analysis from Darabi et al. (2018) on this exact topic revealed a moderately positive result for the effect of learning from failure.

Kapur (2008, 2011) offers examples of the idea of learning from failure. For example, in a series of studies, the students had to work on either ill-defined or well-defined tasks. The results of these studies revealed that students who had worked on ill-defined tasks outperformed students who worked on well-structured ones. It was shown that struggling with a higher degree of complexity promoted students' ability to develop important structures for problem-solving. The results were further confirmed in subsequent studies (Kapur, 2016; Kapur & Lee, 2009), where "productive failure" was compared with the approaches of "lecture and practice" and "direct instruction". Despite students from the "productive failure" condition failing in their problem-solving efforts, the results showed that they outperformed the students from the "lecture and practice" and "direct instruction" conditions in both conceptual knowledge and transfer of knowledge. In short, the results over a decade of the application of productive failure (Kapur, 2008, 2011) show that the outcomes of this instructional practice are beneficial to students in terms of (a) conceptual understanding, i.e., understanding what they know, (b) ability to transfer knowledge to novel problems, and (c) affective aspects of learning.

2.9 Debugging as a productive failure

The research on debugging goes back to the 1970s (Fitzgerald et al., 2010) and includes a huge variety of topics such as (a) the type of bugs that occur, (b) the causes of bugs, (c) strategies employed in debugging, and (d) ways to improve learning and teaching of debugging (see McCauley et al., 2008). One aspect of the research has heavily focused on the question of "what goes wrong" when students are learning programming. Hristova et al. (2003), for example, examined the patterns of student errors to compile a comprehensive list of typical errors. In addition, some research has investigated the strategic approaches to debugging by novices, describing a wide variety of debugging practices (e.g., Fitzgerald et al., 2010). This body of work informs current research on block-based programming, although the tools and languages used for programming today are different from those used decades earlier.

Between 2016 and 2019, UCLA, 9 Dots, and UC Berkeley collaborated on an initiative called "Debugging failure: Fostering youth academic resilience in computer science". The project focused on designing, implementing, and evaluating small coding workshops to foster a culture of productive failure practices among primary and lower secondary school students. The students had access to a wide range of debugging tools such as automatic syntax checkers, ways to step line by line through code, and objects for modelling code. The instructors guided students through these tools using a five-step debugging process that prioritized students' agency and self-refection. As part of this project, DeLiema et al. (2019) examined the process of debugging to foster critical self-refection. The study explored two classroom designs targeting students' growth, specifically by looking at how they responded to failure. Results showed that, when asked to reflect about debugging students generated ideas around critical thinking strategies. Results further showed that instructors' modelling, prompting for, and reflecting on critical thinking strategies with students during failure was an effective instructional strategy.

More recently, Fields et al. (2021) examined the idea of debugging by design using e-textiles. In the study, students created and then solved buggy projects for each other. The researchers used a constructionist approach for productive failure, with the students themselves designing the challenging problem sets. The results demonstrated high levels of interest and engagement with the learning by design approach, greater confidence in debugging, as well as improved abilities to detect and fix bugs.

The practice of debugging presents significant learning challenges (and opportunities) for students completing complex tasks. It also presents instructional challenges to teachers in helping their students to succeed. More recent pedagogical approaches debugging exercises as opportunities or contexts for productive failure, which may result in learning. From this point of view, each programming error represents a meaningful step towards helping the students to learn.

2.10 Curriculum structures in ER research

Given the small number of studies that compared different curriculum structures, the results do not present a comprehensive picture. For instance, a study by Lee et al. (2013) investigated the effect of the curriculum structure in encouraging collaborative interactions, using a structured ER curriculum compared with an unstructured curriculum. The sample included a total of 19 kindergarten children (mean age 5.68 years) participating in a 5-day ER workshop. The 19 children were randomly divided into two groups: the treatment group and the control group. The control group was taught using an instructionist approach in which students learned to programme by engaging in pre-designed challenges while the treatment group followed a constructionist approach in which students did not have structured practice, but instead explored various concepts on their own. The amount of social interaction was measured using a collaboration web, which was a sheet of paper with a child's picture surrounded by pictures of everyone else in the class. Students should draw arrows to show children that they helped and children that helped them during the activity. The results demonstrated that the constructionist group was linked with a significantly greater amount of collaboration than the instructionist curriculum group. Therefore, according to this study, a less structured learning approach is more useful in order to encourage collaboration.

A second study explored the development of students' individual metacognitive and problem-solving skills in ER activities using different levels of metacognitive guidance in two groups (Atmatzidou et al., 2018). The students of each age group were involved in an 18-h group-based activity after being randomly distributed in two conditions:

“minimal” (with minimal metacognitive and problem-solving guidance) and “strong” (with strong metacognitive and problem-solving guidance). The minimal guidance group used worksheets of increasing difficulty, whilst the strong guidance group was prompted to follow specific metacognitive and problem-solving strategies. Evaluations were based on the Metacognitive Awareness Inventory measuring students’ metacognitive awareness and, on a think-aloud protocol asking students to describe the process they would follow to solve a certain robot-programming task. The results suggested that (a) strong guidance in solving problems can have a positive impact on students’ metacognitive and problem-solving skills and (b) students can reach the same level of metacognitive and problem-solving skills development independently of their age and gender. Therefore, according to this study, ER activities, through the appropriate guidance, which means following specific prompting and responding in writing, can improve the students’ metacognitive and problem-solving skills to a statistically significant degree. And as is obvious, ER can be a vehicle for the development of metacognitive and problem-solving skills in students of Elementary and High School grades.

Overall, there is a widespread assumption that ER can be useful in increasing engagement and motivation in learning (Anwar et al., 2019; Kim et al., 2015; Ruiz-del-Solar & Avilés, 2004). Student engagement is positively impacted by the physical presence of robots, making the results of programming immediately available and providing a formative evaluation of the learning process (Gyebi et al., 2016). However, there is a lack of research in the field of ER that compares how different curriculum structures may impact student engagement. Outside the area of ER, research studies have generally found positive to mixed results concerning the relationship between student-centred learning environments and student engagement. For example, in a study by Wu and Huang (2007), students reported significantly higher emotional engagement in a student-centred environment compared to a teacher-centred environment.

2.11 Conceptual framework summary

In sum, the overarching goal of this work was to explore how ER can support students’ development of metacognitive thinking as a key element of collaborative knowledge construction. The conceptual framework for this study draws on the theoretical roots of constructivism and constructionism, the design of CSCL learning environments using ER to improve students' metacognition and collaborative knowledge construction. Based on this conceptual framework, it is expected that students experiencing ER in the CSCL setting will be engaged in collaborative knowledge construction, building on their prior knowledge, and experimenting with failure to improve their metacognitive skills. Learning environments design choices such as structured vs unstructured curriculum and variables such as debugging skills, level of engagement, collaboration quality and group cohesiveness among others are expected to interplay with the observed outcomes from the ER experience.

3 Review of the literature

This chapter identifies the research experience in the use of ER and presents the most recent issues, ideas, and challenges around the use of ER in education. The chapter provides a holistic view of empirical research in the field, along with some brief history of the evolution of this technology.

3.1 The evolution of ER

The idea of using robotics in education is due to Seymour Papert, who created the MicroWorlds platform and the Logo programming language. The idea of a microworld based on a constructivist approach to learning is at the heart of robotics (Papert, 1980). A microworld can be described as a small word through which students can navigate, explore, and test courses of action and information. In the 1960s, Papert was concerned about how students think and learn from constructivist approaches (Papert, 1980). Constructivism invites students to create their own understandings of the world and construct their own knowledge (Martin-Stanley & Martin-Stanley, 2007). Papert moves a further step towards constructivism with the development of the theoretical framework of constructionism, which requires students to transform their understanding into concrete designs (Papert & Harel, 1991). In this framework, students are expected to solve a problem or circumstance to which they may apply. Students must design and plan a potential approach and control artifacts to check their ideas. The manipulation and testing of solutions and the creation of artifacts are important for constructing and producing knowledge as students gain an understanding of their results (Jonassen & Strobel, 2006).

Along with colleagues, Papert created the Logo programming language to facilitate science, math and art concepts through a computer and, ultimately, enable robot control and problem-solving (Rieber, 2005). Based on the emergence of artificial intelligence, the Logo was developed in 1967 to manipulate a robot on a screen. Today, more than 160 Logo language versions have been established in the last 40 years. There are several versions of the Logo which are used in classrooms around the world, such as Turtle Tracks, RoamerWorld, LogoWriter, NetLogo and LEGO Logo.

Another essential aspect of ER is that students are better connected to a robot depicting a specific object. Gray Walter, in the 1950s, explored this idea by creating a robot named "turtle" as it resembled a turtle shell (Papert, 1980). Based on these ideas and the evolution of ER, Papert developed his own Logo-based turtle. The physical presence of a turtle made it easier for students to grasp abstract ideas that were normally deemed too complicated because they watched the actions of an object they could respond to (Rieber, 2005). Robotics was adopted in classrooms in the early 1980s when the LEGO TC Logo appeared. Lego TC focused on the usage of the Logo language and the idea of the physical presence of a "turtle" robot to induce movement and formation of shapes as a result of students' programming commands. The kit fused the easy-to-learn LOGO programming language, with the useful LEGO manipulatives. Therefore, rather than staying restricted to the computer monitor, the robot was now a hand-made object constructed of LEGO's (Resnick & Ocko, 1991).

Towards the end of the 1980s, the Roamer robot has appeared as a three-tier design model composed of Roamer, Tronix (electronics that could be added) and Inventa (building materials). This kind of robot encouraged students to develop their designs using various materials and operate autonomously through a computer software. In the 1990s, hundreds of Logo software versions were produced, such as Turtle Math and LEGO Logo used as an enrichment to the formal instruction (Resnick, 1993). With the critical advances in computer science, several updated versions of robots are used worldwide in education.

In elementary education, most robot's programming interfaces have moved from text-based programming to block-based programming. About 20 years ago, the MIT Media lab introduced the idea of block-based programming. In contrast to text-based programming, block-based eliminates the need to learn the syntax of a language and enables learners to focus their mental energy on the logic of their programmes, rather than on the semantics. This idea made teaching and learning the fundamental concepts of computer science accessible to younger learners with no previous coding experience. At the same time, this idea generated a new strand of research on scaffolding novice programmers with the use of direct manipulation interfaces (Weintrop & Wilensky, 2015). This became more popular once robots were introduced in education, and as a result, block-based programming is now often paired with ER. However, there is a critique about the efficiency of block-based programming in practicing fundamental programming (Grover et al., 2015) as learners sometimes tinker with reusable code, remixing to create a functioning code without understanding the logic behind it (Brennan & Resnick, 2012).

At the same time, some robots continue to use LOGO programming or have moved to C+ and Java languages (Sklar et al., 2007). Nowadays, most robots permit students to program on a robot and also download from a computer program to a robot. Since 1998 LEGO has been utilizing the Smart Brick, a keypad connected to students' designed objects that act as the brains of the device. Given the growing availability, ease of use and reduced prices, ER is more commonly used in secondary education, whereas the usage of robots in elementary education is considered to be an extracurricular activity.

3.2 Empirical work on metacognition in ER

Broadly defined, metacognition is a person’s awareness of his or her own thought processes and the ability to regulate these processes (Goos et al., 2002). Studies have shown that metacognition is associated with math and problem-solving ability (Cornoldi,1997) and course grades (Young & Fry, 2008), and that metacognitive ability can be developed (Bransford et al., 2000). Hypothetically, the use of ER has the potential to foster metacognitive development. Students working in small groups (as in ER teams) can achieve a group metacognition where the members work as peer reviewers of each other’s ideas and processes (Goos et al., 2002). However, work on this subject is still in its infancy.

An initial study conducted by Lai (1990) aimed to explore the effectiveness of the Lego-Logo environment (Table 1). The study involved 24 students (ages 10 to 11) for eight sessions (one and a half hours each) and was intended to promote the development of metacognitive thinking in a student-centered CSCL environment. Students had to identify the goals of their Lego-Logo task, plan for a solution, implement their solution, test their hypotheses, debug their programs, and finally evaluate their solutions. They were also encouraged to reflect upon their thinking by asking themselves metacognitive questions and answering them in their logbooks. The data provided evidence that this learner-centered environment was a solid experience that encouraged the development of metacognitive thinking, planning, and debugging skills and the acquisition of both programming concepts and control technology concepts. The results also showed that this was an exciting learning environment for young students as participants demonstrated their satisfaction when they had successfully operated their models. According to the authors, the environment was stimulating because students were able to control and own their learning process.

In a second study (Lai, 1993) from the same author with 13 students (8 to 10 years old), the results showed that students increased their metacognitive thinking during the learning experience in a LEGO / Logo environment. Specifically, learning in this environment enhances students' high-order thinking skills, such as self-monitoring and evaluation. The impact of the LEGO / Logo environment on their willingness to work together was similar for boys and girls. Comparing these two studies, Lai reported that the younger students (8-9 years old) from the second study, increased their knowledge more than older students (10-11).

A similar study conducted by Lo Ting-kau (1992) used LEGO TC building materials and the LEGO TC Logo programming language as a vehicle to explore the development of students' problem-solving skills and metacognitive thinking. The study involved seven students (aged 14-19) of a secondary school who worked in pairs and were also encouraged to reflect on their thinking. The results showed that the LEGO TC Logo learning environment contributes to students' active problem-solving and promotes metacognitive knowledge. The study results of Lo Ting-kau (1992) generally support Lai's (1990; 1993) research findings showing further that the use of LEGO-Logo in the classroom may provide a rich environment for problem-solving. It was also evident that LEGO construction and Logo programming activities enabled learners to carry out investigations involving both heuristic and algorithmic problem-solving strategies, enhancing concept development and the acquisition of a variety of metacognitive and cognitive skills.

Ishii et al. (2006) proposed a framework for designing and improving the learning environment for creativity in engineering. Based on that framework, they designed and practiced a Lego robot-based course at a university level. The study involved 91 first-year students, who recorded their actions on reflection sheets and graphs and used an online support environment. It was found that students' idea generation skills were improved while their metacognitive skills were activated. According to the authors, the ratio of students who reconsidered the functions of the programs improved from 19% to 38%, indicating that the number of students who undertook autonomous reflection increased due to having experienced reflection in the classes.

McWhorter (2008) examined the possible link between self-regulated learning and LEGO Mindstorms robotic activities in teaching computer programming concepts in an introductory university computer programming course. The study involved 83 students divided into two groups, the control group (n = 40), which used traditional programming and the experimental group (n = 43), which used LEGO Mindstorms. The areas of motivation, learning strategies, and mastery of the course objectives were investigated using the Motivated Strategies for Learning Questionnaire (MSLQ). While the results revealed an improvement in the development of metacognitive skills in both groups, the statistical analysis failed to report any significant differences between the traditional control group and the experimental LEGO Mindstorms group.

Lin and Liu (2011) investigated the relationship between learning motivation and learning strategies in ER learning involving 37 primary school students (Year, 3, 4, 5 and 6) who participated in the World Robot Olympiad 2010. The Robotics Motivated Strategies for Learning Questionnaire (RMSLQ) was used to collect data about student learning motivation and learning strategies. The results indicated that students showed high motivation and used a variety of learning strategies. It was also found that cognitive, metacognitive and resource management strategies had a significant positive correlation with students' control beliefs. Control beliefs have to do with the perceived presence of factors that may facilitate or impede performance of a behavior. This finding suggests that students' control belief was a critical element in robotics learning; students with more control belief used more metacognitive strategies.

In another study, La Paglia et al. (2010) investigated the process of building and programming Lego Mindstorms robots as a metacognitive tool. The data collection included quantitative data and qualitative observations from a sample of 12 children (aged 8-10 years) attending an Italian primary school. The results showed that ER activities could be intended as a new metacognitive environment that allows students to monitor and control their learning in an autonomous and self-centered way. In addition, the results revealed that during the programming phase, students made a higher number of self-corrections than during the construction phase; during the construction phase, they preferred to request help rather than using self-corrections. However, the authors stated that additional research with a larger sample should be carried out to confirm these results.

In their most recent study, La Paglia et al. (2011) investigated the improvement of metacognitive skills in mathematics through the process of building and programming robots. The study involved 30 secondary school students (mean age: 11 years) and assigned them to the control (which did not use robots) or the experimental group (which used robots). The researchers used as a pre-post assessment, the Mathematics and Cognition Questionnaire, which examines attitudes, beliefs, and control procedures. The results showed that ER activities could help students to (a) improve their attitude towards mathematics and (b) reflect on their learning and on their control dimensions such as planning, monitoring and evaluation. In particular, the results showed a statistically significant increase in performance on all metacognitive indicators for the experimental group compared to the control group. In general, beyond the effectiveness of ER activities to develop students' metacognitive thinking, this study showed that robots could be used to modify dysfunctional beliefs that may influence mathematics learning.

Gaudiello and Zibetti (2013) tried to identify and classify the heuristics that are spontaneously applied by 6-10 years old children interacting with robots. Two studies are described: an exploratory investigation into the control of a Lynx AL5A arm and a pilot study about the control of a Lego Mindstorms NXT®. Two issues related to control heuristics are addressed: the heuristic shift and the perceived and objective level of task difficulty. Based on a proposed classification system for children's control heuristics, the researchers recorded the nature of the actions performed by each child when he/she controlled the robot. They additionally used language markers of children's verbalizations and errors made during problem-solving as indicators to understand the task difficulty. The results showed that three main types of heuristics emerge: (a) procedural, (b) declarative and (c) metacognitively oriented. Particularly, they observed that procedural-oriented heuristics occurred more frequently in both robots while metacognitive-oriented heuristics occurred more frequently than declarative-oriented heuristics with the Lego robot. The extensive use of metacognitive-oriented heuristics when children control Lego robots seems to confirm evidence in the literature that this kind of robot should increase metacognitive attitudes during knowledge acquisition.

Keren and Fridin (2014) demonstrated how the Kindergarten Social Assistance Robot (KindSAR) could be used to teach geometric thinking and promote metacognitive development by engaging children in interactive play activities. The study involved 17 preschool children (aged 4-6 years). During the activities, their reactions and performance were recorded on video for further analysis. To measure children's learning, they developed a novel measure of cognitive learning, called "velocity of learning." The results showed that children exhibited positive interaction with the robot and a high level of enjoyment while their performances in metacognitive tasks and geometric thinking improved statistically significantly while they "played" with robots.

Huang et al. (2014), explored metacognition by studying the reflection journals of 17 college students and the change in general self-efficacy and robotics self-efficacy during a semester of ER course. The study results showed that (a) students had increased use of metacognition in terms of planning and evaluation in their reflection journals during the last weeks of the course compared to the first weeks, (b) records of existing knowledge, views and learning showed a declining trend. Also, the results revealed that self-efficacy in students' knowledge and skills about robotics increased significantly. Therefore, according to the researchers, reflection journals can be a beneficial tool for teachers in supporting students to practice metacognition and become active learners.

One more study exploring the development of students' metacognitive skills in ER activities is that of Atmatzidou et al. (2018). The study investigated the development of metacognitive problem-solving skills in the context of robotic activities, using Lego NXT, and implementing different modes of metacognitive guidance in two student groups at two different age groups. The students of each age group were involved in an 18-h group-based activity after being randomly distributed in two conditions: minimal (with minimal metacognitive and problem-solving guidance) and strong (with strong metacognitive and problem-solving guidance). The minimal guidance group used worksheets of increasing difficulty, whilst the strong guidance group was prompted to follow specific metacognitive and problem-solving strategies. The researchers used the Metacognitive Awareness Inventory (MAI) as a pre-post assessment tool to assess students' metacognitive skills and a think-aloud protocol asking students to describe the process they would follow to address a robot-programming task. The results demonstrated that stronger guidance had a larger impact on students' metacognitive and problem-solving abilities. Therefore, the authors argued that ER is a metacognitively powerful learning tool, whose learning benefits can be maximized within an appropriate guidance framework.

Table 1: Context of the studies and major findings

Studies	**Level/Participants**	**Robot**	**Major findings**
1. Lai, (1990; 1993)	24 students (aged 10 to 11) 14 students (aged 8 to 10) Elementary	Lego / Logo	ER activities enhanced concept development and acquisition of metacognitive and higher-order thinking skills, such as self-monitoring and evaluation
2. Lo Ting-kau, (1994)	7 students (aged 14-19). High	Lego TC Logo	Robots' construction and programming activities enabled learners to carry out investigations involving both heuristic and algorithmic problem-solving strategies, enhancing concept development, metacognitive and cognitive skills
3. Ishii et al. (2006)	91 students University	Lego Mindstorms	Learners' idea-generation skills were improved, and their metacognitive skills were also activated through the experience with robotics
4. McWhorter, (2008)	83 students University	Lego Mindstorms	ER activities had not a positive effect on the development of students self-regulated skills, but this was not statistically significant
5. La Paglia et al. (2010)	12 children (aged 8-10)	Lego Mindstorms	ER activities may be intended as a new metacognitive environment that allows students to monitor and control their learning
6. Lin & Liu, (2011)	37 students Elementary	Unspecified	Students participating in ER activities showed high motivation and used a variety of learning strategies using ER. It was also found that cognitive, metacognitive and resource management strategies had a significant positive correlation with students' control beliefs.
7. La Paglia et al. (2011)	30 students Secondary	Unspecified	ER activities could help students to (a) improve their

			attitude towards mathematics and (b) reflect on their learning and on their control dimensions such as planning, monitoring and evaluation
8. Gaudiello & Zibetti, (2013)	26 students (aged 6–10) Elementary	Lynx AL5A and Lego Mindstorms NXT®	The results showed that three main types of heuristics emerge: (a) procedural, (b) declarative and (c) metacognitively oriented.
9. Keren & Fridin, (2014)	17 students (aged 4-6). Kindengarden	KindSAR	Children exhibited positive interaction with the robot and a high level of enjoyment while their performances in metacognitive tasks and geometric thinking improved statistically significantly
10. Huang et al. (2014)	17 students University	Unspecified	Writing reflection journals can be a useful tool for teachers in helping students practice metacognition
11. Atmatzidou et al. (2018)	52 students Elementary and High	Lego Mindstorms NXT®.	Stronger guidance has a larger impact on students' metacognitive and problem-solving skills

3.3 Collaborative knowledge construction in ER

The research tradition building on the socio-constructivist perspective is interested in cognitive processes relevant to collaborative knowledge construction (Fischer et al., 2002). The underlying assumption of this approach is that the cognitive processes and outcomes of collaborative work are related. This type of research has focused on studying the relationship between the cognitive aspects of student interaction and individual learning. Positive results of collaborative interactions have been explained by the notion that peer interaction stimulates the elaboration of knowledge and hence promotes individual cognitive gains (Van Boxtel, 2001). These individual gains are typically measured in pre- and post-test designs as refinement or change of conceptual knowledge structures. Thus, the main interest is in studying how collaboration contributes to individual knowledge construction, the mental content of individual minds.

The socio-constructivist perspective is based on the Piagetian view of learning according to which individuals actively construct knowledge by a process of equilibration. This means that individuals aim to hold a consistent, equilibrated conception of their world. Knowledge construction occurs when individuals accommodate cognitive structures to better represent the context. In accommodation the present knowledge structures or concepts are reorganised or new knowledge is constructed. From the viewpoint of learning, the state of disequilibrium of cognitive structures is important in enhancing the process of equilibration. According to neo-Piagetians (e.g., Mugny & Doise, 1978), the socio-cognitive conflict, causing the state of disequilibrium, is one of the central mechanisms in collaborative knowledge construction (Kruger 1993). In many studies the students' difference in terms of knowledge or perspectives is stressed as a prerequisite for cognitive conflict (e.g., Dillenbourg, 1999) and learning (Kneser & Ploetzner, 2001).

In peer interaction a socio-cognitive conflict may take place through another central mechanism of collaborative knowledge construction; namely externalisation (Fischer et al., 2002) or verbalisation (Van Boxtel, 2001). By externalising their knowledge, ideas, values, presumptions, perspectives, and views students may become aware of their knowledge gaps and misunderstandings, and this pushes them to reconsider their conceptions to solve the cognitive conflict. Elicitation – asking questions and explanations – motivates externalisation further (Fischer et al., 2002). By receiving and giving explanations and answers, thus explaining, and clarifying their own thoughts, students can complement their understanding and correct their misconceptions (Webb & Palinscar, 1996). In order to enhance learning in collaborative situations, where the task is shared and usually a problem has to be solved, it is not enough to have a cognitive conflict, but it must also be solved by coordinating different ideas, perspectives or views. Fischer and colleagues (2002) describe three types of such coordination; quick consensus building, integration-oriented consensus building and conflict-oriented consensus building. In many studies the negotiation to overcome a contradiction is reported to be a significant predictor of higher learning outcomes (Light et al., 1994; Chan, 2001; Nastasi & Clements, 1992).

An ER class can potentially contribute to the collaborative knowledge construction process. In a learning environment, ER has the role of mindtools. The term "mindtools," as proposed by Jonassen (2000) in the sense of cognitive tools, represent the constructionism dimension of constructivism. Using ER as mindtools, in a classroom, we apply constructivism -- students construct a physical object, while at the same time they construct problem-solving knowledge. Learning is no longer teacher-centered, but knowledge is actively constructed by the learner (Harel & Papert, 1991). Students can change or negotiate their existing knowledge into explicit knowledge. Knowledge construction is therefore, formed through a dual pathway; through interaction with the artifact and through interaction with peers. Several studies indicate that ER can be used as mindtools supporting knowledge construction through the design of meaningful artifacts in authentic projects, learning by doing, facing cognitive conflicts, and learning by reflection and collaboration (Mikropoulos & Bellou, 2013; Jonassen, 2000).

3.4 Metacognition and problem-solving skills in ER

Metacognitive and problem-solving skills are distinct but profoundly interrelated and interdependent. For example, Van der Stel and Veenman (2010) found metacognition to be a powerful predictor of students' success in completing complex learning tasks. It was also recognized as an effective strategy for improving student learning (Chin & Brown, 2000). Therefore, a student with developed metacognitive skills knows when and how he learns best, uses strategies to overcome problems, and regulates problem-solving processes.

Problem-solving is the most important cognitive activity in which students apply their knowledge and monitor behavior to solve problems (Jonassen, 2000). Learning to solve problems enables students to learn how to monitor their knowledge, identify when they have a gap in learning, and comprehend why the content is being learned and how it is useful (Barrows, 1996).

However, the literature has shown that students have difficulties in problem-solving (Lorenzo, 2005). Therefore, the research supports that in order to help students learn how to solve problems, it is crucial to make problem-solving strategies a part of their thinking processes (Fülöp, 2015). Metacognition is a crucial element in supporting problem-solving skills. According to Jacobse and Harskamp (2012), metacognition is used in mathematical problem-solving to monitor solution processes, regulate problem-solving episodes, make, and implement a solution plan, and verify the answer. In addition, several studies claim that metacognitive processes help students overcome obstacles that occur during problem-solving (Pugalee, 2001) and improve their problem-solving performance (Kramarski & Mevarech, 1997).

Meanwhile, problem-solving activities provide ideal opportunities for students to reflect on and analyze their thinking (Du Toit & Kotze, 2009) and enhance their metacognitive skills (Siegel, 2012). According to Kuhn (2000), a promising approach to fostering metacognitive development focuses on the idea of exercising, at an external, social level, the cognitive forms we would hope to become operative as well at the individual level. As Kuhn (2000) explained, the meta-level directs and is modified by the performance level. The meta-level directs the application of strategies but the feedback from this application is directed back to the meta-level. As a result, the feedback leads to enhanced meta-level awareness. This includes an enhanced meta-level awareness of the use of different strategies to achieve the goal of a task. Then, the strategy changes, in turn, feedback to further understanding in the meta-level, in a continuous cycle. Therefore, collaborative problem-solving with ER looks promising for the application of the cycle/model described by Kuhn (2000). ER activities have a clear performance level through the immediate feedback from the execution of a program which is directed and leads to enhanced meta-level awareness.

The benefits of using ER activities for the development of these skills have been the focus of some studies. The literature has shown that playing with robots allows students of different ages to improve their planning (La Paglia et al., 2011), reasoning and problem-solving skills (Atmatzidou et al., 2018). For example, La Paglia et al. (2011) investigated the improvement of metacognitive skills in mathematics using ER. The results showed that ER activities could help students to reflect on their learning and on their control dimensions such as planning, monitoring and evaluation. Jordan and McDaniel (2014) explored how peer interaction affected the way in which students handled uncertainty during collaborative problem-solving with ER. They found that peer interaction was meaningful as students counted on the supportive social response to perform their uncertainty strategies.

3.5 Summary

Overall, previous studies in the literature contribute to a better understanding of ER' value in promoting students' metacognitive skills. Many researchers report that ER activities can improve students' cognitive and metacognitive skills as well as problem-solving skills. Yet, a more precise analysis is required. Overall, most studies evaluated students' metacognitive skills through observation, questionnaires, or verbal interviews. Most of them have a small sample indicating that further research with larger samples is required. A few studies use experimental designs to compare the effect of the intervention and produce comparative results in terms of students' metacognitive development. Moreover, some studies have applied quasi-experimental research designs to compare the effect of different curriculum structures to support students' metacognitive and problem-solving skills. Furthermore, the effect of social interaction in supporting group metacognitive processes during ER problem-solving activities is largely ignored in the literature. Last but not least, there is indeed a huge gap in research that systematically designs and changes the learning environment over time, collecting evidence of the various changes toward the documentation of conceptual models or design principles that can facilitate a successful integration of ER for the promotion of metacognitive thinking. This is the gap that this dissertation aims to address. By adopting the DBR methodology, it addresses the development of metacognitive skills via ER while it documents design principles for successful ER implementations, based on collected evidence for cycles of work.

4 Methodology

DBR as a methodology and paradigm for educational inquiry, blends empirical educational research with theory-driven design of learning environments for understanding how, when, and why educational innovation works in practice (The Design Based Research Collective, 2003). DBR was employed in this work, in order to address ER learning design to promote student metacognitive thinking as a key element of collaborative knowledge construction.

This chapter has four sections. First, the principles of DBR are elaborated along with its appropriation for this work, challenges, and strengths of this paradigm for educational inquiry. Second, the DBR context, cycles of work, and RQs of the study are presented. Third, the procedures, including participants in each cycle, data collection and instrumentation, are described.

4.1 Design-Based Research (DBR)

Educational researchers and practitioners accept that educational research is separated from the problems of everyday practice. Therefore, this assumption creates a need for new research methods that can solve problems of practice (National Research Council, 2002) and lead to the development of “usable knowledge” (Lagemann, 2002). DBR appears as an emerging methodology and paradigm that can help create and extend knowledge about learning environments and bridge the gap between theory and practice.

Educational research differs from research in other areas in a number of ways. One of those ways is the difficulty that researchers and practitioners have in controlling all the variables in educational research. They have interactions amongst students, students, and teachers, amongst classrooms, amongst the broader school culture, which cannot be controlled. One of the educators' and educational researchers’ difficulties is to understand the full range of different variables and dynamics in the classroom. In educational research, researchers and practitioners are not just interested in understanding learning; they also want to improve it. They want to help students learn better. Therefore, when a teacher observes something, and s/he recognizes a reason why students have trouble learning some material, it is difficult (and rather unethical) not to intervene and help the student learn. In sum, DBR is often used in education to improve teaching and learning. DBR is the idea of creating tools, protocols, behaviors as probes into classroom interaction and for the learning process.

What we do in DBR is to build a tool that would work if our theory of learning is accurate. For example, if we believe that students learn better from individualized feedback (theory), we will create a tool that uses individualized feedback or give students individualized feedback. Based on how that tool improves learning (or not), we would reflect on our original theory. If the tool gives students individualized feedback, but they do not improve their understanding of some material, then we might conclude that the theory used to justify that tool was false. And if that tool does work, we would conclude that, because students learned, because of the use of this tool, the theory about individualized feedback supporting learning must be accurate. In short, in DBR, we are designing tools, then using those tools as probes into the phenomenon that those tools are designed to address.

DBR is a methodology designed by and for educators that strengthen educational research's impact in practice (Brown, 1992). It is an emerging educational paradigm that explores learning in real environments where the action occurs and produces usable insights and progressing theories of learning and teaching. DBR involves an iterative process of design, enactment, analysis, and redesign, in which the connection between interventions and social interactions are refined, supporting teaching, and learning and providing solutions in educational problems (Collins, 1992; Design-Based Research, 2003). In this process, a flexible design method is used where "subjects" are considered co-participants in the design and in the analysis process (Barab & Squire, 2004). The essential aim of DBR is to report and propose insights regarding the potentials and opportunities, as well as good practices for implementing these effectively in learning contexts. From this perspective the DBR framework intends to advance and strengthen the theory in naturalistic learning environments.

Wang and Hannafin (2005) define DBR as: "systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually sensitive design principles and theories." (p.

6). Therefore, the outcome of DBR does not only include an increase in theoretical knowledge, but also adds a societal and educational contribution (Edelson, 2002; Reeves, 2006). While only few studies report overall DBR procedure (McKenney & Reeves, 2013), a review reveals positive findings for this method (Anderson & Shattuck, 2012).

Barab and Squire (2004) clarified that DBR is not a cookbook method; it is a collection of approaches intended to study the activity in naturalistic settings, developing theories, artifacts, and practices through multiple iterations. According to Bell (2004), DBR involves the intentional design of empirical research and theorizing on what occurs in authentic contexts where the designed objects come to be used. In addition, Bell (2004) explained that DBR in education focuses on promoting innovation across many theoretical perspectives and various educational phenomena and linking research and design to reinforce our understanding of learning-related phenomena.

According to the Design Based Research Collective (2003), DBR has the following basic principles: (1) the designing of learning environments is linked with the development of theories of learning; (2) the research takes place through consecutive cycles of design, intervention, analysis, and redesign; (3) the communication and collaboration between researchers and practitioners is essential during the implementation period; (4) the research procedure takes place in authentic learning settings to understand the way of learning in its complexity in where is actually occurs; and (5) the design involves mixed methods of collecting the data.

As an emerging methodology, DBR faces some challenges and accepts some criticism. The immaturity of the methodology is one of the critiques of DBR. According to Kelly (2004), DBR is more a loose set of methods than a rigorous methodology. He claims that DBR studies are described as a series of processes rather than defining the inherent underlying conceptual structure. Dede (2004) further claimed that it is not easy to determine whether to continue or quit an iterative design as there are no rules to judge its effectiveness. Even when the design is seen to be efficient in a particular context, it can be challenging to evaluate if appropriate design principles can be developed. An effective design that was good for generating design principles could be dismissed because of its inefficiency in a particular context. To be developed into a rigorous methodology, these methodological challenges need to be addressed (Kelly, 2004).

DBR has been criticized for being one more formative evaluation technique. Indeed, DBR shares and extends conventional evaluation approaches, but in general, these extensions are essential and describe major changes in aims, scope, and methodology. However, DBR researchers make sense of the discrepancies of DBR as compared to the formative evaluation: (1) DBR closely ties design interventions with existing theory; (2) DBR may result in theory generation - not only testing existing theory and (3) the naturalistic context in which DBR takes place is the minimum level under which the variables are intersecting i.e., we cannot go back to the laboratory to test theoretical hypotheses (Barab & Squire, 2004).

Another challenge encountered by design-based researchers is to report what counts as credible evidence. This leads us to the heart of the discussion about the method's reliability, validity, and generalizability. The critique of DBR in terms of validity refers to whether a researcher who is involved in conceptualization, design, evaluation and redesign reports data with credibility (Barab & Squire, 2004). Since design-based researchers work closely with participants, unexpected influences may result from their presence in the context. The influence of the researcher-designer may affect research outcomes. This paradigm shift requires improvements in how researchers plan and implement such approaches and how they interact with participants. This critique is a common one for many forms of qualitative research. Neither of these approaches claims that the researcher's bias is removed from the research process.

On the contrary, some qualitative advocates argue that the researchers, with their biases and deep knowledge of the context, are the strongest research tool. Anderson and Shattuck (2012) argue on this, that this inside knowledge adds as much as it detracts from the research validity. DBR utilizes the notion of consequential validity (i.e., how research data are used do not exceed the research's capability and the action-related consequences of the investigation). Barab and Squire (2004) encourage researchers who employ DBR to be transparent in their arguments that exceed the local context and express recognition of their limitations. In terms of validity, design-based researchers claim that the evidence for validity is the changes it produces in the context of the application (Messick, 1994). The Design-Based Research Collective (2003) argues that in DBR the issue of the validity of findings is often addressed by the partnerships and the continuous cycles of design, enactment, analysis, and redesign, which end up in "increasing alignment of theory, design, practice, and measurement over time." Critics also consider these interventions as "taint" in the research context. The answer from DBR capitalizes on the value of these interventions, as they provide the refinement and testing of efficient instructional models. Each new application is an extension of the theory as its specific characteristics are situated in local dynamics (Barab & Squire, 2004).

Another criticism of DBR is the replicability. According to critics of the method, it often does not make a significant contribution to theory. In addition, the highly contextual nature of DBR is seen as making it difficult to generalize to other contexts. A DBR study needs to support "petite generalizations" (Stake, 1995), describing insights into the potentials and opportunities that emerge and approaches for navigating these potentials and opportunities. Therefore, the aim of this method is to elaborate and problematize the completed design and implementation in a way that delivers insights into the dynamics of the local context. It does not involve only a simple description of the design and its context but should involve theory work that promotes theory generation. However, if success means that a particular form of intervention could be effective in other settings, then the intervention should be investigated in various settings. DBR researchers should leave the whole design open, offering with this way a rich description of the local dynamics in an endeavor to advance theory that will be of use to others (Barab & Squire, 2004). As a research method that attempts to improve practice and advancing theory, DBR researchers must engage in work that will be useful to others. It is also important that DBR researchers not simply share the designed artefacts but do so by providing the evidence of “triangulation, thick description, systematic analysis of data with carefully defined measures, and consensus building within the field around interpretation of data” (Design-Based Research Collective, 2003).

Regarding the data utilization, DBR has been characterized as over-methodologized. According to Dede (2004), only a limited volume of collected data is analyzed to report findings. DBR researchers need to record the entire design process using various research methods in real-world settings. The data are extensive and comprehensive, requiring extended time and resources to collect and analyze (Collins et al., 2004). Therefore, a large amount of data is often dismissed, and research quality may negatively be influenced. The gap separating the methodology used to collect data and its meaningful use in reporting requires it to be reduced.

4.2 DBR context, cycles, and RQs

The overarching goal of this work was to understand and define the appropriate ER activities that can promote students’ metacognitive thinking and collaborative knowledge construction. The work completed in three cycles, with an eye to claiming success by “generating heuristics for those interested in enacting innovations in their own local contexts” (The Design Based Research Collective, 2003, p. 6). This inquiry envisioned to draw connections to theoretical assertions (see theoretical framework of the study) that transcend the local context but are by no means decontextualized principles or grand theories that function with equal effect in all contexts (Anderson & Shattuck, 2012; Barab & Squire, 2004). Overall, by demonstrating how ER can be used in real educational contexts to support students' metacognitive thinking as a key element of collaborative knowledge construction, we provide theoretical ideas and detailed instructions that can guide educational practice. The DBR attempted to inform theory and practice on the use of ER as a tool for promoting thinking skills. Based on the overarching goal of the work, a set of research questions were formulated to be addressed in three cycles. Each of these cycles operates with one another to inform theory and strengthen the design of a theory and practical guidelines. The DBR context of this study is illustrated in Figure 5.

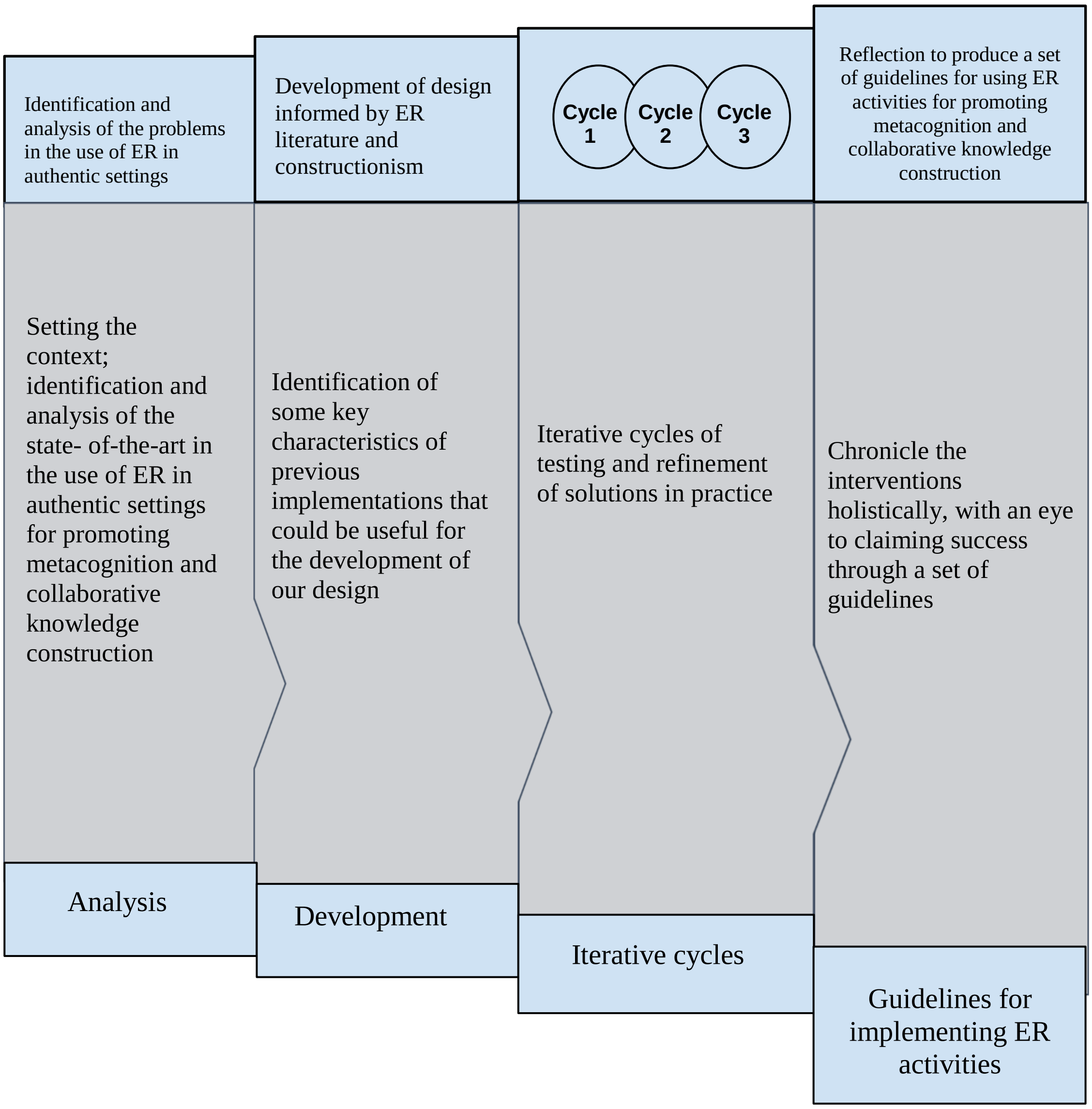


Figure 5: The DBR context of this dissertation (adopted from Reeves, 2006).

Below we elaborate on the researcher’s decision for three cycles of work, i.e., the decision to “continue or quit the iterative design” (Dede, 2004) considering the overarching goal of the work (exploring how ER can support students’ development of metacognitive thinking and collaborative knowledge construction).

The implementation of the intervention in Cycle 1 made feasible the identification of (a) the effectiveness of unstructured ER activities in supporting collaborative knowledge construction (b) the conditions under which collaborative knowledge construction can be promoted with an unstructured ER curriculum, (c) the core elements of collaborative knowledge construction, (d) details of the metacognitive processes such as features of ER that activate group metacognition and the relationship among metacognitive and collaborative talk using an unstructured ER curriculum. Yet, the design of Cycle 1 was insufficiently detailed to account for the overarching research question of this dissertation or for addressing emerging patterns. We also recognized that in Cycle 1 student groups often struggled with the challenges because of the unstructured curriculum. Therefore, our initial plans changed; the exploration of other instructional practices which could better promote learning became the focus of investigation. To inform the design, with the purpose of improving students' metacognitive thinking as a key element of collaborative knowledge construction, we tried to use a structured curriculum. Therefore, the outcomes from Cycle 1 provided explanatory details that specified our expectations and became the focus of investigation during Cycle 2. Considering the results from Cycle 1, we tried to expand our design in order to explore its effectiveness and validate the results of Cycle 1. In Cycle 1, we saw features of ER that activate metacognitive processes, we saw the conditions under which collaborative knowledge construction could be promoted and we saw the effectiveness of ER to support collaborative knowledge construction. But these findings were grounded on observational data. Therefore, a more rigorous study design, considering the use of a control group, was adopted in Cycle 2, to extend our knowledge, improve our design, validate the previous results, and address the overarching research question of this dissertation.

The implementation of the intervention with a structured curriculum in Cycle 2 helped as to (a) address the problem faced in Cycle 1 and (b) address the effectiveness of ER activities to support individual metacognition, (c) explore in which dimensions of metacognition can be supported in the learning experience and (d) explore for learning gains in logical-mathematical problem-solving. The results of the two previous cycles (Cycle 1 and Cycle 2) helped to inform the design of the 3rd intervention. The purpose of Cycle 3 was to compare the effect of the curriculum structure and to have measurable results regarding the effectiveness of each approach. In sum, in the previous cycles, especially in Cycle 2, we recognized that students' debugging processes involved metacognitive elements. Therefore, in Cycle 3, we focused on students debugging processes as a part of their metacognitive thinking. In Cycle 2 the focus was on individual metacognition while in Cycle 1 we saw that these processes involve collective aspects. Therefore, in Cycle 3 group metacognition became the focus of our investigation. Since all ER interventions in this dissertation were conducted in CSCL settings we also considered the role of social interaction in mediating and sharing metacognitive knowledge (Brown et al., 1983).

Considering the results of the previous cycles in the implementation of Cycle 3 we expanded our design adding the variable of the curriculum structure. We supposed that this approach could refine our understanding of the learning issues involved. Therefore, in Cycle 3 we sought to explore the effect of the curriculum structure in: (a) the type and the number of programming errors, (b) students' ability to identify and debug programming errors (c) students’ level of engagement, (d) students’ perceived group metacognitive processes, (e) group cohesiveness and (f) collaboration quality. In addition, considering the role of social interaction we tried to explore how the different levels of cognition such as individual, group and community level involved in group metacognition.

In sum, the DBR cycles and research questions (RQs) addressed in each DBR cycle were as follows:

- DBR Cycle 1 explored the use of ER in supporting collaborative knowledge construction and group metacognition in addition to providing insights into classroom practice and students' interaction with the technology and their peers. In Cycle 1, we explored patterns of collaborative knowledge construction to unfold its' elements in an ER learning environment. We examined how ER might be effective in engaging students in higher levels of collaborative knowledge construction (RQ1.1). We also explored the conditions under which collaborative knowledge construction can be promoted (RQ1.2), identified the elements of collaborative knowledge construction in our ER context (RQ1.3) and explored ER as instructional tools that can activate group metacognitive processes (RQ1.4). Finally, this cycle explored the relationship between collaborative and metacognitive talk (RQ1.5).

- DBR Cycle 2 extended our understanding of the added value of ER in promoting students' metacognitive thinking and mathematical problem-solving at an individual level of analysis. In Cycle 2, we addressed the effectiveness of ER activities in supporting the development of students' metacognitive thinking (RQ2.1). Mainly, this cycle aimed to reveal how ER activities influenced metacognitive skills and mathematical problem-solving (RQ2.3) through a structured curriculum. By applying a quasi-experimental research design using a control group, we also aimed at identifying which metacognitive dimensions were impacted more by this kind of activity (RQ2.2).

- In DBR Cycle 3, the study examined how different ER learning design approaches could influence student learning. Namely, this cycle presented differences between a structured and an unstructured ER curriculum in supporting students' learning in terms of group metacognition, collaboration quality and group cohesiveness (RQ 3.2), as well as debugging skills and engagement (RQ3.1). Finally, we aimed at addressing how the individual, group, and community levels of cognition were involved in the process of knowledge building and group metacognition (RQ 3.3).

Figure 6 is a schematic representation of the research questions used in the three cycles of the investigation aimed at the overarching goal to explore how ER can support students' development of metacognitive thinking and collaborative knowledge construction.

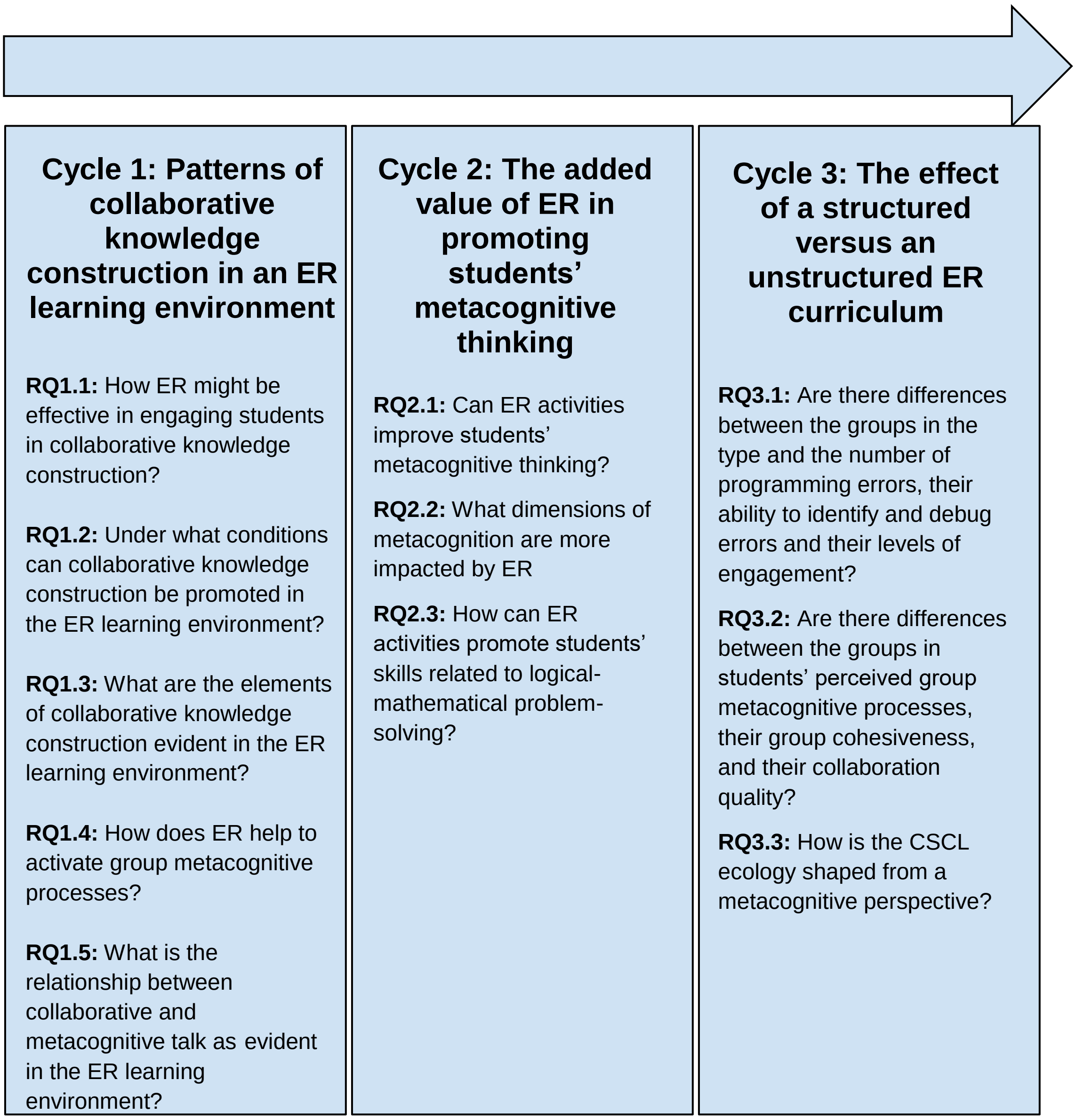


Figure 6: DBR cycles and RQs of the study

4.3 Participants, procedures, data collection and instrumentation

4.3.1 Participants

In Cycle 1, the sample was composed of a teacher and 14 elementary students (six boys and eight girls) in Grades 4-5 and 6 (9-11 years old) who attended a public elementary school in Cyprus and participated in five sessions of ER activities for 1.5 months. One of the students (female) had special educational needs and learning difficulties while the participating students had no previous experience in robotics. The instructor was a male teacher (author of this dissertation) who was both participant and observer of students' activities and his role provided access to a wide range of data.

In Cycle 2, the sample was 42 primary school students (4th graders) from two public elementary schools in Cyprus (24 girls, 18 boys). The 42 students were not randomly assigned to two conditions. Therefore, two non-equivalent groups were formed. The experimental group consisted of one class of 21 fourth-grade students (13 girls and 8 boys), and the control group consisted of another class of 21 fourth-grade students (11 girls and 10 boys) from a different school of the same region. The mean age in the experimental group was m=9.68 years old (SD=0.26) and for the control group was m=9.76 years old (SD=0.32). Two children of the experimental group and one from the control group were students with special educational needs and motor impairments (two boys and one girl). Only two students from both groups had previous experience with programming and ER. Designing the technology-enhanced learning experience was a task undertaken by a teacher and an educational technologist. The instructor was a male teacher (author of this dissertation) who was both participant and observer of students' activities.

In Cycle 3, the sample was 35 primary school students (Year 3, 20 boys, and 15 girls) from two classes at the same school in Cyprus. The classes naturally formed the comparison groups: the structured curriculum group (16 Year 3 students, 9 boys and 7 girls, divided into 4 groups) and the unstructured curriculum group (19 Year 3 students, 11 boys and 8 girls, divided into 5 groups). For the ER experience, students worked in mixed gender and ability groups of 3 or 4, to allow for different problem-solving approaches to develop. Three of the participating students (two in the unstructured curriculum group and one in the structured curriculum group) had prior experience with ER and programming, while four were students with special educational needs and learning difficulties (two in each group). The experience, consisting of STEM problem-solving activities, was implemented during 10 sessions over three months. The instructor was a male teacher (author of this dissertation) who was both participant and observer of students' activities.

To sum up, all participants were elementary students attending mainstream public elementary school in Limassol, Cyprus. Before the study started, all the necessary release forms from the Cyprus Ministry of Education, Culture, Sport, and Youth were obtained (see Appendix II). Students in all cycles participated in the study after providing proper consents (see Appendix III). Table 2 shows the participants involved in the three studies.

Table 2: Three cycles of empirical research in school

	Participants	Context	Intervention period	Technology
Cycle 1	14 students 9-11 years old 1 teacher	STEM Education	1.5 months (5 sessions)	Lego Mindstorms EV3
Cycle 2	42 students 9 years old 1 teacher	STEM Education	2 months (8 sessions)	Lego Mindstorms EV3
Cycle 3	35 students 8 years old 1 teacher	STEM Education	3 months (12 sessions)	Lego Mindstorms EV3

4.3.2 Procedures

In all three cycles, the intervention was conducted in a real classroom setting. Designing the technology-enhanced learning experience in all cycles of the research was a task undertaken by a teacher and an educational technologist. The Lego Mindstorms EV3 toolkit was used. The content for the activities came from (a) the national curriculum on mathematics and science education, and (b) the EV3 STEM curriculum.

In Cycle 1, the teacher presented students with a challenge and a mat. There was no clear path to the solution; students could adopt any strategy to come to a solution to the challenge. The teacher acted as a facilitator, supporting students' thinking without providing any answers. Upon completion of each task, a debriefing phase took place; groups demonstrated their strategies in addressing the challenge and answered questions asked by the teacher and students in other groups. The teacher facilitated discussion on best strategies and reflection on what kinds of problem-solving and STEM skills were learned.

Cycle 2 took place in two classes, with the ER structured design only for the experimental group. The control group did not participate in any ER activities. The first two sessions for the experimental group were introductory lessons with introductory activities to support students to get familiar with the EV3 environment. During this phase, essential programming details associated with this setting were explained to them by presenting examples (directional commands, sensors, loop, and wait for). The next six sessions were STEM problem-solving activities; the students' groups should program a robot using a tablet or a computer to solve different problems according to the instructions and conditions of the activity. The student-groups first completed the worksheet activities with the teacher's help and then continued with the session's final challenge. The teacher's role was to provide information, ideas, and feedback as needed. Both the worksheets and the teacher's guidance facilitated the student groups in implementing ideas that were related to the final challenge. This also served as preparatory work for the session's challenge.

In Cycle 3, a different approach was followed. We used two different classes of third graders as comparison groups. Students of the first class were part of an environment in which they were instructed how to program their robot by participating in pre-designed tasks using worksheets as a reference before the final challenge (labelled as the structured curriculum group). In the second classroom, students were part of an unstructured approach in which they did not have structured practices, and instead were provided with 80 minutes of free time to investigate ideas and concepts by themselves but limited to the purpose of solving a challenge (labelled the unstructured curriculum group). Both groups took part in two introductory sessions and eight sessions of the same problem-solving activities for 80 minutes each.

4.3.3 Data collection and instrumentation

Following the DBR approach, we collected data using various methodologies. During Cycle 1, we focused more on qualitative measures, using a video recording of all the sessions. For Cycle 2 quantitative data were collected to examine how ER activities can promote students' individual metacognitive thinking. In Cycle 3 both quantitative and qualitative data were gathered to examine the effect of the curriculum structure on students' group metacognitive thinking, debugging skills and collaboration quality by mapping students' interaction with the robot and their peers in CSCL settings. The following sections describe each data collection method used for this research (see Table 3).

4.3.3.1 Metacognitive Awareness Inventory [MAI]

The metacognitive awareness scale was adapted from Schraw & Dennison (1994), and it was used as pre- and post-assessment, to assess the development of students' metacognitive thinking. The MAI questionnaire was given to the experimental group before and after the learning experience in Cycle 2. For the control group, it was given in two different times, the same as the experimental group (first implementation when the instrument was given to the experimental group and second, after two months as a post-test assessment). The MAI questionnaire is a 52 items self-report instrument consisted of multiple items which can assess individual metacognitive awareness in two factors; knowledge of cognition and regulation of cognition (see Appendix IV). The participants answered these items by indicating their degree of agreement with each record, on a 5-point Likert scale. The first factor, "knowledge of cognition," consists of 17 items and can be classified into three subscales: declarative knowledge, procedural knowledge, and conditional knowledge. The second factor, "regulation of cognition" (35 items) consists of five subscales: planning (goal setting), information management (organizing), comprehension monitoring (assessment of one's learning and strategy), debugging strategies (strategies applied to correct failures) and evaluation (evaluation of performance). The reliability and validity of the MAI have been recorded in several previous studies (e.g., Baker & Cerro, 2000; Panaoura & Philippou, 2003).

4.3.3.2 Visualization and Accuracy Instrument [VisA]

The VisA test instrument was given to all participants before and after the learning experience to further investigate the development of students' metacognitive thinking in Cycle 2. VisA combines students' prediction and postdiction judgments, and visualizations to assess online metacognition and especially the combination of metacognitive monitoring and regulation, which are interrelated used during problem-solving (Jacobse & Harskamp, 2012). Students responded to four mathematical problems. In each problem students were asked to distribute their solutions into four steps: (a) read and rate their confidence in solving the problem correctly (prediction judgment), (b) draw a sketch to visualize the problem (visualization), (c) solve the problem, and (d) rate their confidence for having found the correct answer (postdiction judgment) (see Appendix IV).

4.3.3.3 Mathematics test

For assessing mathematical knowledge gains in Cycle 2, we used the data from the four problem-solving tasks from the two administrations of the VisA instrument. We looked for the correctness of their solutions (not their judgments). Each correct task was scored with 25 marks, and the maximum possible score was 100 marks. The four tasks were adapted from the released 4th-grade assessment questions from previous studies of Trends in International Mathematics and Science Study (TIMSS).

4.3.3.4 Debugging test

Following the learning activities, in Cycle 3 the students were given a debugging test - developed based on categories of common programming errors - that put forward ten tasks. The test gave the students a scenario in which they had to find the error in a programme; they were told the purpose of the programme and were supplied a screenshot of the EV3 programming interface. Students had to circling the error block(s) and write down how they would fix it (see Appendix IV). Each task was scored out of a total of ten marks (five marks for finding the error and five for a correct proposal to overcome the error). The maximum possible score for the test was 100.

4.3.3.5 Engagement survey

In Cycle 3, a post-experience survey aimed at evaluating student engagement was administered. Student engagement was measured using a 5-point Likert scale, with 33 items derived from the Math and Science Engagement Scales (Wang et al., 2016). The scale was developed considering a multidimensional viewpoint of engagement and is comprised of four subscales: (a) cognitive engagement (b) behavioural engagement, (c) emotional engagement, and (d) social engagement (see APPENDIX IV). Since the instrument measures student engagement in math and science, we modified the items by substituting the word "math/science" with "STEM".

4.3.3.6 Collaboration quality Rubric

The Collaboration Quality Rubric was adopted from Menekse et al. (2017), who developed this rubric for assessing the collaboration quality in groups in robotics competitions, based on prior research on collaborative learning (see APPENDIX IV).

The rubric has four indicators in a three-level rating, combining: (a) the quantity of the discussion and the depth of knowledge-building (b) the elaboration of ideas, (c) the collective nature of decisions and (d) the use of questions in examining the ideas elaborated (Menekse et al., 2017). The instrument was administered in the two last sessions of Cycle 3. Video data from sessions 9 and 10 of Cycle 3 was used as sampling to assess the quality of collaboration in each team.

4.3.3.7 Focus groups

One week after the learning experience in Cycle 3, 16 students participated in semi-structured focus group interviews (two focus groups for each condition, 50-60 minutes each). The focus group interviews were organised into two sessions (see APPENDIX IV). The first session looked to enrich our understanding of the students' common errors during programming. The interviews included questions that prompted students to remember errors that they encountered and how they managed to overcome these errors (e.g., What difficulties did you face during programming? How did you overcome the difficulties?). The second session was aimed at providing additional evidence for student engagement (e.g., Do you think ER activities were useful to you? [Cognitive engagement]. How did you feel, while you were working on robotics activities in class? [Emotional engagement]). The focus group data were video-recorded and transcribed for analysis using a thematic approach.

4.3.3.8 Group cohesiveness survey

At the end of Cycle 3, a post-interventional survey aiming at evaluating group cohesiveness was administered right after the intervention for both groups. Group cohesiveness was measured using an individual 5-point Likert scale questionnaire with eight items (e.g., "I am glad I belong to this group", "I am an important part of this group") based on Gillies' (2003) study on small cooperative groups (see Appendix IV).

4.3.3.9 Group Metacognition Scale (GMS)

We used the Group Metacognition Scale (GMS) (Biasutti & Frate, 2018) as pre- and post-assessment to analyse the development of students' group metacognitive skills. The GMS is a 20-item scale for assessing the metacognition of groups (see Appendix IV). The items are divided equally into four subscales: (a) knowledge of cognition (e.g., "we know our strengths as learners"), (b) planning (e.g., "we determine what the task requires"), (c) monitoring (e.g., "we ask questions to check our understanding") and (d) evaluating (e.g., "we make judgments on the difficulty of the task"). The scale introduces a collective aspect to measuring metacognitive skills during CSCL and can be used for evaluating the level of reasoning in groups engaging in collaborative activities. The students answered the 20 items by indicating their degree of agreement on a 5-point Likert scale.

4.3.3.10 Video recorded collaborative sessions

All classroom activity in the three cycles was video recorded. Two cameras were placed in the room to fully cover student interaction and technology use. Verbal contributions were captured separately via audio recorders next to each team; audio was later synced with the video. The video material of the collaborative sessions was intended to provide communication examples and rich information about the physical interaction of the students. Collecting video and audio material also allowed us to view what students did in the learning setting, capturing behaviour that would otherwise have gone unreported.

4.3.3.11 Screen recorded data

In Cycle 3, the tablet screens and dialogue by the nine teams in both groups were recorded using Mobizen Screen Recorder. One of the challenges we encountered during Cycle 1 was to use the audio data from students' discussion to give meaning on what they were doing on their tablet using the programming interface of their robots. The absence of screen-recorded data in Cycle 1 made our analysis quite challenging and may have left unreported behaviour or programming actions. Therefore, in Cycle 3 we decided to record the tablet screens of the students during the sessions as this could provide insights on several points of interest such as students' debugging skills and common errors during programming.

Table 3: Data collection and purpose of the three Cycles

Phase	Data collecting method	Purpose
Cycle 1	Video & audio recording	Investigate patterns and unfold the elements of collaborative knowledge construction Explore the mediating role of the technology in our context

Cycle 2	Metacognitive Awareness Inventory (MAI) Visualization and accuracy instrument (VisA) Mathematics test	Investigate the value of ER as metacognitive tools Insight into the influence of ER on particular dimensions of metacognition Investigate students’ accuracy on performance judgments, as another evidence of metacognitive development Explore improvement in mathematical problem-solving
Cycle 3	Video & audio recording Tablet Screen recording Debugging test Engagement survey Focus group with each group Collaboration Quality Rubric Group cohesiveness survey Group Metacognition Scale (GMS)	Insight into students’ interaction with technology and peers Identify the type and the frequency of students’ programming errors Explore the effect of the curriculum structure on debugging skills Evaluate the outcomes of the curriculum structure on students’ engagement Insight of the process adopted for debugging and confirm the findings for the list of the common programming errors. Confirm the high levels of engagement Examine the impact of the curriculum structure on collaboration quality The impact of the curriculum structure on group cohesiveness The impact of the curriculum structure on group metacognitive processes

5 Chapter 5: DBR Cycle 1

Results of this study are published in the proceedings of the 13th International Conference of the Learning Sciences (ICLS) 2018 (Socratous & Ioannou, 2018) and the International Conference on Computer Supported Collaborative Learning (CSCL) 2019 (Socratous & Ioannou, 2019a).

This first cycle of research aimed to field-test our design and explore the mediating role of ER in our context. Namely, DBR Cycle 1 explored the use of ER in supporting collaborative knowledge construction (RQ1.1) and the conditions under which collaborative knowledge construction can be promoted (RQ1.2). In Cycle 1, we aimed to unfold the elements of collaborative knowledge construction (RQ1.3), identify details of the metacognitive processes during students' interaction with the robot and their peers, and document the educational potential of ER as instructional tool for supporting group metacognition (RQ1.4). Finally, this cycle (see Figure 7) explored the relationship between collaborative and metacognitive talk (RQ1.5).

Findings from Cycle 1 revealed the effectiveness of ER to engage students in collaborative knowledge construction in the STEM field. The findings also demonstrated elements of ER and teamwork that can promote collaborative knowledge construction in an ER learning environment. In addition, the results from this investigation demonstrated that CSCL activities using ER can engage students in collaborative knowledge construction with prevalent elements of metacognitive processes, questioning, and answering. Furthermore, the study showed the instrumental role of the technology in supporting students' metacognitive thinking; namely, the embodied interaction, direct feedback and openly accessible programmability were tightly coupled with group metacognitive processing and overall collaborative knowledge construction. Finally, DBR Cycle 1 showed some initial evidence for a temporal relationship between collaborative and metacognitive talk in problem-solving with ER.

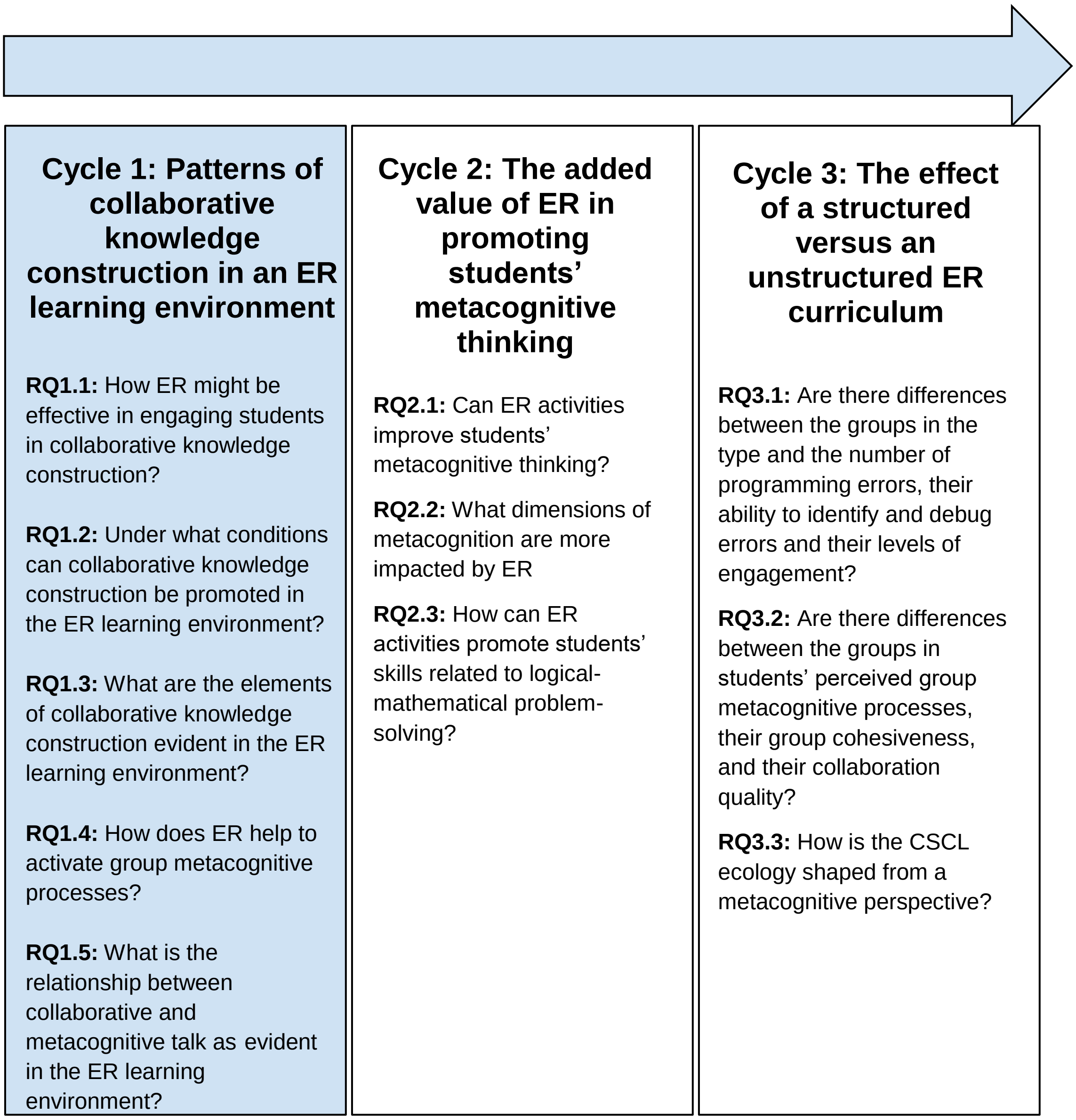


Figure 7: RQs of DBR Cycle 1

5.1 Introduction

In the last 20 years, researchers have seriously studied learning in small groups. The nature of cooperation and interaction has turned into a focal issue for research on learning in social settings. Essential to collaborative learning is knowledge construction, where collaborative learning aims to co-construct knowledge upon sharing information in groups to solve given tasks (Alavi & Dufner, 2005). In recent years, the focus of knowledge construction moved from knowledge attainment to skill development in order to prepare students for the challenges of the 21st century (Wen et al., 2015). The focus moved from simply gathering information to a more complex process of researching and thinking critically about the new information in order to use it in meaningful ways.

The joint construction of knowledge allows learners to experience a greater level of understanding (Kafai & Resnick, 1996) because they must construct their own knowledge to learn the truth (Tam, 2000). Knowledge is constructed by students when they participate and evaluate their own learning. Collaborative knowledge construction encourages students to investigate a subject deeper to reach their highest potential level of development. The development of new understanding is coming as a combination of prior knowledge and skills with new experiences.

An ER learning experience can potentially contribute to the collaborative knowledge construction process. In a learning environment, ER has the role of mindtools. Using ER as mindtools, in a classroom, we apply constructivism – students construct a physical object, while at the same time, they construct problem-solving knowledge. Learning is no longer teacher-centered, but knowledge is actively constructed by the learner (Harel & Papert, 1991). Students can change or negotiate their existing knowledge into explicit knowledge. Therefore, knowledge construction is formed through a dual pathway; through interaction with the artifact and peers. Several studies indicate that ER can be used as mindtools supporting knowledge construction by designing meaningful artifacts in authentic projects, learning by doing, facing cognitive conflicts, and learning by reflection and collaboration (Mikropoulos & Bellou, 2013; Jonassen, 2000).

The ground for the integration of technology as a learning tool in education, is attributed to Jonassen (2000), who first introduced the theoretical background and the motivation for the integration of robotic technologies as learning tools. The argument is that technology and many other technological tools can be considered as cognitive tools or "Mindtools," which enhance and enrich the educational process. Mindtools act as extensions of the mind, and when engaged in "intellectual partnership" with learners, they can promote critical, creative, and complex thinking and support knowledge construction (Jonassen, 2000). According to Gaudiello and Zibetti (2013), ER has two inherent features that give them a high educational potential as a learning tool. These features are their transparency and interactivity. Transparency refers to the openly accessible programmability of the robot (Kynigos, 2008; Resnick et al., 1996), and interactivity refers to the immediacy of the feedback given by the robot when a student programs and executes the commands (Gaudiello & Zibetti, 2013).

While many studies have focused on exploring the affordances of ER in promoting several transversal skills such as problem-solving (e.g., Atmatzidou et al., 2018), collaboration (e.g., Ardito et al., 2014), and computational thinking (e.g., Bers et al., 2014), still, ER as metacognitive tools have been considered only recently (e.g., La Paglia et al., 2010; Gaudiello & Zibetti, 2013) and the research evidence is inconsistent. Further investigation in the area is needed to fully understand ER's potential in supporting students' metacognitive processes and especially socially mediated metacognitive processes in CSCL settings.

5.2 Methodology

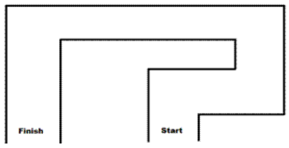
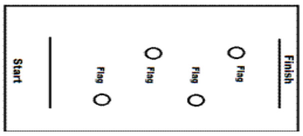
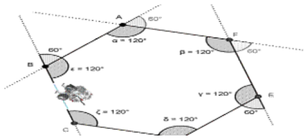
5.2.1 Participants

This first exploratory study involved 14 elementary students (six boys and eight girls) in Grades 4-5 and 6 (9-11 years old) and their teacher. The participants attended a public elementary school in Cyprus and participated in five sessions of ER collaborative activities for 1.5 months. One of the students (female) had special educational needs and learning difficulties, while none of the participating students had any previous experience in robotics. The instructor was a male teacher (author of this dissertation) who was both participant and observer of students' activities, and his role provided access to a wide range of data.

5.2.2 Description of activities

Designing the technology-enhanced learning experience was a task undertaken by a teacher (author of this paper) and an educational technologist. The activities' content came from the national curriculum on mathematics and science education, and the EV3 STEM curriculum. The Lego Mindstorms EV3 toolkit was used. There were two weeks of preparatory activities to help students get familiar with the EV3 robot (e.g., move straight ahead, turn base on some angle, use sensors, robot decisions, e.g., loops), followed by three 80-minutes sessions of STEM problem-solving activities (see Table 4 and Figure 8).

Table 4: ER learning activities worked with the children

Activity	Explanation	Main STEM Pillars
	Maze challenge (80 min) Groups program the robot to move from its starting position through a without touching any walls	Numbers & calculations, robot sensors, robot wheels diameter and speed vs. turns, loops, measurements
	Robot-slalom challenge (80 min) Groups program a robot to move along the outside of each flag and cross the finish	Numbers & calculations, robot sensors, geometrical symmetry, swing turn and point turn, loops, measurements
	Draw a hexagon challenge (80 min). Students program their robot to draw a hexagon using a gyro sensor	Numbers & calculations, polygons, supplementary & complementary angles, internal & external angles, design a pen holder, measurements

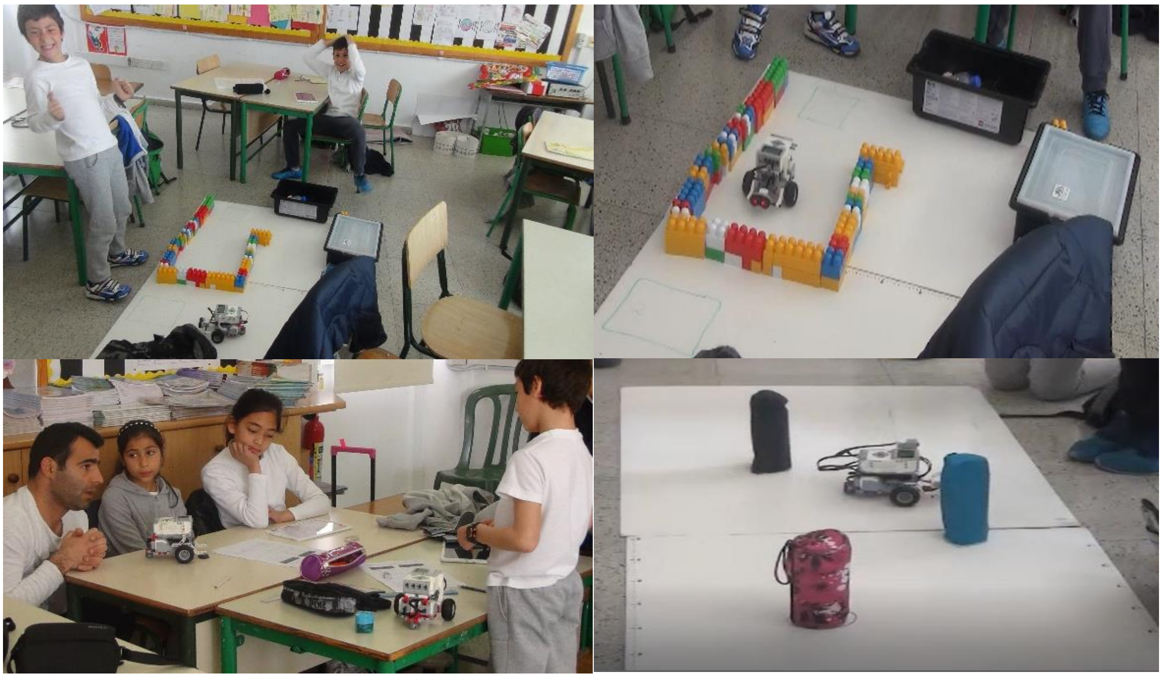


Figure 8: Intervention in the classroom - Cycle 1

5.2.3 Procedures

The students were divided into four groups of mixing gender, technological, and problem-solving abilities. Typically, the teacher presented students with a challenge and a mat. There was no clear path to the solution; students could adopt any strategy to come to a solution to the challenge. The teacher acted as a facilitator, supporting students' thinking without providing any answers. Upon completing each task, a debriefing phase took place: groups demonstrated their strategies in addressing the challenge and answered questions asked by the teacher and students in other groups. The teacher facilitated discussion on best strategies and reflection on what kinds of problem-solving and STEM skills were learned (see the learning cycle in Figure 9).

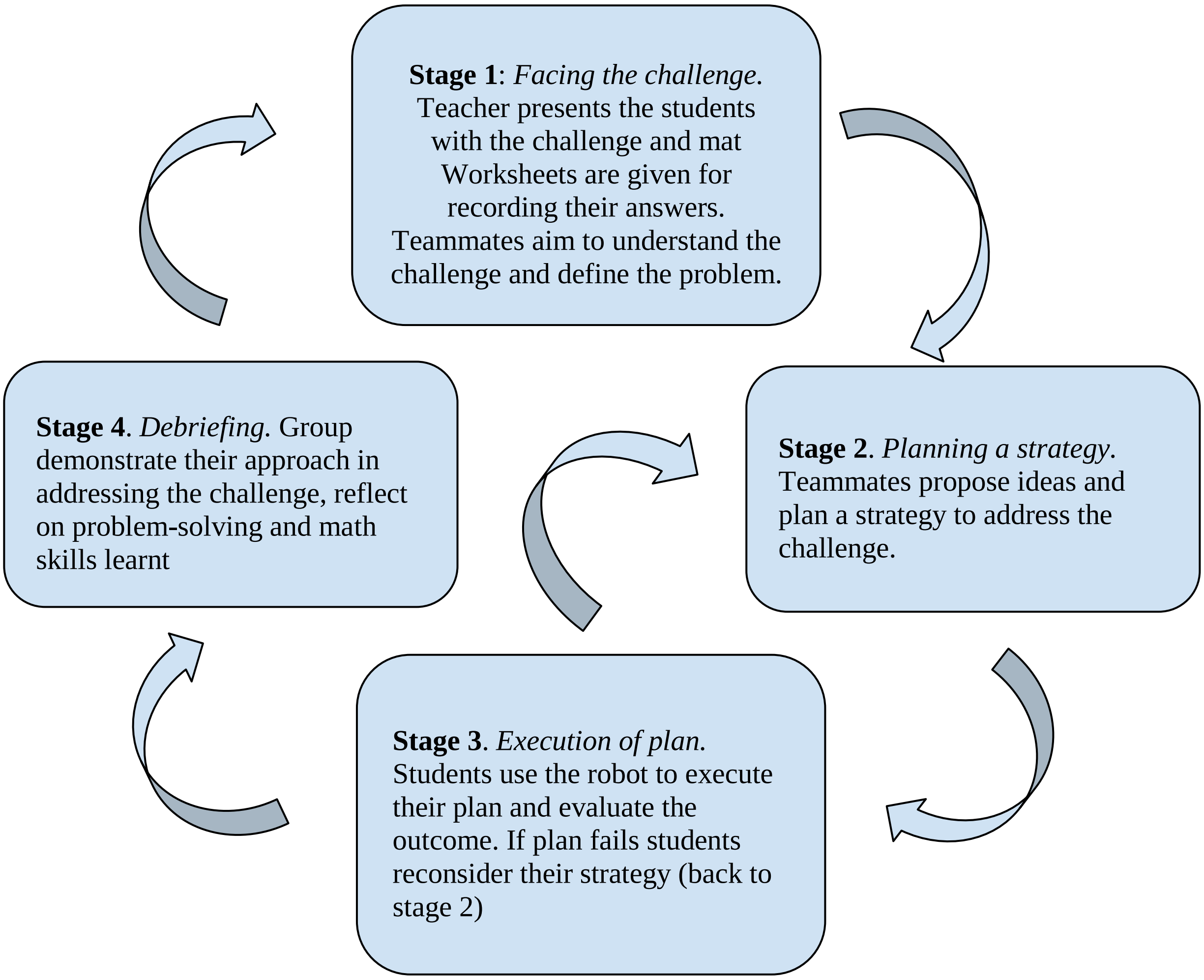


Figure 9: The problem-solving cycle of the ER activities

We further decided to assign roles within teams to support positive interdependence, interaction, and group processing and ensure that everyone contributes and participates in the learning process. Three distinct roles were assigned (see Figure 10):

- the recorder (responsible for taking notes and keeping track of group data)
- the programmer (accountable for the programming and controlling the movements of the robot using a tablet)
- the distance-measurer (responsible for measuring the position of the robot, putting the robot to the starting line, and observing the robot moves in order to give feedback to the rest of the group)

In practice, the roles were interdependent. That is, the programmer interacted with the distance-measurer to acquire relevant data through the distance-measurer's observations on the robot's behavior. The distance-measurer interacted with the recorder to report data for recording while the recorder interacted with the programmer to indicate the data collection's readiness for further action or give auxiliary data based on current data collection that could help with programming the robot. The roles were randomly assigned to students. From task to task, the teacher ensured that the roles rotated amongst the team members.

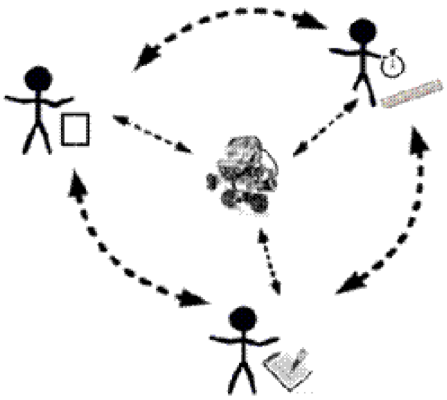


Figure 10: Interactions between team-members roles (programmer, recorder, distance-measurer)

5.2.4 Data collection and analysis

Two cameras were placed in the room to fully cover student interaction and technology use. Verbal contributions were captured separately via audio recorders next to each team, which were later synced with the video.

All video data were transcribed verbatim, and content analyzed. We used the coding scheme reported in Gunawardena's et al. (1997) Interaction Analysis Model, which visualizes the level of social and collaborative knowledge construction. The analysis focused on the "unit of meaning," each unit fitting into a sole category of the coding scheme (e.g., from minute 0:30 to 0:35, teammates share ideas on potential strategies). The overlapping talk was coded to the most dominant category and team member. Around 30% of the video was coded by the first researcher, with a second researcher independently coding the same units. Reliability was high (agreement over 90%), and therefore, the first researcher finished coding the complete dataset. Table 5 presents examples of the application of the coding scheme.

We further plotted student's discourse and activity on diagrams for a chronological investigation of within-group collaboration. We used the CORDTRA technique, initially suggested by Hmelo-Silver et al. (2011). This visual representation technique enables one to combine the chronological visual of discourse with other types of coded data, allowing for the examination of patterns and behavioral sequences.

In addition, for a fine-grade analysis, we used the coding scheme reported in Hmelo-Silver (2003), which conceptualizes the thinking processes and the general cognitive, metacognitive, and social characteristics involved in collaborative knowledge construction (see Table *5*). The unit of analysis was the individual participant, and the discourse was coded on a turn-by-turn basis. A new turn was considered to start when the speaker changed. When the speaker shifted the discussion theme, or a different kind of discourse appeared, they were parsed into extra coded units. Generally, a conversational turn had more than one coding unit. For instance, when a student asked a question but also added one or more statements, this was coded as two or more different coding units. Two independent raters coded 35% of the data to verify the reliability of coding. Reliability was acceptable (agreement 75%), and therefore, the first researcher completed coding the complete dataset. To answer RQ1.4 and RQ1.5, a group was selected for further examination with a chronological investigation of within-group interaction. We used the CORDTRA technique initially presented by Hmelo- Silver et al. (2011) and later applied in varied CSCL settings by Ioannou et al. (2015). CORDTRA was examined in combination with excerpts of students' discourse to identify details of metacognitive and collaborative processes and the technology's role.

Table 5: Application of the coding scheme of collaborative knowledge construction

Level	Operation	Example excerpts from the data
KC-1: Sharing/ comparing/ adding of information.	Statement of observation, opinion, or a background information; Definition description or identification of a problem;	P2: “We will use the ultrasonic sensor to avoid the flags. (Participant from group 1).
KC-2: Discovery and exploration of dissonance or inconsistency.	Identifying areas of disagreement; Asking and answering questions to clarify disagreement; Restating participant’s position.	P3: “No, we tried using the ultrasonic sensor when we solved the maze challenge and took us a lot of time. What do you think”? (Participant from group 4).
KC-3: Negotiation of meaning/co-construction of knowledge.	Negotiation or clarification of the meaning (building on previous statements); Synthesis-proposal, and negotiation of new statements (creating solutions);	P4: “I will draw a hexagon to find how many triangles are formed.” P5: “So, 4 triangles multiply by 180° equals 720° divides by 6 angles…(thinking) 120°”. (Participants from group 3).
KC-4: Testing and modification of proposed synthesis or co-construction.	Testing of new synthesis against existing cognitive knowledge, personal experience, and formal data with the prospect of finalizing it.	P5: “No, what is he doing? It is turning too much (while observing the drawing of the robot). What went wrong?” P6: “There is a problem with the gyro sensor. Let's remove it and put it back”
KC-5: Agreement/application of newly constructed meaning.	Summarization of agreements; Application of new knowledge; Metacognitive statements illustrated changes of in knowledge	P13: “Yes, that’s it. Bravo! The robot must turn as much as the supplementary angle of the internal angle. That was clever.”(Participant from group 2).

5.3 Findings

5.3.1 Conditions under which collaborative knowledge construction can be promoted (RQ1.1 & 1.2)

5.3.1.1 Finding 1: Embodied interaction with the physical robot is linked to higher levels of knowledge construction

As shown in Table 6, most verbal interaction (38,4%) was coded in the lowest knowledge construction level (KC-1). This was followed by students' KC-4 level involving 43 verbal units (25%) and KC-3 level involving 37 verbal units (21,5%). KC-2 appeared with a relatively lower percentage than expected, with only 18 coded units or 10,6%. The highest level of knowledge construction (KC-5) was difficult to achieve and was represented only by eight units (4,5%). The Interaction Analysis Model has been almost exclusively used only in online learning discourse in computer-mediated communication (CMC) and CSCL settings (e.g., Ioannou et al. 2015). According to these studies, KC-1 statements accounted for the largest percentage of the overall discussion and were prerequisites for subsequent higher levers of knowledge construction. This study's findings differ from typical research results on online learning activity in that KC-4 accounted for the second-largest proportion of discourse units.

The increased KC-4, compared to previous CMC and CSCL studies, lead us to hypothesize that ER might have encouraged knowledge construction at this level because of the hands-on experimentation and embodied interaction with the physical robot. We, therefore, used chronological diagrams, to pinpoint what students were doing, when they exhibited KC-4 of knowledge construction. By zooming into the groups' chronological diagrams, we found that "Execution of Plan" was tightly coupled with higher levels of knowledge construction. That is when students interacted with the physical robot to execute their plan, they often engaged in KC3-KC5 (see Figure 11). Students were engaged in a process of "conversation with the robots," through which they promoted self-directed learning and engaged in the construction of new knowledge. The physical and embodied interaction with the robot gave students the opportunity to test or modify their new synthesis (KC-4) against existing cognitive knowledge, personal experiences, and data.

Table 6: Number of codes across levels of knowledge construction and groups

	Group 1	Group 2	Group 3	Group 4	Total (%)
Sharing/adding (KC-1)	20	15	12	19	66 (38,4%)
Exploration of dissonance (KC-2)	5	6	3	4	18 (10,6%)
Negotiating meaning (KC-3)	16	9	4	8	37 (21.5%)
Testing synthesis (KC-4)	13	9	6	15	43 (25%)
Applying co-constructed knowledge (KC-5)	3	2	0	3	8 (4.5%)
Total	57	41	25	49	172(100%)

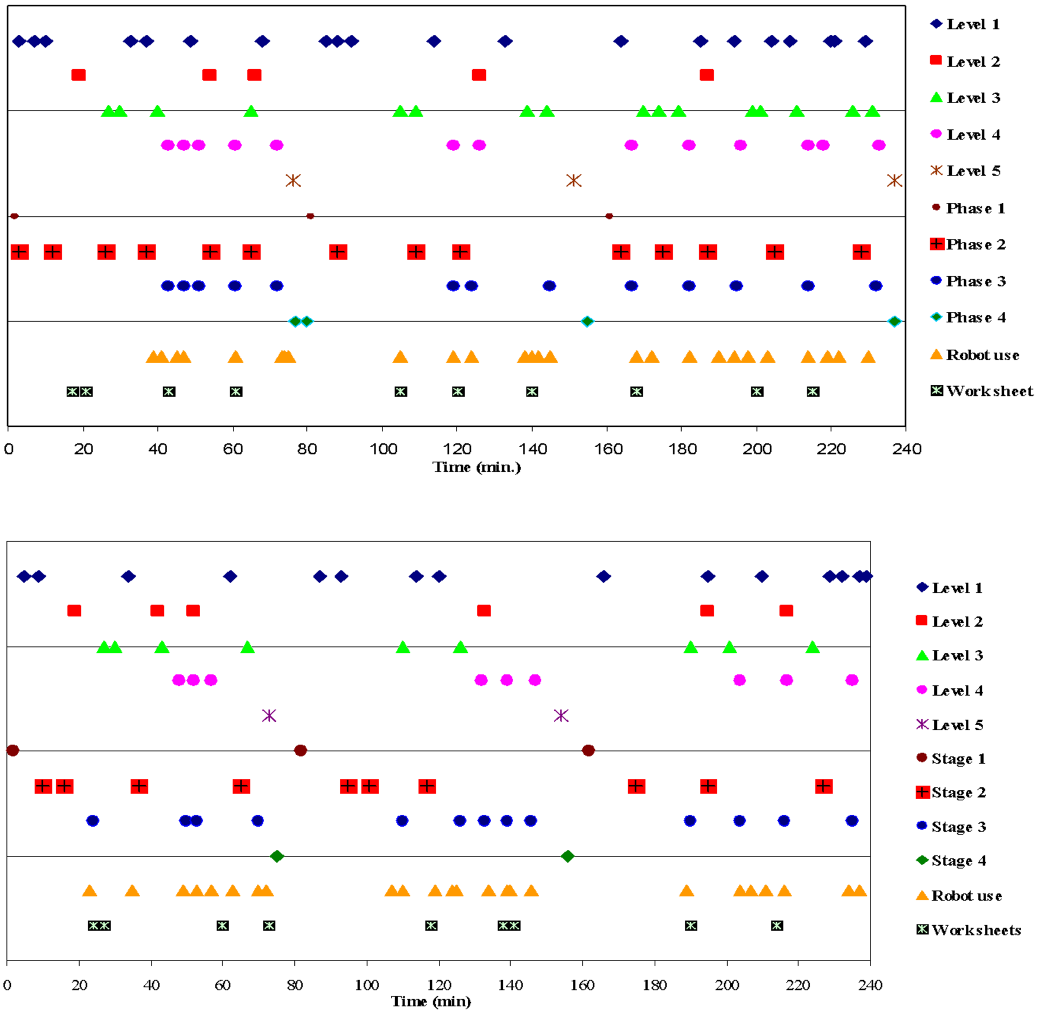


Figure 11: Chronological visual for group 1 and 2. The time of the contribution runs at the horizontal axis and the discourse-coded levels, and the stages of the problem-solving cycle are listed on the vertical axis.

5.3.1.2 *Finding 2: Fair contribution by teammates adhering to predefined roles is linked to higher levels of knowledge construction*

We found that collaborative knowledge construction was more evidenced in some groups than others. Groups 1, 2 and 4 appeared successful in engaging in the collaborative knowledge construction process, since their discourse involved contributions along all phases of knowledge construction. On the other hand, group 3 with only 25 coded units demonstrated limited engagement with the activities, whilst their discourse never reached the higher levels of knowledge construction. This case made us hypothesize that lack of within group interaction might have hindered collaborative knowledge construction. Therefore, we took a closer look at videos and chronological diagrams (for the sake of space, we present only the visuals of 2 groups) of all groups (Figure 11) to pinpoint patterns of collaboration in relation to knowledge construction. We found that in groups 1,2 and 4 all teammates were active participants in the learning process, whilst they participated fairly adhering to their predefined roles. Instead, members of group 3 did not serve their predefined roles and did not participate fairly in the tasks which seemed to have led to failure in engaging in the collaborative knowledge construction process. It therefore appears that, assigning roles to teammates and serving these roles enabled fair contribution, individual accountability, and social interdependence (Johnson et al.,1991) leading to better quality discourse and knowledge construction.

5.3.1.3 *Finding 3: Cognitive dissonance is linked to higher levels of knowledge construction*

A detailed examination of chronological visuals and associated groups' discourse helped us understand the progressive interactions and breakdowns within each group. We noted that KC-2 (discovery and exploration of dissonance or inconsistency) was relatively rare in students' contributions (only 10,6%). What's more, when KC-2 type of discourse appeared it took a while for the next level of contribution to appear. Therefore, we sought to understand cognitive dissonance and when it occurred. Zooming into the groups' chronological diagrams and associated discourse, we found that cognitive dissonance was less often related to disagreement between the teammates and more often related to the robot's failure to perform the expected outcomes during the execution of a planned strategy (stage 3 of Figure 9). In this case, students had to reconsider their strategies (i.e., going back to stage 2 of Figure 9). The finding suggests that the robot and its failure to deliver the expected result was a mediator to the discovery of cognitive dissonance or inconsistency; the latter was a time-consuming process and teammate struggled to overcome. Nevertheless, when the group overcame this stage, they engaged in higher levels of knowledge construction as evidenced in their chronological discourse. That is, inspection of the chronological diagrams of groups 1, 2 and 4 makes obvious that KC-2 contributions are followed by contributions coded in the higher levels of knowledge construction (see Figure 11).

5.3.2 What are the elements of collaborative knowledge construction evident in the ER learning environment? (RQ1.3)

Knowledge - As presented in Table 7, the student groups rarely referred to prior conceptual knowledge or experience of knowledge (5.2%). Not surprisingly, the student groups made comparisons and links referring to observations of previous actions in the same task.

Metacognition - The students used a larger number of metacognitive utterances (24.1%). The majority were monitoring statements. Planning contributions occupied the second largest percentage of metacognitive utterances and were almost always in response to data derived from the results of previous trials. However, students did not mediate their planning with prior knowledge, experience, or existing theories.

Interpretation - Student groups dedicated some effort in interpreting data derived from the robot or the tablet display (6.8%). Interpreting data was an opportunity to reconsider, test and refine their solutions.

Collaboration - The collaboration category included three subcategories: conflict, questioning/responding, and facilitator's input. Conflicts within groups were few and appeared mostly at the early stages of the task. When conflicts occurred, they were often associated with the robot's failure to perform the expected outcomes; conflicts were rarely over a concept. Student groups generated many questions (22.7%), most of which referred to teammates rather than the facilitator (Table 7). Most of these questions were planning-related questions as well as software- and robot-related questions. As shown by the relatively large number of statements related to an agreement with peers (12.8%), students' consensus-seeking behavior was frequent. Responses by the students (24.3%)

revealed the degree of consensus within the group. Students constructed simple explanations and brief answers more often than they elaborated explanations. Facilitator questioning was mainly concerned with software and robot use. The main operation of the facilitator's input was coded as monitoring (7.4%).

Table 7: Major categories and subcategories frequencies

Coding categories	N (%)	Coding categories	N (%)
Knowledge	***29 (5.2%)***	***Collaboration***	***355 (63.9%)***
Conceptual knowledge	5 (0.9%)	Conflict	26 (4.8%)
Prior experiences	4 (0.7%)	Conceptual	3 (0.6%)
Analogies	20 (3.6%)	Task-specific	23 (4.1%)
Metacognition	***134(24.1%)***	***Questioning***	*126 (22.7%)*
Monitoring	74 (13.3%)	Clarifications	30 (5.4%)
Evaluation	4 (0.7%)	Plan-related	44 (7.9%)
Reflection	19 (3.4%)	Software-related	22 (4%)
Total planning	37 (6.7%)	Self-answered	5 (0.9%)
Theory-driven Planning	2 (0.4%)	General	2 (0.4%)
Data-driven Planning	33 (5.9%)	Facilitator	23 (4.1%)
Unjustified	2 (0.4%)	***Responses***	135 (24.3%)
Interpretation	***38 (6.8%)***	Agreement with facilitator	20 (3.6%)
High-level	7 (1.3%)	Agreement with peer	71 (12.8)
Low-level	31 (5.5%)	Brief answers	24 (4.3%)
		Simple explanations	16 (2.9%)
		Elaborate explanations	4 (0.7%)
		Facilitator's input	68 (12.1%)
		Monitoring	41 (7.4%)
		Explaining concepts	3 (0.4%)
		Explaining Software	24 (4.3%)

5.3.3 How does ER help to activate group metacognitive processes? (RQ1.4)

To answer RQ1.4 we examined an integrated view of an episode, using the CORDTRA diagram of Figure 12. On the CORDTRA diagram, the numbers on the x-axis represent the chronological order of the coded units, whilst the y-axis represents the coded categories (records 6 to 29) and the speakers (records 1 to 5). The diagram reveals the nature of student's talk, including metacognitive talk, and its temporal relation to the robot's use when students tried to solve the "Draw a hexagon" challenge. Combining the diagram with discourse excerpts helped us to understand student's interactions across time. We zoomed in to an episode in which the students work on solving the "draw a hexagon" challenge (lines 90-190).

5.3.3.1 Finding 1: Through embodied interaction/Embodied experimentation

This theme explored examples where children implicated their bodies experimenting possible ideas or solutions to the problems. In Cycle 1, we saw that students used the robot as a mean for experimentation. Students in the activity should combine mathematical knowledge, experience with ER (i.e., introductory lessons), and programming skills to solve the problem for the activity. First, students started to discuss how they could solve the problem without having many ideas. A student stated that they should use the gyro sensor while another student added that they should place a robot's pen holder. A detailed discussion about where they could set the pen holder took place in lines 91-99. Here, questioning discourse appeared as an essential aspect of collaborative knowledge construction. The students' questioning about where to put the gyro sensor and the kinds of turns the robot should make triggered the dialogue for the next steps. The students started to research the question using the robot as a tool to experiment by adjusting the pen holder in different places on the robot. Students seemed to recognize the significance of where they should adapt the pen holder; this meaningful discussion moved students' thinking forward. The overall experimentation involved their bodies as students held the robot in their hands and tried to simulate (with their bodies) possible movements of the robot and thinking of possible pen footprints on the paper. Students involved their bodies in understanding the difference between swing and point turn (lines 100-114). Students' embodied interaction with the physical robot triggered further social interaction and stimulated group metacognitive processes. The students tested and modified their new ideas against existing knowledge and new data. Therefore, it appears that ER, through embodied interaction, served as a tool for experimentation, activating group metacognitive processes, and collaborative knowledge construction. In addition, in the same task students involved their bodies in understanding the difference between swing and point turn. Students' embodied interaction with the physical robot triggered further social interaction.

Student 1	We must draw a hexagon *(laughing)*. Any ideas?
Student 3	We must use the gyro sensor to turn exactly as degrees as we program it *(for accurate angle measure)*.
Student 2	Yes, the robot must turn exactly as degrees as we program it.

Student 4	We also need to adjust a marker to draw the hexagon as the robot moves and turns.
Student 2	What kind of turns?
Student 3	Turns.
Student 1	Pivot turns. The robot must turn very sharp and make pivot turns to draw an angle.
Student 1	Ok! Where can we apply the marker?
Student 2	If we put it here *(holds marker and robot and try to make turns to draw a random angle).*

These tests continued until students managed to draw angles formed by two rays rather than curved lines. Students placed the marker on different parts of the robot and tried to draw random angles. They tried to put the marker in different places (between the wheels, next to the right wheel and on the back of the robot) to understand where it would be more efficient to place the marker.

5.3.3.2 Finding 2: Through interactivity and transparency

In lines 160-176 of the CORDTRA diagram (Figure 12), students went through an exploration where they used their conceptual knowledge of mathematics and programming in a real-world situation. Students were concerned about how many degrees their robot should turn. With the teacher's assistance, they managed to connect their mathematical knowledge and programming skills with real-world conditions. A student, influenced by the introductory robotics lessons, used a flowchart describing the robot's required moves to draw a hexagon (line 168). They then decided to program the robot to turn 120º, as much as the internal angle and observed their robot turning much more than expected. Immediate feedback from the robot's moves (i.e., observing the robot turn more than they expected) made the students think and monitor their thoughts (line 169). The robot's failure to produce the expected outcome seems to have triggered the group's metacognitive thinking. Thinking of what they were doing wrong, checking various aspects (lines 169-172), and building on each-other's thoughts, they excluded different possibilities and proposed a solution to the problem. After that, Student 4 contributes advanced thinking to the discussion, suggesting that they should put a smaller value for the turning angle because, with 120º, the robot was turning too much. Student 4 proposed to represent the problem on a paper in order to calculate the turning angle. Students acknowledged this idea and began to model the problem on a paper. By representing the problem on paper, students managed to find the correct value for the turning angle. Then, Student 1 made his thinking visible, showing the correct angle on the paper (line 174). Student 2 built on a previous thought proposing the solution to the problem (line 175). Therefore, the process of socially shared metacognition emerged in this group when Student 4 provided a metacognitive regulation statement (i.e., "If the robot turns 120º left, it will get into the hexagon. Let's draw the hexagon on a piece of paper to find the angle"). The other group members acknowledged this contribution and developed a solution to the problem.

The ER's transparency features helped the students think, apply, and check their ideas to overcome the problem. Easy changes to the software and hardware, at no cost, helped the students to avoid frustration. Through the open and accessible programmability of the robot, they managed to overcome the obstacles. The robot's programming, the expected results, and the actual results of its actions served as a metacognitive tool and as a data reference that students could use to negotiate their developing solutions. The students identified gaps in their knowledge and collectively discussed, elaborated, and improved their solution. Regulatory statements generated due to the robot's interactivity and transparency characteristics promoted group metacognition and facilitated collaborative knowledge construction.

Student 3	Now, we will program the robot to move forward, then make a turn for some degrees then again forward and then turn, etc.
Student 2	Ok, we have to think about how many turns and how many degrees.
Student 1	Six turns and six forward. I do not know how many degrees.
Teacher	What do we know about the total internal angles of polygons?
Student 4	It depends on how many different triangles are formed into the hexagon that does not overlap with each other.
Student 2	How many different triangles does a hexagon have?
Student 3	I will draw a hexagon to find how many triangles are formed.
Student 3	Four different triangles. So, multiplies by 180º each equal 720º
Student 1	Divide by six angles of a hexagon *(thinking)*. Equals 120º. So, we will program the robot to move forward and then turn 120º for six times.
	(The team programmed the robot and is going to test the program).
Student 2	No, it is turning too much. Perhaps we calculate the angles wrong. Let's check it.
Student 3	Or the sensor is not working
Student 2	The gyro sensor looks ok!
Student 1	*(They are doing the calculations)* The angle is correct 120º. Must be something else.
Student 4	Yeah, but I think we just have to take a smaller angle. 120º are all the internal angles of the hexagon. The robot moves on one of the sides of the hexagon. If the robot turns 120º left, it will get into the hexagon. Let’s draw the hexagon on a paper to find the angle.
	(They draw a hexagon with a robot, representing it with a dot, on one of its angles)
Student 1	The robot is this dot and must turn here *(showing with his finger)*. So, the turning angle is this one, we must find this one *(showing on the paper)*.

Student 2	This angle is supplementary to the internal angle. So, it's 180-120 = 60.
Student 4	Yes, that is. The robot must turn as much as the internal angle's supplementary, only 60º, not 120º.

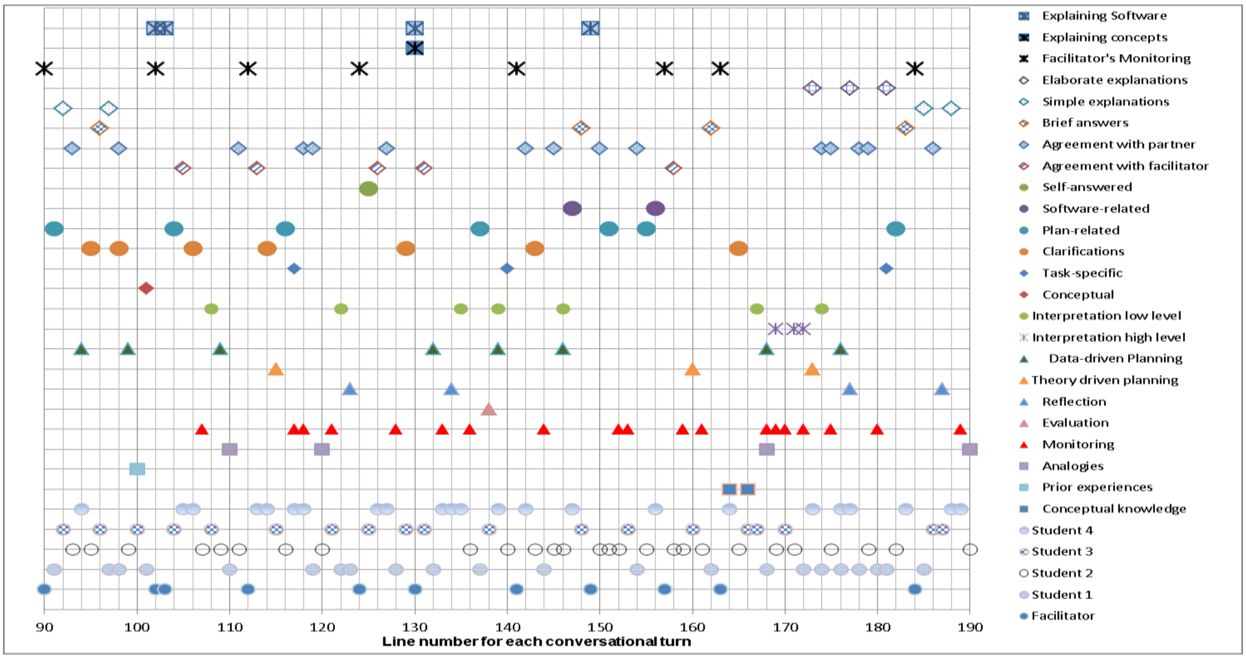


Figure 12: CORDTRA diagram of students' contributions

5.3.4 What is the relationship between collaborative and metacognitive talk as evident in the ER learning environment? (RQ1.5)

In the previous excerpt and the one below, the students made their metacognitive thinking visible mainly in mutual interaction with their teammates. Student 1 tried to explain their failure to solve the challenge by proposing that the flags were small, so the sensor could not detect them. This contribution triggered the thinking of Student 3, leading him to suggest a new idea, that is, the use of two ultrasonic sensors instead of one. Student 1 pointed out his disagreement over the proposed idea and documented his position using the experience of a previous failing effort outside the current activity. Then, Student 1 contributed a metacognitive statement to justify his position proposing that they do not know well how to handle an ultrasonic sensor. Therefore, he suggested a trial-and-error plan. Student 3 ignored Student's 1 plan highlighting that it would be easier for the robot to detect the flags with two sensors. When they failed, Student 3 agreed to use the alternative plan, but he first proposed to measure the distances among the flags so that they did not use a trial-and-error plan. In the excerpt below, the students compared their thinking with the thinking of their peers, and this involved the use of collaborative talk in parallel with metacognitive talk. Also, as shown in the CORTDRA (Figure 12), collaborative and metacognitive talk seemed to have a temporal relationship between them. For example, contributions that were coded as collaborative talk were usually followed by one or more metacognitive contributions vice versa.

Student 2	We will use the ultrasonic sensor to avoid the flags.
Student 3	Ok then. Put the ultrasonic sensor. *(They executed their plan, but they failed)*.
Student 1	The flags are small, so the sensor cannot detect them.
Student 3	We can use two ultrasonic sensors. What do you think?
Student 1	No, we tried to use the ultrasonic sensor once, and we failed. We do not know how to handle it. Let’s program the robot to move, and then we can adjust the values.
Student 3	If we put two sensors, it will be easier for the robot to detect the flags.
Student 2	Ok! Let’s try with two sensors.
Student 1	Ok then. *(They executed their plan using two sensors, but they failed)*.
Student 1	I told you, we do not need the sensors.
Student 3	One more trial with two sensors and then, if we fail, we can move with your plan. *(They changed the position of the two sensors and tried again, but they failed).*
Student 3	Ok. Let’s do what you said, but first, we can measure the distance between the flags to calculate the value of rotations.

5.4 Discussion

A few studies in the field of ER have focused on exploring the potential of ER in terms of collaborative knowledge construction. The ER learning environment can integrate the benefits of robotics technology, computer supported collaborative learning (CSCL) and problem-based pedagogy, in an authentic learning space, simulating real-world problems. This Cycle 1 begins to collect the much-needed evidence around ER's practical utility and potential impact in school contexts. We described the design of a learning experience using EV3, allowing 14 students in the math and science classroom to engage in collaborative learning and problem-solving. Overall, the findings provide a better understanding of ER's use to benefit collaborative knowledge construction in the STEM field. The findings also demonstrated the elements of ER and teamwork that can promote collaborative knowledge construction in a CSCL environment.

In sum, the video data from the implementation of the ER sessions revealed three conditions that appear to relate to higher levels of knowledge construction: (i) embodied interaction with the robot (ii) fair contribution by teammates adhering to predefined roles, and (iii) cognitive dissonance as a result of the robot’s failure to perform the expected outcome.

In general, the results of the study are encouraging as they not only support our initial expectations regarding the value of ER as learning tools but also, confirm results of previous works making of use ER to improve collaboration and peer interaction (Ardito et al., 2014; Mitnik et al., 2009). In addition, both the research results and the design of the teaching intervention enabled us to improve the teaching practice further to maximize learning outcomes.

In short, it was expected for the students to generate more contributions at the lowest level of knowledge construction (i.e., KC-1) but it was not expected the same for the Testing synthesis level (KC-4). This unexpected result made it possible to zoom in on the particular level of knowledge construction in order to understand or make assumptions about why this was happening. Retrospective analysis using the CORDRA technique enabled us to understand that the “Execution of Plan” in the learning cycle was tightly coupled with the KC-4 level of knowledge construction. When students interacted with the physical robot to execute their plan, they were engaged in a process of “conversation with the robots,” through which they promoted self-directed learning and engaged in the construction of new knowledge.

In addition, the students in that step of the learning cycle had the opportunity to test or modify their new synthesis (KC-4) against existing cognitive knowledge, personal experiences, and data. This enabled students to produce metacognitive contributions and became the focus of our subsequent inquiry. To be precise, based on our aim, the DBR methodological framework helped us first to investigate patterns of collaborative knowledge construction (Cycle 1) and then, unfold the elements of collaborative knowledge construction and define group metacognition as one of the prevalent elements of this process.

The second part of this phase presents evidence that CSCL activities using ER can engage students in collaborative knowledge construction with principal elements of metacognitive processes, questioning, and answering. Indeed, students' discourse demonstrated logical reasoning coupled with metacognitive statements enabling the students to predict and plan the flow of actions required to solve the problem. Monitoring dimensions of metacognition seem to be activated in an ER learning environment, engaging students in exploration for the acquisition of knowledge. The large volume of monitoring dimension of metacognition can be explained as the ER's value in encouraging procedural knowledge rather than declarative knowledge, i.e., student learning by doing and understanding strategies of problem-solving rather than concepts.

During the ER activity, intensive collaboration was enacted in the form of questioning and answering, while metacognition was enacted in the form of monitoring and planning. Many researchers have identified questioning (e.g., Hmelo-Silver & Barrows, 2008) and reflective thinking (e.g., Baker & Lund, 1997) as important kinds of discourse in knowledge building situations. Contributions of prior knowledge were limited, although this might not be replicated in a setting where learners have prior experiences with ER. Our findings confirm previous evidence about ER promoting collaborative knowledge construction (Chambers et al., 2007). This work contributes further in that it presents a fine-grained analysis of the phenomenon to strengthen the scientific evidence in the area. While previous studies rely heavily on the study of metacognition as an individual endeavor, using self-reported data (e.g., Atmatzidou et al., 2018), this study documents metacognition as a result of group work, while it occurred in-situ.

Metacognitive elements, coded as monitoring, evaluation, reflection, and planning, are activated in ER activities through embodied interaction with the physical robot. Indeed, when a robot is being used in the activity, it enables students' physical action and simulation of the robot's expected actions. Such activities seem to encourage expression and personal involvement in the learning process while supporting teamwork, which is essential for the metacognitive process. Moreover, the transparent software design and the direct interactivity (feedback) coming from the robot's moves in response to students' programming seem to facilitate the group's metacognitive thinking. In fact, when the robot failed to perform the expected outcomes, monitoring and planning dimensions of metacognition were documented on our chronological diagrams. Metacognition was necessary for students to understand how the tasks were performed and to be able to identify problems, negotiate modifications, and operating changes to solve the problems. Embodied interaction with the physical robot, combined with feedback from the robot, acted as an extension of students' minds, scaffolding knowledge construction by re-evaluating their solutions. From this perspective, ER can be considered as "scaffolding embedded technological tools" (Chambers et al., 2007).

Our research has provided some initial evidence for a temporal relationship between collaborative talk and metacognitive talk in a problem-solving collaborative ER environment. The study further presents an instrumental role of ER technology in supporting metacognitive processes in CSCL settings. Metacognitive and collaborative talk appear to mediate each-other in this CSCL, ER setting. We understand that this evidence is not clear yet. Further development of our understanding of ER as metacognitive tools will help us develop strategies to maximize their effectiveness in group problem-solving CSCL tasks.

6 Chapter 6: DBR Cycle 2

Results of this study are published in the proceedings of the International Conference of Immersive Learning Research Network (iLRN 2019) (Socratous & Ioannou, 2019b).

Cycle 2 aimed at investigating the potential added value of ER in promoting students' metacognitive thinking in the context of elementary STEM education. Following the encouraging findings of Cycle 1, we wanted to confirm and extend our understanding regarding the impact of this tool on students' metacognitive thinking as a key element of collaborative knowledge construction. Namely, DBR Cycle 2 extended our understanding of the added value of ER in promoting students' metacognitive thinking and mathematical problem-solving at an individual level of analysis. In Cycle 2, we addressed the effectiveness of ER activities in supporting the development of students' metacognitive thinking (RQ2.1). Mainly, this cycle aimed to reveal how ER activities influenced metacognitive skills and mathematical problem-solving (RQ2.3) through a structured curriculum (Figure 13). By applying a quasi-experimental research design using a control group, we also aimed at identifying which metacognitive elements were impacted more by this kind of activity (RQ2.2).

The results of this Cycle showed the positive effect of structured ER activities on student's metacognitive thinking and mathematical problem-solving skills while the structured ER activities looked to tackle more on regulation and self-control components of metacognition, such as planning, monitoring, and debugging strategies.

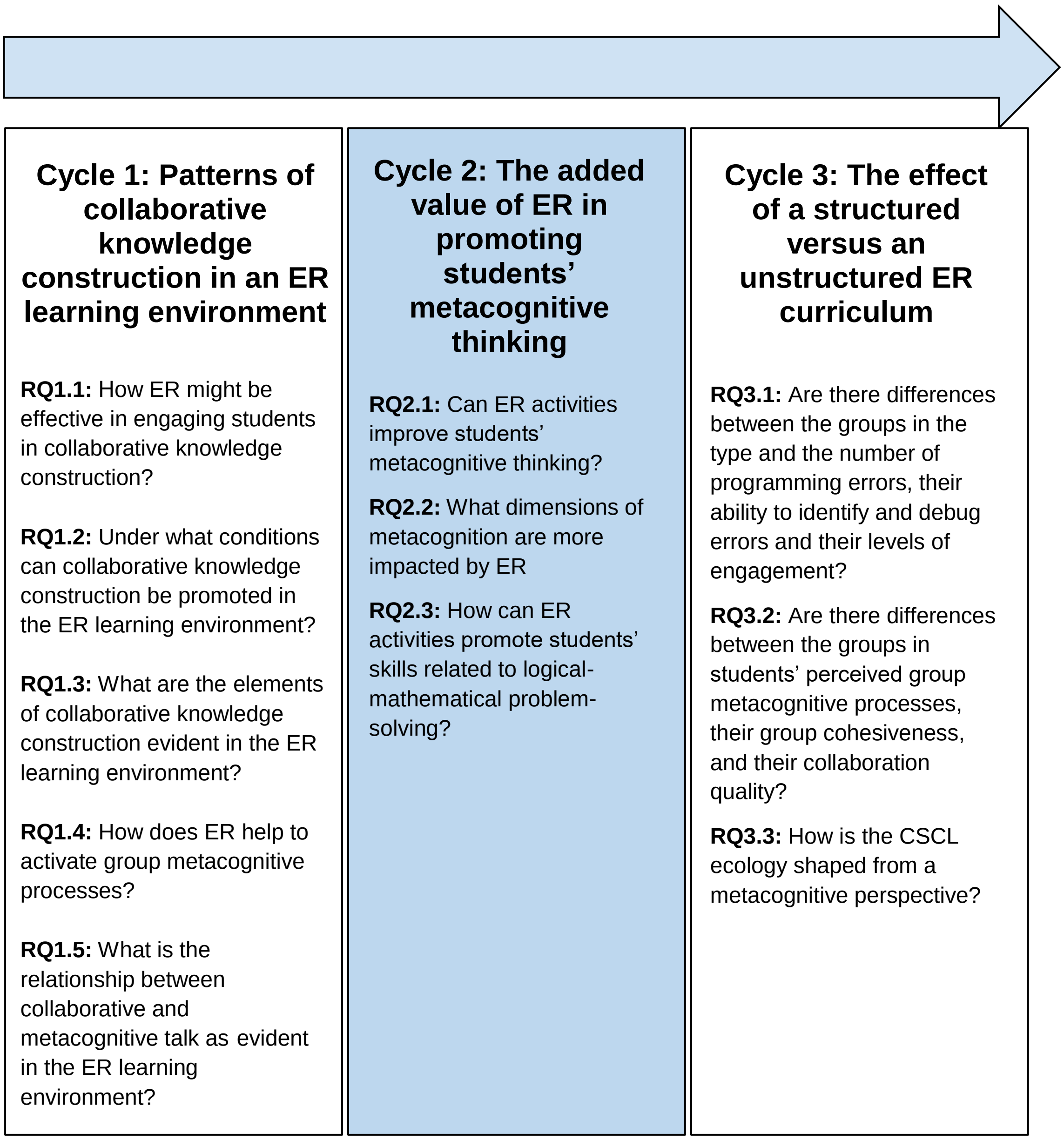


Figure 13: Research questions of Cycle 2

6.1 Introduction

During the last decade, several researchers and instructors have been frequently and fruitfully used ER in several contexts and disciplines, for the teaching of particular content knowledge in a field (e.g., mathematics and science) or for supporting learning associated mainly with transversal skills such as problem-solving (Castledine & Chalmers, 2011), metacognition (La Paglia et al., 2011), computational thinking (Bers et al., 2014), creativity (Sullivan, 2011), and collaboration (Ardito et al., 2014).

The current research suggests that ER may be a tool to improve problem-solving abilities, STEM knowledge, cognitive flexibility, teamwork, and metacognition from childhood to elementary and secondary education. However, despite the considerable attention that emerged around ER and the promising results from empirical studies, the evidence is not clear. The ER literature lacks careful research designs as control groups are often absent (Xia & Zhong, 2018; Benitti, 2012). Various variables are concurrently examined, and consequence measures are directed to be based on qualitative data (Benitti, 2012). The same problem exists regarding the use of ER as a tool to support metacognition. Several studies investigating the potential influence of ER projects on pupils' metacognitive thinking did not use reliable study designs or validated measurement instruments (e.g., La Paglia et al., 2011). Also, most of the previous efforts have used qualitative approaches to evaluate the outcome of ER activities in metacognition (e.g., Socratous & Ioannou, 2019a). A holistic perspective on the issue of promoting metacognition via ER is still missing from the literature. There is a need for more rigorous studies to contribute a better understanding of the cognitive construct underlying ER effects.

Cycle 2 intends to respond to the need for evidence on ER effectiveness to increase students' metacognitive awareness, providing quantitative data on ER impact in elementary STEM education. To achieve this, a two-group pre-test post-test research design (quasi-experimental) was used. Students in the experimental group participated in structured ER activities, while students in the control group did not participate in any ER activities. Comparing students' abilities and perceived and in situ metacognitive thinking before and after the learning experience for both groups give us evidence about students' metacognitive development due to the use of structured ER activities. This second cycle of investigation focuses on students' learning gains on (a) individual metacognition, (b) accuracy on performance judgments, and (c) abilities on mathematical problem-solving. Also, Cycle 2 tried to investigate which subcomponents of metacognition seem to be affected most by the use of structured ER activities and confirm previous evidence about a more significant effect on the regulatory components of metacognition.

6.2 Methodology

6.2.1 Participants

The study sample was 42 primary school students (4th graders) from two public elementary schools in Cyprus (24 girls, 18 boys). The 42 students were not randomly assigned to two conditions. Therefore, two nonequivalent groups were formed. The experimental group consisted of one class of 21 fourth-grade students (13 girls and eight boys), and the control group consisted of another class of 21 fourth-grade students (11 girls and ten boys) from a different school of the same region. The mean age in the experimental group was m=9.68 years old (SD=0.26) and for the control group was m=9.76 years old (SD=0.32). Independent sample t-test was conducted indicating no statistically significant difference in students' age between the groups [t (40) = -0.61, p= .55]. Two children of the experimental group and one from the control group were students with special educational needs and motor impairments (2 boys and 1 girl). Only two students from both groups had previous experience with programming and ER.

6.2.2 Description of activities

A teacher and an educational technologist designed the technology-enhanced learning environment. As presented in Table 9, the first two sessions were introductory lessons with introductory activities to help pupils get familiar with the EV3 environment. During this phase, essential programming details associated with the programming environment were explained to them by presenting examples (directional commands, sensors, loop, and wait for). The next six sessions were structured STEM problem-solving activities. The student groups first completed the training phase in which they completed the worksheet activities with the teacher's help. Then, the students continued with the session's final challenge. Students should program a robot using a tablet or a computer to solve different problems according to the instructions and conditions of the activity (see Table 9, Table 8, and Figure 14).

Table 8: The organization of a structured curriculum session

Phase	Duration	Activity
Introductory	5 min	Distributing materials Introduction to the learning goals and the purpose of the session
Training	35 min	Preparatory work for the session' challenge

Challenge	40 min	Session’s final challenge

Table 9: The eight sessions of the course (80 minutes each)

Sessions	Tasks
Session #1 Introductory	a) Introduction to the learning objects of the curriculum**.** b) Opening the software, writing, and saving a program, connecting the tablet or the computer to the brick with Bluetooth, running a program. c) Controlling the EV3 Motors (start programming motors); start, to finish, backup to start; start, to finish, turn around, back to start.
Session #2 Introductory	Using EV3 Sensors (start programming sensors); ultrasonic sensor, touch sensor, color sensor, and gyro sensor.
Session #3	Program your robot to move forward exactly 1.20m using (a) rotations, (b) degrees and (c) seconds.
Session #4	a) Program your robot to turn exactly 90 degrees using a gyro sensor. b) Program your robot to move on a square using a gyro sensor.
Session #5	a) Use the ultrasonic sensor to stop before hitting a wall. b) Program your robot to move forward by pressing the touch sensor until the ultrasonic sensor is 10cm from the wall. c) Program a robot that can move into the classroom without hitting any objects.
Session #6	a) Program your robot to say “green” when seeing a green object and “red” when seeing a “red” object. b) Program your robot to move forward when seeing a green tape and stop when seeing a red tape.
Session #7	Program your robot to move a block from one square to the other using the medium motor (cargo delivery attachment).
Session #8	Design a maze using objects from the classroom and program your robot to solve the maze without touching any objects.

Figure 14: Two groups are executing their programs in session #5; the goal was to program the robot to move into the classroom without hitting any objects (left); a group trying to solve its own designed maze challenge (right)

6.2.3 Procedures

Students in the experimental group participated in structured ER activities during a two-month period, while students in the control group did not participate in any ER activities. They followed the traditional curriculum and standards for Grade 4 with a male teacher. The 21 students of the control group completed the assessments during pre- and post-administration under the same conditions as the experimental group (i.e., same assessments, same time, and same procedures as the experimental group). Before the study, all the ethical approvals and consent forms from the students' legal guardians were obtained regarding the data collection.

The students of the experimental group were divided into five groups of 4-5 students of different genders and abilities. Four groups of four students and one group of five students were formed. Students participated in eight sessions (80 minutes each) of structured ER activities (one session per week) in a typical classroom setting over a two-month period (as in Figure 15), during April and May of 2018.

We followed a low coercion approach for students' metacognitive training. Typically, in each task, students were provided with a worksheet with assignments of progressive difficulty. The worksheets were structured to support students on technical aspects but not to lead or guide them in solving the problems. The teacher served as a facilitator, assisting student's thoughts in the form of hints, prompts, and feedback without providing any answers. He often prompted students with questions such as: Why are you doing it? What are you doing? He prompted students to externalize representations of metacognitive thinking and problem-solving procedures verbally.

The groups followed a typical problem-solving cycle, without any formal prompting from the teacher and without any previous training. A typical problem-solving cycle of an ER activity as undertaken by the students included three main steps: (i) understanding the problem – teammates read and defined the problem, (ii) plan a strategy – teammates proposed ideas and planned together, (iii) executing of a plan – students used the robot to execute; their strategy was reconsidered based on the robot's performance (i.e., teammates evaluated the outcome).

Figure 15: Classroom setting from an introductory session

Data was collected via a profile questionnaire on demographic data and two assessments measuring individual metacognitive awareness, accuracy on performance judgments as an indication of metacognitive awareness, and mathematical problem-solving as presented below.

Metacognitive Awareness Inventory (MAI) - To assess the development of students' metacognitive awareness we used the MAI instrument (Schraw & Dennison, 1994) as pre- and post-assessment. The MAI questionnaire was given to the experimental group before and after the learning experience. For the control group, the instrument was given in two different times the same as the experimental group (first implementation when the instrument was given to the experimental group and second, after two months when the instrument was given to the experimental group as a post-test assessment). Due to low reading levels, the questionnaire was read aloud by the teacher, i.e., the teacher read each statement to the whole class, students answered, and when he was sure that all the students completed an answer, then he proceeded to the next question. MAI is developed based on the theoretical structure of two main components: the knowledge of cognition and the regulation of cognition. Earlier research reports indicate that the MAI produces structurally valid and internally congruent results as a whole. Furthermore, structurally valid, and internally congruent results have been produced according to the division of the two main components. The questionnaire was set out to confirm the theoretical existence of two components: knowledge of cognition and regulation of cognition. The final factor structure was best represented by dividing the factors into eight subcomponents: conditional knowledge, declarative knowledge, procedural knowledge, planning, monitoring, information management strategies, debugging strategies, and evaluation of learning, respectively. This structure was also confirmed by the results of Sperling et al. (2004).

Visualization and Accuracy Instrument (VisA) - VisA instrument was used as an on-line measure to investigate the development of students' metacognitive thinking. VisA combines prediction and postdiction judgments, and visualizations to assess metacognition and especially the combination of metacognitive monitoring and regulation, which are interrelated used during problem-solving (Jacobse & Harskamp, 2012). Judgments of performance and problem visualizations theoretically measure different aspects of metacognition but are both practical on-line measurement instruments with sufficient predictive validity. The students were asked to distribute their solutions for each problem scenario into four steps. In the first step, students had to rate their confidence in solving the problem correctly. The second step asked them to draw a sketch to visualize the problem scenario and the solution. In the third step, they solved the problem, and in the last step, students rated their confidence for having found the correct solution. The scoring procedure was simple. Students got one point for each correct judgment and zero points for each uncertain or incorrect judgment regardless of whether they had solved the problem correctly or not (i.e., if a student predicted that he could solve the problem and indeed did it, he got one point; or if he predicted that he could not solve the problem and indeed didn't, he again got one point). For the visualizations, students got zero points if they made pictorial or irrelevant sketches without showing any important aspects or relationships of the problem, they got 0.5 if their sketches were partly pictorials with some schematic or mathematical features, and they got one point if their sketches were primarily schematic visualizations with mathematical features (see Figure 16). The maximum score for each student was 12 points (4 problems x 3 points each). The first 30 visualizations (8.9%) were evaluated with two judges until a consensus about scoring practices was obtained. Reliability was high (agreement over 90%), and, consequently, the first researcher completed the scoring procedure alone.

Pre-post mathematics test - We used the data from the four problem-solving tasks from the two administrations of the VisA instrument for assessing mathematical knowledge gains. We looked for the correctness of their solutions (not the accuracy of their judgments). Each correct task was scored with 25 marks, and the maximum possible score was 100 marks. The four tasks were adapted from the released assessment questions from previous studies of Trends in International Mathematics and Science Study (TIMSS).

Mary plants rose bushes along a path to her home. The path is 27m long. She plants a rosebush every 3m on both sides of the path. She also plants rose bushes at the beginning of the path (on both sides). How many rosebushes does Mary need?

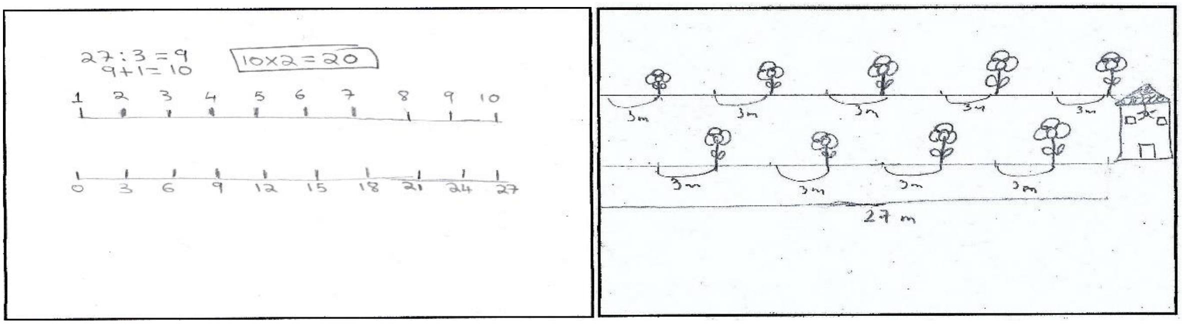


Figure 16: Example of students' artifacts from post-VisA administration; schematic visualization with mathematical features (left), and wrong, pictorial representation of the problem with mathematical features (right)

6.3 Findings

6.3.1 Finding 1: Outcomes on metacognitive thinking (perceived) (RQ 2.1.)

Un-weighted mean scores were calculated for scales and subscale. A Paired-sample t-test analysis was conducted for each group. The analysis showed statistically significant differences only for the experimental group, while the mean scores in the control group remained unchanged (Table 10). For the experimental group, statistically, significant differences were observed on the subcomponents of "regulation of cognition" [t (21) = -7.83, p< .001] with students exhibiting higher levels of "regulation of cognition" in the post-test (M=4.02; SD=0.21), compared to the pre-test (M=3.70; SD=0.29). Particularly, the results demonstrated statistically significant differences in three of the five dimensions of regulation of cognition: Planning [(t (21) = -9.28, p= .000], Comprehension Monitoring [t (21) = -3.65, p= .002] and Debugging Strategies [t (21) = -6.97, p< .001]. Instead, there was no statistically significant difference in the "knowledge of cognition" subscale from pre-testing to post-testing for both groups.

Table 10: Descriptive statistics of MAI scores (pre and post) and paired t-test per group

Dimensions	Group	Pre-MAI	Post-MAI	Paired t-test
		M (SD)	M(SD)	
Knowledge of Cognition	EG	3.68 (0.46)	3.72 (0.32)	t(21)= -0.61, p= .55
	CG	3.68 (0.23)	3.70 (0.27)	t(21)= -0.26, p= .80
Regulation of cognition	EG	3,70 (0.30)	4.04 (0.20)	t(21)= -8.36, p< .001
	CG	3.73 (0.23)	3.75 (0.20)	t(21)=-0.53, p= .61
Planning	EG	3.47 (0.59)	4.01 (0.44)	t(21)= -9.28, p< .001
	CG	3.51 (0.41)	3.54 (0.49)	t(21)=-0.33, p= .74
Monitoring	EG	3.79 (0.64)	4.18 (0.39)	t(21)= -3.65, p= .002
	CG	3.74 (0.45)	3.77 (0.27)	t(21)= -0.22, p= .83
Debugging Strategies	EG	3.74 (0.64)	4.26 (0.44)	t(21)= -6.97, p< .001
	CG	3.77 (0.42)	3.85 (0.48)	t(21)=-0.74, p= .47

Then, to further examine the comparison of the differences between the posttest and pretest scores in each treatment group, a mixed-design ANOVA, with repeated measures was conducted (i.e., a "time by treatment interaction" effect). In the analysis, the independent variables were the group condition (experimental and control) and measurements at two-time points (before and after the intervention). The dependent variable was the mean scores of the MAI scale.

The ANOVA revealed a statistically significant time by treatment interaction for the overall MAI scale F (1, 40) = 4,319, p=,044, indicating that students in the experimental group had statistically significant larger gains on metacognition compared with students in the control group. Moreover, a statistically significant time by treatment interaction was detected for the subscale of "regulation of cognition" F (1, 40) = 5,781, p = ,022 (Table 11). This shows that students in the experimental group had statistically significant larger gains on the "regulation of cognition" subscale than students in the control group (Figure 17). There were no statistically significant main or interaction effects for the "metacognitive knowledge" subscale, indicating no significant increase or decrease in the self-reported "knowledge of cognition" scores in both groups.

Table 11: Mixed-design ANOVA, interaction effects for pre-posttest on the Knowledge of cognition (KG) & Regulation of cognition (RQ)*Group condition

	Sum of Squares	df	Mean Square	F	Sig.
pre_post MC*Group	0,404	1	0,404	4,319	,044
pre_post KG*Group	0,001	1	0,001	0,009	,924
pre_post RQ*Group	1,892	1	1,892	5,781	,022

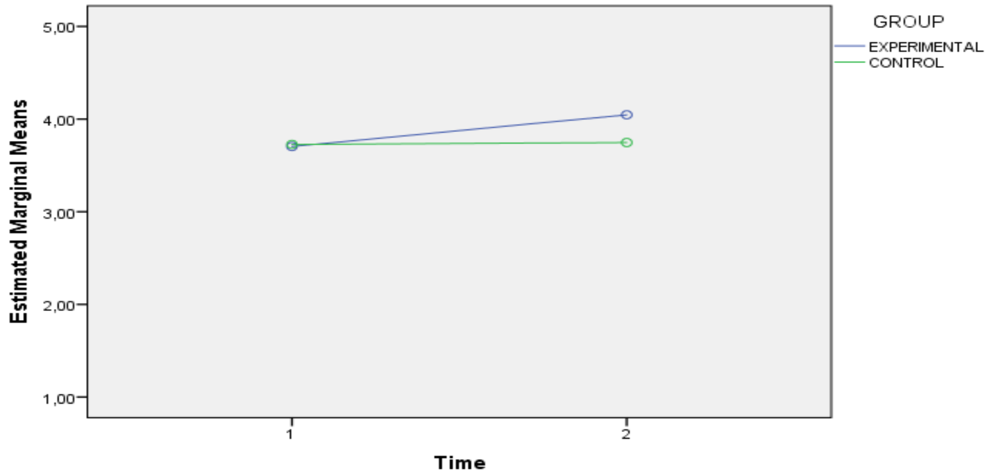


Figure 17: Statistically significant "time by treatment interaction" for the "regulation of cognition"

6.3.2 Finding 2: Outcomes on metacognitive awareness (on-line) (RQ 2.2)

A Paired sample t-test was conducted to examine mean differences from pre-to-post testing on the VisA instrument; the analysis showed that the students improved their performance from pre- to post-testing. This difference was statistically significant [t (21) =-2.96, p<.005)] only for the experimental group. Particularly, the analysis in the experimental group showed a statistically significant increase in students' accuracy on prediction and postdiction judgments from pre-testing to post-testing (Table 12). However, there was no statistically significant difference in students' visualizations for both groups. The one-way ANCOVA test with pre-VisA as a covariate showed that the use of ER activities had a significant effect on the development of students', accuracy on performance judgments [F (1,39) =4.49, p= .04, η2=0.103].

Table 12: Comparing pre- and post- VisA scores between groups

	Group	Pre-test M (SD)	Post-test M(SD)	t-test Statistics	ANCOVA Comparing Post-VisA across student groups with Pre-VisA as covariate
Visualization & Accuracy	EG	2.03(0.66)	2.33 (0.59)	t (21) = -3.65, p= .002	F (1,39) =4.49 p= .04, η^2=0.103

	CG	2.10(0.39)	2.16(0.31)	t (21) = -0.67, p= .51	
Prediction	EG	2.33 (0.73)	2.71 (0.64)	t (21) = -2.96, p= .008	F (1,39) =3.155 p= .842, η^2=0.08
	CG	2.38(0.74)	2.43(0.60)	t (21) =-0.271, p= .79	
Visualization	EG	1.43(0.88)	1.45 (0.72)	t (21) = -0.204, p= .84	F (1,39) =0.022 p= .883, η^2=0.001
	CG	1.50(0.57)	1.57(0.45)	t (21) =-0.548, p= .59	
Postdiction	EG	2.33(0.73)	2.81 (0.68)	t (21) = -3.21, p= .004	F (1,39) =5.32 p= .02, η^2=0.120

6.3.3 Finding 3: Outcomes on mathematical problem-solving (RQ 2.3)

A total pre- and post-test score was computed for each participant in both groups, by summing up the correct answers and adjusting to 100. Paired-samples t-tests were conducted using students' data from the two administrations of VisA for the two conditions. The analysis showed a statistically significant increase, t (21) = 2.65, p = .016, from pre- (M=59.52%; SD=16.73) to post-testing (M=67.86%; SD= 19.59) for the experimental group. There was an increase in mean scores for the control group, but this improvement was not statistically significant (Table 13).

Table 13: Comparing the two groups for any learning gains in mathematical problem-solving

	Pre-Test Scores	Post-Test Scores	t-test Statistics
	Mean (SD)	Mean (SD)	
Experimental group	59.52 (11.92)	67.86 (12.13)	t (21) = -5.29, p= .000
Control group	54.76(13.92)	57.14(12.41)	t (21) = -1.16, p= .261

6.4 Discussion

Despite the extensive use of robotics in education, their role as a metacognitive tool remains uncertain. This study investigated the hypothesis that ER can serve the learning process as metacognitive tools, supporting and promoting students' metacognition in the context of elementary STEM education.

Four significant breakthroughs have emerged in this cycle. Following prior empirical studies (La Paglia et al., 2011; Atmatzidou et al., 2018), our research has provided evidence supporting the positive impact of structured ER activities on students' metacognitive thinking (RQ2.1). Our teaching procedure can be considered as a low coercion approach for students' metacognitive training. In contrast with the study of Atmatzidou et al. (2018), which found an improvement in students' metacognitive skills only in "strong guidance" groups, we found that metacognition can also occur with a minimal guidance approach. This finding further emphasizes the instrumental role of the technology in supporting students' metacognitive processes. The improvement in students' metacognitive thinking in the experimental condition is seen as a collective result of the technology use, group work, teacher's interventions, and the activities' nature. However, we think that the technology's role was instrumental since it enabled a spontaneous 4-stages problem-solving process (understanding the problem, planning, executing, and evaluating), which can be considered by itself as a metacognitive learning protocol.

The collection of evidence of students' metacognitive processes by assessing students' judgments of their own performance (calibration) demonstrated a statistically significant increase for students' accuracy on prediction judgments and postdiction judgments from pre-testing to post-testing in the experimental group. The ability to judge one's performance has been conceptualized as an expression of metacognitive monitoring (Boekaerts & Rozendaal, 2010). Therefore, we replicate the previous finding of the positive impact of ER activities on students' abilities to monitor their own learning. Both structured and unstructured ER collaborative activities seem to positively affect metacognition. Possibly, that is because ER collaborative activities are based on procedural knowledge and engage students naturally in the process of exploration for solving a problem; yet further research is needed to fully understand what elements of

ER contribute to students' metacognitive thinking as a key element of collaborative knowledge construction.

Furthermore, we found that structured ER collaborative activities have no impact on students' abilities to visualize a problem scenario in both groups. The latter contradicts the previous finding of students' improvement in performance accuracy (for the experimental group) as someone would expect them to improve their visualizations. However, we know that the accuracy of performance judgments gives information into a limited part of metacognitive processes (only in monitoring by looking forward or backward about a solution plan for a problem). Also, to visualize a problem scenario is an activity that may need additional skills or something that may require a longer time to be improved.

Moving a step forward, our study provides evidence that structured ER collaborative activities have a greater positive impact on three regulatory subcomponents of metacognition, such as planning, monitoring, and debugging strategies (RQ2.2). These subcomponents are related to "regulation of cognition," and ER seems to tackle these aspects of metacognition well. This finding can be considered as crucial knowledge for educators who see their elementary students struggling to solve multi-step problems. Training these aspects of metacognition can help their students become more effective in solving multi-step problems in several disciplines and, in general, to become more effective problem-solvers. Since a low level of guidance was applied, this improvement cannot be explained beyond the role of ER as "scaffolding embedded technological tools" (Chambers et al., 2007). These findings are in line with Cycle 1, showing that students' discourse over ER activities includes a large volume of regulatory and self-control elements such as metacognitive monitoring and planning.

Last but not least, in agreement with the prior work (e.g., Korkmaz, 2018), the present study demonstrated a statistically significant increase in students' ability to solve logical-mathematical thinking problems (RQ2.3). It should be noted that our ER structured activities were not specifically aimed at improving students' abilities in mathematical problem-solving; instead, it was more about STEM and programming concepts. Therefore, students' improvement in solving mathematical problems may have emerged due to the development of metacognition through ER activities since metacognition is strongly related to problem-solving. It becomes evident that positive results in mathematical problem-solving can be documented via an interdisciplinary approach to ER activities in elementary education, capable of expanding the curricular space (Ioannou & Socratous, 2018).

7 Chapter 7: DBR Cycle 3

Results of this study are published in the proceedings of the International Conference of the Learning Sciences (ICLS 2020) (Socratous & Ioannou, 2020) in the Educational Technology Research and Development (ETRD) journal (Socratous & Ioannou, 2021) and in the TechTrends journal (Socratous & Ioannou, 2022).

Cycle 3 (see Figure 18) aimed to compare the effect of a structured versus an unstructured ER curriculum in CSCL setting by looking at (a) the frequency and type of programming errors made by students in block-based programming, (b) their ability to find and debug errors, and (c) their engagement in the learning process (RQ3.1). In addition, Cycle 3 aimed to compare the effect of a structured versus an unstructured ER curriculum on students' group metacognition taking into account students' collaboration quality and group cohesiveness during collaborative problem-solving with ER (RQ3.2). Furthermore, this cycle explored how the CSCL ecology shaped from a metacognitive perspective using a micro-ecological approach (RQ3.3).

Findings revealed a list of errors commonly made by both groups. The unstructured ER curriculum group was associated with a significantly higher frequency of errors. The structured ER curriculum group demonstrated significantly greater efficiency in debugging. Yet, the students in the unstructured ER curriculum group outperformed their peers in terms of engagement levels (RQ3.1). In addition, the results showed that students in the structured curriculum group demonstrated higher levels of group metacognition and better collaboration than students in the unstructured curriculum group (RQ3.2). Examining group interactions from a more ecological approach enabled us to recognize the critical role of individuals' students, technology, and the problems that emerge from their interactions in forming a collaborative ecology. The individual metacognitive contributions from students in the unstructured curriculum group had a systemic impact on the group work's progress (RQ3.3).

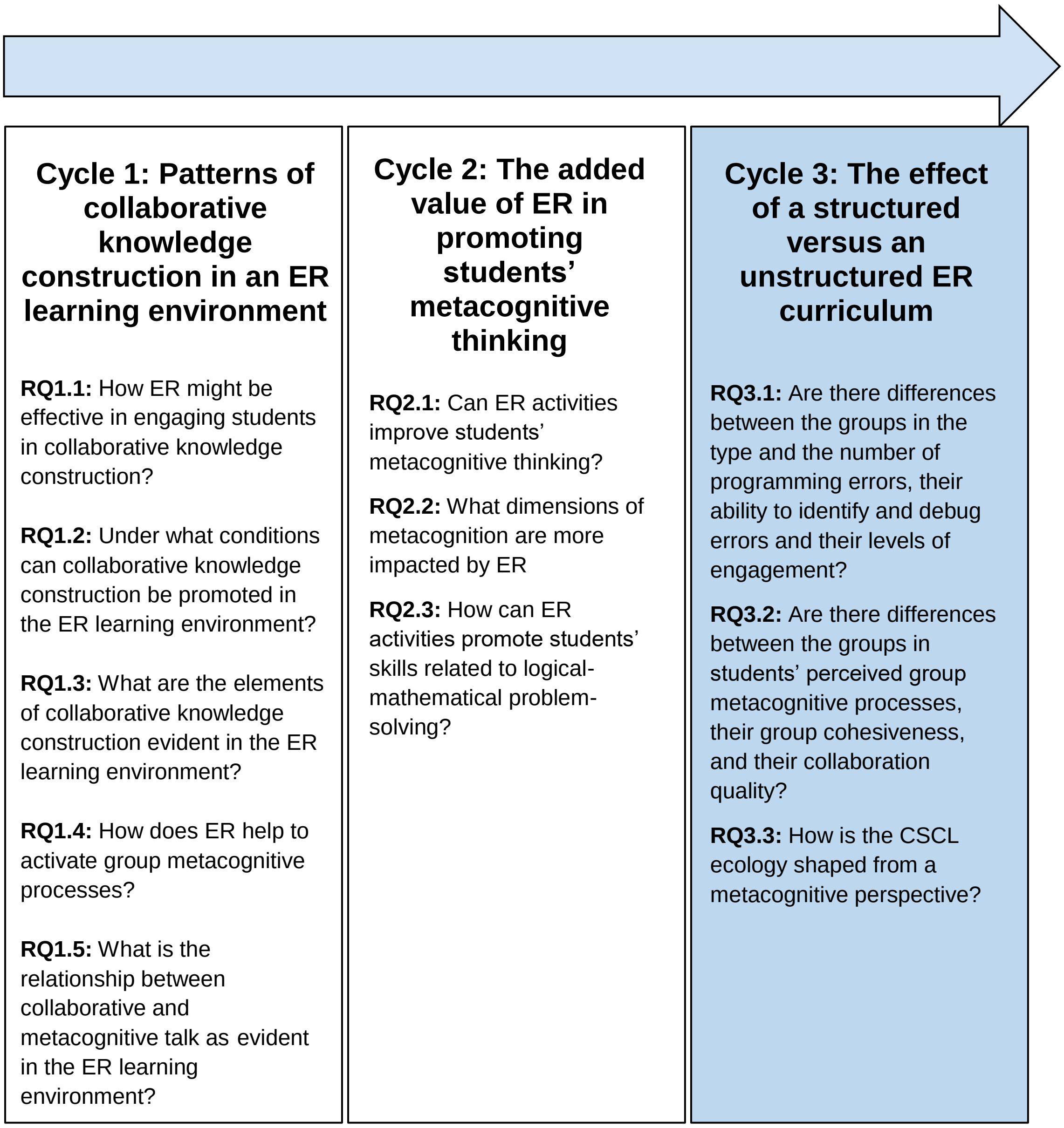


Figure 18: Research questions of Cycle 3

7.1 Introduction

ER has gained much attention as an innovative learning tool that allows students to develop higher-order thinking skills. ER may also support other important learning processes such as programming, which demands the planning of complex sequences of steps before the execution of the programme. During programming, students must set the goal, conceive the sequential steps required to accomplish that goal, programme actions, and check performance. These processes require various complex cognitive and metacognitive functions that are essential to students' cognitive development, including logical reasoning, decision-making, problem-solving, and sequential thinking (Di Lieto et al., 2017).

The Computer Science for All, highlights that young student require to learn to program (K12 Computer Science Framework Steering Committee, 2016). Still, limited knowledge exists about how to prepare primary school students for such learning. Learning the basic programming concepts and processes does not need mastering text-based programming languages but it is achievable using more friendly programming languages such as block-based programming. Block-based programming has been used successfully in primary education since robots became more popular. To be used more extensively, primary school students should gain the experiences, abilities, and confidence to engage more in this process.

An essential skill in computer programming is debugging or finding the error in code to get it to function. Most software applications in our days go through extensive stages of debugging. Therefore, for future programmers, understanding the process of debugging and improving their skills in this area is important. Debugging is difficult for novice programming students despite how they learn. They are expected to learn a new way of thinking in which various new skills are used simultaneously (Fitzgerald et al., 2008).

This challenges students to be more independent, purposeful in learning, and rely on their own effort. One way to support this, is to allow students to learn from their mistakes. Learning from failure has recently become a common idea in education because it appears like a natural sense to many people. In a general way, the idea of "picking yourself up after a fall" has long existed in many cultures worldwide. In Kapur's ideas about constructive failure, the failure is framed as part of learning, helping students activate knowledge and prepare them to learn (Kapur, 2014). However, this kind of learning should be supervised so that each programming error represents a meaningful role in the process of learning how to debug. These issues collectively need a careful design of the curriculum structure, which is efficient and effective. Different curriculum structures may affect students' programming errors or debugging skills differently. However, there will not be one completely suitable method, but we expect to establish good practice.

Therefore, although ER has great potential to assist in teaching, learning gains are not guaranteed with a simple application of robotics; there are several factors that can determine the outcome (Benitti, 2012). One such factor is the level of structure that educators adopt in their activities. To date, there is relatively little work focused on the level of structure that educators should adopt in their ER activities. Very little is known about the impact that different curriculum structures might have on student learning. In addition, using contrasting approaches, i.e., a structured curriculum design on one group, and an unstructured design on the other, could generate different outcomes. In short, here we propose the curriculum structure as an independent variable and examine its impact.

7.2 Methodology

7.2.1 Design and participants

This study follows a quasi-experimental design comparing two groups—one following a structured ER curriculum and the other, an unstructured ER curriculum. Within the quasi experiment, both qualitative and quantitative data were collected. Qualitative data were collected to demonstrate the most common programming errors, students' engagement level during the ER activities and their collaboration quality. Quantitative data were collected to identify differences in the common programming errors between the two groups (i.e., experimental conditions), students' ability to debug, their engagement with the learning process, their metacognitive processes and group cohesiveness. The study is part of a larger-scale research aiming to inform and encourage the use of ER in authentic learning environments.

The sample for this study was composed of 35 primary school students from two Year 3 classes (20 boys and 15 girls) who participated in classroom-based ER activities in a public school in Cyprus. The population of two intact classrooms formed the comparison groups: the structured curriculum group (16 3rd graders students: nine boys and seven girls, who were divided in four groups) and the unstructured curriculum group (19 Year 3 students, 11 boys and eight girls, who were divided in five groups). Three participants had prior experience with ER (two in the unstructured group and one in the structured group), while four were students with special educational needs and learning difficulties (two in each group). Prior to the educational intervention, the students' legal guardians provided consent forms providing the allowance for data collection.

7.2.2 Procedures

The research took place in two regular classrooms with desks arranged in groups to allow students to engage in collaborative work. Students were organised in mixed-gendered groups of 3-4 taking into consideration their abilities, as well as their varying emotional and social behaviour levels. Pencils, rubbers, rulers, a tablet, an EV3 robot and a blank paper were available for each group during the enactments of the unstructured curriculum, whereas in the structured curriculum the student groups had all the aforementioned aids, plus worksheets. The curriculums were implemented in the course of 10 sessions that took place over three months including two introductory sessions and eight sessions of problem-solving STEM activities.

7.2.2.1 The Learning Intervention

The introductory sessions consisted of preparatory activities to support student familiarisation with the EV3 robot. Essential programming rules were explained in a practical manner to both curriculum groups (directional commands, sensors, loop, wait for, and conditional logic). This deliberate design choice, which involved considerable top-down instruction, ensured that both groups had basic knowledge to cope with the problem-solving sessions that followed. The next eight problem-sessions were all grounded on the same content. Each session started with a five-minute introduction regarding the learning goals as well as a brief description of that lesson’s challenge.

The structured curriculum group - The structured curriculum group experienced an instructionist approach to teaching: the student groups were shown how to programme their robot based on pre-designed tasks and with the additional support of worksheets. The students’ groups first completed the worksheet activities with the teacher's help and then continued with the session's final challenge (see Table 14). The teacher's role was to provide information, ideas, and feedback as needed. Both the worksheets and the teacher's guidance facilitated the student groups in implementing ideas that were related to the final challenge. This also served as preparatory work for the session’s challenge.

Table 14: The organization of a structured curriculum session

Phase	Duration	Activity
Introductory	5 min	Distributing materials Introduction to the learning goals and the purpose of the session
Training	35 min	Preparatory work for the session' challenge
Challenge	40 min	Session's final challenge

The unstructured curriculum group - The unstructured curriculum group did not follow any structured activities but instead could investigate ideas linked to the given challenge. In each session, the teacher merely reminded the student groups that they could use existing robotics material by Lego Education (i.e., videos and programming examples). The student groups did not use any worksheets and did not participate in any preparatory activities for the session's final challenge (see Table 15 and 16). The role of the teacher was to facilitate and scaffold the student groups' thinking with hints, prompts, and feedback without providing any information or answers.

Table 15: The organization of an unstructured curriculum session

Phase	Duration	Activity
Introductory	5 min	Distributing materials Introduction to the learning goals and the purpose of the session
Challenge	60 min	Session's challenge
Instruction	15min	Consolidation phase

Table 16: Conditions of the study

	Group 1:Structured curriculum	**Group 2: Unstructured curriculum**
Introduction (same activities for both groups)	Two sessions of Introductory activities	Two sessions of Introductory activities
	Instruction + Problem-solving	Problem-solving + Instruction (Consolidation phase)
Eight sessions of STEM problem-solving activities (grounded on the same content for the two groups)	Student groups were shown how to programme their robot based on pre-designed tasks and with the additional support of worksheets (Instruction). Then the student groups continued with the session's final challenge (Problem-solving).	Investigate ideas linked to the given challenge (Problem-solving). The groups share and compare the effectiveness of their solutions or methods. The teacher then focused on students' solutions and shared the canonical solutions to the problem (Consolidation phase).
Teacher's role	Provide information, ideas, and feedback and scaffold with hints and prompts during the Instruction and the Problem-solving phase.	Scaffold the students with hints, prompts, and feedback without providing any information or answers during the Problem-solving and the consolidation phase.

7.2.2.2 The Problem-solving STEM Activities

Following the two preparatory sessions, the next eight sessions were problem-solving STEM activities. The activities were grounded on the same content but taught differently, as described earlier.

In session 3, the goal for the student groups was to programme a robot to move accurately over a certain distance using variables such as rotations, degrees, and seconds. The worksheet for the structured curriculum instructed the student groups to complete a table by taking measurements of various values (guided experimentation). Once they had completed the worksheet, the student groups could proceed to the challenge.

In session 4 of the structured curriculum, the worksheet helped the student groups to practice different turns and understand how the turning variable is related to distance. The student groups had to execute several programmes associated with turns and explore the output of their applications. The session's goal was to programme the robot to move on a square without using a gyro sensor.

In session 5, the student groups were further exposed to activities related to turns. The worksheet was a combination of the two previous worksheets about distance and turns while introducing new concepts such as spin, pivot, and smooth turns. The goal of the challenge for the student groups was to programme the robot to move on a path with different kinds of turns to arrive at the final destination.

In session 6, the student groups were tasked to build and fix the cargo delivery attachment on their robots. The cargo delivery attachment then had to be controlled via the medium motor to move objects. The worksheet for the structured curriculum group had two sub-tasks of increasing difficulty. They had to programme the robot to move a block that was located directly across from the starting position and then, they had to move a block that had been placed randomly on the mat.

During session 7, the student groups investigated the color sensor's use and the concepts of loops and wait/until. The structured curriculum worksheet asked the student groups to place the colour sensor close to several objects and observe the reading value through the programming interface. The goal was to programme a robot to move on the mat that featured lines of red and black: “When the robot detects a red line, it stops for one second and says red, then continues until it detects a black line, stops and says black, then goes back and forth until it detects the black line ten times”.

In session 8, the student groups were further exposed to activities related to the concepts of loops and wait/until. This session’s challenge was to programme an autonomous robot that could move along a desk without falling off for one minute.

In session 9, the student groups were expected to programme the robot to move and stop before reaching an object. The worksheet for the structured curriculum group asked the student groups to place the robot across from several objects and measure the distance using the ultrasonic sensor. The session’s challenge was to programme a robot that could move around the classroom without hitting any objects.

Finally, in session 10, the student groups used the worksheets to explore the concept of conditional logic. They were asked to programme the robot to say "red" when the colour sensor detected the colour red and "not red" when the colour sensor detected another colour. This activity was designed to help students to respond to the last task and complete the line following challenge (see Figure 19 and Table 17).

Table 17: ER activities DBR Cycle 2

Sessions	**Trained computational concepts**	**Tasks**
Session 1 Introductory	Introduction to programming Simple sequences	a) Introduction to the learning objectives. b) How to launch the software, write and save a programme, connect the tablet to the brick, run a programme. c) How to control the EV3 Motors (start programming motors), becoming familiar with basic commands.
Session 2 Introductory	Introduction to programming Simple and advanced sequences	Introduction to basic computational thinking concepts, such as loops and conditionals. Using EV3 Sensors (start programming sensors); ultrasonic sensor, touch sensor, and colour sensor.
Session 3	Simple sequences	Programme your robot to move forward by exactly 1.50m using (a) rotations, (b) degrees, and (c) seconds.
Session 4	Simple sequences	Programme your robot to move on a square without a gyro sensor.
Session 5	Simple sequences	Programme your robot to move on a path with turns to arrive at the final destination.
Session 6	If-then conditionals If-then-else conditionals While conditionals	Programme your robot to move on a path with turns and collect a Lego block on its way using the medium motor (cargo attachment).
Session 7	If-then conditionals If-then-else conditionals While conditionals	Programme your robot to move on a mat with red and black lines. When it sees a red line, it stops for 1 second and says "red," then continues until it finds a black line. Then, it stops at the black line and says "black," then goes back and forth until it finds the black line 10 times.
Session 8	If-then conditionals If-then-else conditionals While conditionals	Programme an autonomous robot that can move on your desk without falling off for one minute.
Session 9	If-then conditionals If-then-else conditionals While conditionals	Programme a robot that can move around the classroom without hitting any objects. Then make several changes to improve your programme (i.e., add a sound when an object is detected, or display something on the screen).
Session 10	If-then conditionals	Programme a robot that can follow the black line.

	If-then-else conditionals While conditionals	

Figure 19: Activities and video-recorded tablet screen used for programming

7.2.3 Instrumentation, data collection and analysis

The data collection included classroom recordings, tablet screens, and audio recordings, a post-debugging test, a post-engagement survey, focus group interviews, a pre-post Group metacognitive questionnaire, a rubric regarding students' collaboration quality, and a group cohesiveness survey. Tablet screens and dialogue by the teams were recorded using Mobizen Screen Recorder.

Screen-recorded and audio data - We used open coding for the screen-recorded and audio data. We narrowed the investigation to errors linked with programming; We did not code videos related to the assembly. Almost 40% of the video was coded by the first researcher, with a second researcher independently coding the same units. Inter-rater reliability between the two raters was high (Cohen's Kappa = .88). Hence, the first researcher finished coding the complete dataset. To analyze the frequency of errors between the two groups, the average number of errors per session were computed. The data were then analyzed using independent samples t-test to investigate any differences between the two groups on the total number of errors.

Debugging test- After the learning activities, the students were given a debugging test - developed based on categories of common programming errors - that put forward ten tasks. The test presented the students with a scenario in which they had to find the error; they were told the program's purpose and were provided a screenshot of the EV3 programming interface. Students had to circle the error block(s) and write down how they would fix it. Each task was scored out of ten marks (five marks for finding the error and five for a correct proposal to overcome the error). The maximum possible score for the test was 100. Two raters evaluated the debugging tests of the 35 students in both conditions assigning scores for each student independently. Then by averaging the students' scores for each condition, an overall mean score was produced. Interrater reliability was estimated, and 88.6% of the agreement was established.

Engagement survey - A post-experience survey aimed at evaluating student engagement was also administered. Student engagement was measured using a 5-point Likert scale, with 33 items derived from the Math and Science Engagement Scales (Wang et al., 2016). Since the instrument measures student engagement in math and science, the items were adjusted by substituting the word "math/science" with "STEM." The scale was developed taking into account a multidimensional viewpoint of engagement and is comprised of four subscales: (a) cognitive engagement (e.g., I try to understand my mistake when I get something wrong), (b) behavioral engagement (e.g., I keep trying even if something is hard), (c) emotional engagement (e.g., I enjoy learning new things about STEM), and (d) social engagement (e.g., I try to understand other people's ideas in STEM class). The participants were Greek speakers; therefore, we used a translated version of the scale. To determine the content validity of the translated version, we calculated Cronbach's alpha, receiving a value of 0.81, which shows that the translated version's internal consistency is reliable. The un-weighted mean scores for scales and subscale were calculated to analyze the data derived from the engagement survey. Then, independent samples t-test was used to examine any difference between the two conditions.

Focus group interviews- After the learning experience, 16 students participated in semi-structured focus group interviews. The interviews were organized into two sessions. The first session looked to enhance our understanding of students' common errors during programming, while the second session aimed to provide additional evidence for student engagement. 40% of the screen-recorded data was used to identify the common programming errors first. Then we designed the first session of the focus groups based on the common errors derived from the previous analysis. The interviews included questions that prompted students to remember errors that they encountered and how they managed to overcome these errors (e.g., What difficulties did you face during programming? How did you overcome the difficulties?). The second session was aimed at providing additional evidence for student engagement (e.g., Do you think ER activities were useful to you? [Cognitive engagement]. How did you feel while you were working on ER activities in class? [Emotional engagement]). The focus group data were video-recorded and transcribed for analysis using a thematic approach. The data analysis was conducted by two researchers working separately. At the completion of the coding, the inter-rater reliability was assessed to 0.736 (Cohen's Kappa).

Group metacognition - We used the Group Metacognition Scale (GMS) (Biasutti & Frate, 2018) as a pre- and post-assessment to analyse the development of student' groups metacognitive skills. The participants were asked to rate themselves on a 5-point Likert-type. Students answered the GMS with the teacher's guidance; the teacher read the statements one by one to the class and ensured that all the students had responded before moving on to the next statement.

Collaboration quality - Video data from sessions 9 and 10 were used as sampling to assess the quality of collaboration in each student group. Two raters observed the collaboration process in the nine groups in both conditions using a Collaboration Quality Rubric and assigning scores for each student group independently. The unit of analysis was the group level; therefore, an overall score for each student group was obtained by averaging the scores given by the raters for each session. Then, by averaging the student group scores for each condition, an overall mean score for each condition was produced. Interrater reliability was computed between the two raters, and 82% of agreement was established. The Collaboration Quality Rubric was adopted from Menekse et al. (2017), who developed this rubric for assessing the collaboration quality in groups in robotics competitions.

Group cohesiveness - A post-interventional survey aiming at evaluating group cohesiveness was administered right after the intervention for both groups. Group cohesiveness was measured using an individual 5-point Likert scale questionnaire with eight items based on Gillies' (2003) study on small cooperative groups. Cronbach's alpha reliability was calculated for the Group Cohesiveness Scale, indicating a good consistency (0.81 Cronbach's alpha). Studies have shown that cohesiveness is essential for the performance of a group; the more cohesive a group is, the better it performs (Brannick & Prince, 1997).

Use of an ecological approach - According to Alibali and Nathan (2010), our current research practices hinder our ability to provide a more holistic understanding of learning processes. Taking this into account, Borge, and Mercier (2019) argue that the way we use theories might be preventing us from a deeper understanding of CSCL. In their paper, they discuss the need for a more ecological approach drawing on the challenges posed by common theories to present a holistic view of the full complexity of collaborative activities. They reveal how these theories prioritise a mono ecological approach in which the emphasis is on a single level of an ecological system. Therefore, they suggest a micro-ecological framework that recognizes collaborative learning as a complex and cognitively nested ecological phenomenon to address this problem. They propose a microanalysis of students' interactions at the individual level, small groups, classroom community, and learning objects with the purpose to identify critical points where actions at one level of cognitive activity influence other levels of individual and joint activity. In this study, we acknowledge the existence of these systems. We acknowledge that cognition is an ecological phenomenon. Therefore, as proposed by Borge and Mercier (2019), we use a micro-ecological approach to understand how the CSCL ecology is shaped from a metacognitive perspective. We also use this approach to capture metacognitive behaviour that cannot be captured using a self-report instrument.

7.3 Findings

7.3.1 Finding 1: Common programming errors (bugs) (RQ3.1)

Six typical errors made by students when programming were observed (see Table 18). First, they often failed to define the correct values for a variable, such as the accurate distance to move forward. Second, they made errors in choosing the correct block or sequence of blocks. At times, they omitted the blocks required for the robot to operate as planned. Robots could not function as expected due to omitting commands such as loop, move block, or turning block. Third, students chose unsuitable block variables. They would pick the correct block and then make errors in selecting which variable of the block they should use. Choosing the wrong variables often led to errors until students realized the difference between the variables within a block. For instance, students tried to define the distance the robot should move but tried to do so by changing the motor power variable or the turning variable, causing an error in the program. Fourth, they attempted to match up motors and sensors with the incorrect ports. For example, the right motor should have been attached to port A on the robot, but instead, they chose motor C. The same happened with sensors; for example, the students should have connected the ultrasonic sensor to port 4, but instead, they chose port 3. Fifth, students defined conditionals improperly. They had difficulty in understanding conditional logic such as if/then or wait until, resulting in several bugs in their programs. Last, students did not understand when a program failed due to factors other than an error. They looked for errors when the error was actually in the robot's assembly or its positioning on the mat. They did not realize that the robot's accurate positioning on the mat was a variable affecting their program's accuracy.

Table 18: Common programming errors

Common errors	Description	Example
1. Error in defining value in block variables	Not accurate or wrong calculation of the value of a variable	Wrong calculation of the distance variable
2. Error in selecting the correct sequence of blocks	Selecting an inappropriate block or omitting a command	Omitting a turn command
3. Error in selecting the appropriate block variable	Selecting a different variable in the same block	Instead of distance in rotations, choosing engine power
4. Error in matching a motor or a sensor to the port	Connecting the motors or the sensors with wrong ports	The program required connection to port A, but the motor was connected to port C
5. Error in defining conditions	Struggling to understand conditional logic	Struggling to debug an error related to conditionals

6. Error in recognizing external factors as the cause of a program failure	Not recognizing a program free of errors	Looking for an error when the problem was in the assembly

7.3.2 Finding 2: Differences in the common programming errors between the groups (RQ3.1)

The most common errors for both groups fell under category 1 (error in defining the value of a variable). Both groups produced a significant number of errors trying to define a value in a block's variables (see Table 19). Concerning the frequency of each type of error, we observed that in the structured curriculum group, the errors that had to do with knowledge about the programming interface, such as category 2 and 3, were fewer than those made by the unstructured curriculum group (41.66 % versus 31.70%). We also noticed that category 2 and 3 errors in the later sessions became less frequent for both groups, as students became more familiar with the programming interface. Furthermore, looking at the significant amount of category 5, the students from both groups struggled to define and understand conditional logic, such as if/then and wait until commands.

Table 19: Common programming errors by group

Common errors	Structured group		Unstructured group	
	N of errors	%	N of errors	%
1. Error in defining value in variables of a block.	10	24,40%	24	33,33%
2. Error in selecting the correct block or the exact sequence of blocks.	7	17,07%	16	22,22%
3. Error in selecting the appropriate variable of a block needed for the robot to operate as intended.	6	14,63%	14	19,44%
4. Error in matching a motor or a sensor to the correct port.	6	14,63%	5	6,95%
5. Error in defining conditions.	8	19,51%	11	15,28%
6. Error in recognising external factors as cause of programme failure	4	9,76%	2	2,78%
Total	41	100%	72	100%

A big variation in the frequency of errors between the two groups was also observed. Students in the unstructured curriculum group generated more bugs (72) than the structured group (41). We first applied normality (Shapiro-Wilks), and variance (Levene) controls on the data. The results showed statistical non-significance, suggesting that the data come from normal distributions and populations with the same variance, therefore being suitable for parametric test analysis. The average number of errors per session was computed in order to examine the differences between the groups. The unstructured group showed a higher mean number of errors per session (see Table 20). Then, an independent sample t-test was conducted to compare mean error scores between the groups. The results revealed that the unstructured curriculum group ($M = 9$, $SD = 2.12$) had a statistically significant higher mean number of errors than the structured group ($M = 5.13$, $SD = 1.90$); $t(14) = 3.60$, $p = 0.003$. These results suggest that a structured curriculum results in students producing fewer programming errors than a constructionist one.

Table 20: Descriptive statistics of errors by group

Group	Number of errors	Mean	SD
Structured	41	5.13	2.03
Unstructured	72	9	2.27

7.3.3 Finding 3: Debugging skills (RQ3.1)

The assumptions for parametric test analysis were also met in the case of the debugging test. Therefore, an independent samples t-test showed that students in the structured curriculum group outperformed their counterparts in the unstructured group (see Table 21), in terms of finding ($t(33) = 2.17$, $p<0.01$) and debugging ($t(33) = 3.58$, $p<0.01$) errors in a program. These outcomes suggest that a more structured learning environment may be more effective in promoting students' ability to find and debug programming errors.

Table 21: Student debugging test scores by group

	Structured group		Unstructured group		t
	Mean	SD	Mean	SD	
Post-debugging test scores	72.8	9.91	60.63	11.07	3.26**
Found the error	39.73	6.17	32.18	5.85	2.17**
Proposed a solution (Debugging)	33.16	4.65	28.45	6.30	3.58*

Note. *p<.05, **p<.01

7.3.4 Finding 4: Student engagement (RQ3.1)

The engagement survey data showed that both groups appreciated and enjoyed the ER learning experience with mean scores well above the midpoint (see Table 22). In the case of the engagement survey, the sample violated the normality criterion. Therefore, the non-parametric Mann-Whitney U test was applied. Results showed that the unstructured curriculum group (M=3.91, SD=0.38) exceeded their counterparts in the structured curriculum (M=3.65, SD=0.33) in terms of emotional engagement; this difference was statistically significant (*U* (33) =54.5, z=-2.46, *p*<.05). Students from the unstructured group (M=4.02, SD=0.44) also had a statistically significant higher mean score on the dimension of social engagement than the unstructured group (M=3.45, SD= 0.37); *U* (33) =58.2 z=-3.27, *p*<.05. There were no significant differences in cognitive and behavioral engagement between the two groups.

The additional evidence provided by the focus groups was consistent with the quantitative data, demonstrating a positive level of student engagement. Students showed their cognitive engagement by describing the exchange of ideas and explanations in their groups. For example, one student noted: "*It was a nice activity. We were required to discuss and explain our ideas to group members. Then we agreed on a plan, and then we had to apply it*" (Unstructured group, Participant 5). The same theme, indicating cognitive engagement, was documented in this statement: "*At the beginning of the sessions, we had help from the worksheets or the teacher, but in the final challenges, we were alone. We had to apply what we had practiced earlier. It wasn't so* *easy because it was a different challenge, so we had to think of what we needed to do and how we could do it*" (Structured group, Participant 1).

Table 22: Comparison of engagement between the two groups

	Structured group		Unstructured group		**Z**
	Mean	SD	Mean	SD	
Cognitive engagement	3.74	0.41	3.66	0.57	0.25
Behavioural engagement	3.82	0.38	3.76	0.38	0.23
Emotional engagement	3.65	0.33	3.91	0.38	-2.46*
Social engagement	3.45	0.37	4.02	0.44	-3.27**

Note. *p<.05, **p<.01

Students showed a high level of behavioural engagement, reporting that they fully participated in the experience without losing focus and highlighted that this was something that they had never done before. One participant noted: *"I was really focused on what I was doing throughout; I wasn't distracted by other things or thinking about other things" (Structured group, Participant 2).*

Participants demonstrated emotional engagement by expressing happiness and interest. For instance, one participant noted. "We were so pleased! When you see the robot complete the activity the way you wanted it to, you feel happy" (Unstructured group, Participant 3). Another student said: "It was exciting, and I loved the robots. I asked my mother to buy one to practice at home" (Unstructured group, Participant 2).

It was observed that one reason that the structured group did not feel as emotionally engaged was their inability to choose the way they could work during the first phase of each session. As one child said: "*the first part of the lessons was boring; we had to follow instructions. The second part was better; we could do what we wanted to address the challenge."* The second source of emotional disengagement was observed in both groups, who expressed anger and frustration at dealing with programming errors. For example, one participant noted: "*Sometimes we were frustrated when we came up against obstacle after obstacle. We would find an error in our programme, solve it, and carry on. Then, something else, another error, the robot was not moving as we had planned."*

Students in the structured group did not report any cases of collaboration or working with others, which would allow for social engagement, except one statement which described a failure of members to work as a group, as they fought over who would be the programmer. Students in the unstructured group, on the other hand, frequently referred to social engagement. Two notable sources of students' positive social engagement were identified. The first was good teamwork, and the second, the respect and acceptance of the ideas and contributions among group members. For example, one participant noted: "*I felt comfortable with my team. We worked very well together, and we knew our responsibilities. When there was a problem, we tried to figure it out by expressing our ideas.*"

These qualitative results are consistent with the quantitative results of the survey, which demonstrated a higher level of social and emotional engagement for students in the unstructured group. One would expect that since the unstructured curriculum group had produced more bugs, it would also have a lower level of social and emotional engagement. However, this didn't happen; in fact, those errors may have had a positive effect on the students' efforts to cope with the challenge, promoting emotional engagement and social interaction.

7.3.5 Finding 5: Group metacognition (RQ3.2)

First, un-weighted mean scores were calculated for scales and subscale. Then, scale's internal consistency was investigated. Cronbach's Alpha for each of the four dimensions of the scale was .74, .82, .77, and .76, respectively, and the scale's overall value was .85. Table 23 shows the descriptive statistics for the two conditions pre-post GMS test scores.

A Mann-Whitney U test was used to identify any potential differences between the two conditions in students' pre-test scores, taking into account the small sample and the not-normal distribution of the data. The results showed that there were no statistical differences in pre-test scores ($z = -0.515$, $p = 0.607$), indicating that students had not difference in their perceived group metacognition before the intervention (Table 23). A comparison of students' scores in the structured curriculum condition, before and after the intervention, using the Wilcoxon signed-rank test statistical analysis, indicated that students in the structured curriculum condition improved their scores from pre to post testing; this difference was statistically significant (z = -3.367, p < 0.001). The same test for the unstructured curriculum condition showed that students did not improve their scores from pre- to post-testing to a statistically significant degree (z=-1.31, p>0.001 p=0.19). To further examine the comparison of the differences between the post-test and pre-test scores in each condition, normalized learning gains were computed i.e., (Post-test scores – Pre-test scores)/ (100% – Pre-test scores). Differences in students' normalized gains between the two conditions were examined using the Mann–Whitney U test. Results (Table 23) showed that there were statistically significant differences between the students' normalized gains in the two conditions (z = -3.56, p < 0.001).

Table 23: Pre-test scores, post-test scores and normalized gains on group metacognition

	Condition 1 Structured curriculum		**Condition 2 Unstructured curriculum**		Z
	Mean	SD	Mean	SD	
Pre-test scores	3.23	.68	3.29	.79	-0.515
Post-test scores	3.71	.74	3.37	.74	-3.735**
Normalized gains	0,27	.15	0,05	.21	-3.560**

Note. * p < 0.05, ** p < 0.01.

7.3.6 Finding 6: Collaboration quality (RQ3.2)

A Mann–Whitney U test was used to identify differences between the conditions in terms of collaboration quality. The results (Table 24) showed that students in the structured curriculum condition demonstrated higher levels of collaboration quality than the students from the unstructured curriculum condition; this difference was statistically significant (z = -2.484, p < 0.001).

Table 24: Comparison of Collaboration Quality between the two conditions

	Condition 1 Structured curriculum		**Condition 2 Unstructured curriculum**		Z
	Mean	SD	Mean	SD	
Collaboration quality	1.70	0.60	1.37	0.62	-2.48*

Note. * p < 0.05, ** p < 0.01.

7.3.7 Finding 7: Group cohesiveness (RQ3.2)

A Mann–Whitney U test was also administered to examine potential differences between the groups regarding cohesiveness. While the perceived group cohesiveness was slightly higher for the students who participated in the structured curriculum condition, (Table 25) there was no significant difference between the two conditions ($z = -0.766$, $p > 0.001$, $p = 0.444$).

Table 25: Comparison of Group Cohesiveness between the two conditions

	Condition 1 Structured curriculum		**Condition 2 Unstructured curriculum**		Z
	Mean	SD	Mean	SD	
Group cohesiveness	3.79	0.52	3.69	0.46	0.766

Note. * $p < 0.05$, ** $p < 0.01$.

7.3.8 Finding 8: A micro-ecological approach (RQ3.3)

To understand how the CSCL ecology is shaped from a metacognitive perspective, we looked at a student group within the unstructured curriculum condition in the course of session 4, using the micro-ecological approach proposed by Borge and Mercier (2019). Figure 22 presents a description of the narrative events that emerged at the three levels of cognition (community, group, and individual). In this diagram, the event's time appears on the horizontal axis, while the three levels of cognition are listed on the vertical axis. For instance, at timepoint C12 (Community level at 12th minute), F (Facilitator) shows the Whole Class (WC) how to connect the Robot (R). The episode here focuses on metacognitive events that took place in Student Group 5.

The goal of the challenge of this session was to programme the robot to move on a square without a gyro sensor. In Figure 22, we can see the facilitator (F) at timepoint C1 introduce the learning goals and give a brief description of the challenge. Since this was only the second time that the groups tried to connect the robot to the tablet on their own, we were unsurprised at the inability of two groups to do so, at timepoint G6 and G11. Group 5 asked for help (G6). The Facilitator checked and solved the problem (G9).

Then, Group 7 has the same issue (G11) and Student A from Group 5 helped them to overcome the problem (G12). As two of the groups faced the same problem, the facilitator (F) thought it best to act at the community level and explain to the whole class (WC) how to connect the Robot (timepoint C13). At timepoint G14, the groups were all ready to use the materials and proceed with the challenge.

While the facilitator (F) started to walk around observing the student groups (I15), Group 5 started discussing the purpose of the challenge and forming a plan. All group members contributed to this discussion. First, student D (timepoint I15) summarised the purpose of the task and then contributed a key idea (planning). The idea was to programme the robot so that it repeated an action four times: to "move forward and then turn 90 degrees to the left". He added that they should find the correct value to turn exactly 90 degrees. He went on to suggest finding the value of the turning variable first. Student L (timepoint I16) added a metacognitive judgment about the difficulty of the activity (evaluating), pointing out that "*this is an easy activity, and we could finish up fast*". M, although at first seeming to agree with D, suggested that they should programme the two repeating blocks first and then try to find the required value to turn exactly 90 degrees (timepoint I17). D then supported his idea, stressing that it would be easier for them to control one block instead of eight (I18). Later, student C expressed a sense of knowing how to create the programme (knowledge of cognition) and put himself forward to be the group programmer (timepoint I21).

It seems that the individual level is the basis for what happens on a group level, as indicated by these episodes. For example, if D had not made that contribution, then subsequent events would be different at the group level. These individual contributions led to events at a group level. At timepoints G21, G22, and G26, respectively, Group 5 determined the project requirements, decided on the planning and the roles within the group. G21 and G22 were therefore events that occurred due to D's contributions, while the G26 occurred due to C's contribution, again at an individual level.

The Facilitator (timepoint C35) pointed out at a community level the importance of observing the robot's movements to identify and correct errors. At timepoint G37, the group produced a code and tested it on the mat. The result was poor, as they didn't calculate the turning variable accurately. Then, student D (timepoint I40), considering the Facilitator's prior advice, while observing the movement of the robot, suggested some changes to the code in order to have more accuracy (monitoring). He noted that the robot was turning more than 90 degrees, making each turn more inaccurate. He suggested reducing the turning variable (monitoring in terms of detecting and correcting errors). This individual metacognitive monitoring contribution affected the decision of the group (timepoint G42) as the other group members did not disagree and did not ask for further explanations, expressing generic responses of agreement instead.

Next, Group 5 rotated the roles within the group (G51). At the group level, the new programmer (D) asked the previous student who had held that position (C) some details related to the turning variable (G53); the group proceeded to make some changes to the last version of the code and produced a new one for testing (G61). The execution was quite accurate, and so Group 5 was able to present the execution on a community level (C65).

This micro-ecological analysis makes evident the role that individual students played in promoting metacognition from an individual level to the group level. It gives us a multifaceted dimension of what was happening in the classroom and facilitates an understanding of the progressive interactions on the three different levels from a metacognitive perspective.

7.3.9 Finding 9: Emerging themes

Consistent with Cycle 1 embodiment was an essential part of children's interactions across the sessions. We identified two emerging themes from the observations: (i) embodied explanation/reasoning and (ii) embodied expression of knowledge.

7.3.9.1 Embodied explanation/reasoning

This theme explored examples where students used their bodies when they explained or represented processes in support of communicative and interactional goals. When responding to the robot's actions, students often developed their explanations in an elaborate manner. This elaboration often involved more than one idea and was typically accompanied by visible physical actions. In addition, this elaboration regarding the observed outcomes of an execution of the program, served as a communication channel among group members. Figure 20 shows a sequence of actions that accompanies such elaboration. For example, the girl in Figure 20 shows an embodied representation of the robot’s action. She elaborated on that the robot should have turned more, with a steeper turn. The other girl agreed and suggested to program the left wheel to move faster than the right so that it turns more sharply. Therefore, the embodied explanation here had a dual role. The representation and explanation of the robot’s moves and a social act, the communication of the results with teammates.

Figure 20: Embodied representation of the robot's moves

7.3.9.2 Embodied expression of knowledge

This theme encompasses instances when children engaged their body simultaneously with thinking and talking about mathematical knowledge. For example, the student in Figure 21 embodied her explanations of mathematical properties using her feet as a unit for measuring the length. The girl expressed her knowledge on mathematical measurement showing that the length can be measured using standard units such as centimeters or meters or by non-standard units like a handspan, foot span, etc. In addition, the creation of powerful expertise is obvious here. The student seems to have realised, through her experience, by engaging in such activities, that approximately one rotation of the robot wheels covers the same distance as the length of her foot. Furthermore, in Figure 21(right) for example, the boy tries to explain to his teammates the idea of a loop. He used his fingers to explain the idea, making a circle with his fingers in order to describe the repetition of a sequence of instructions. The boy here tried to explain the powerful idea of loop using his own mental model regarding the idea.

Figure 21: Embodied expression of knowledge

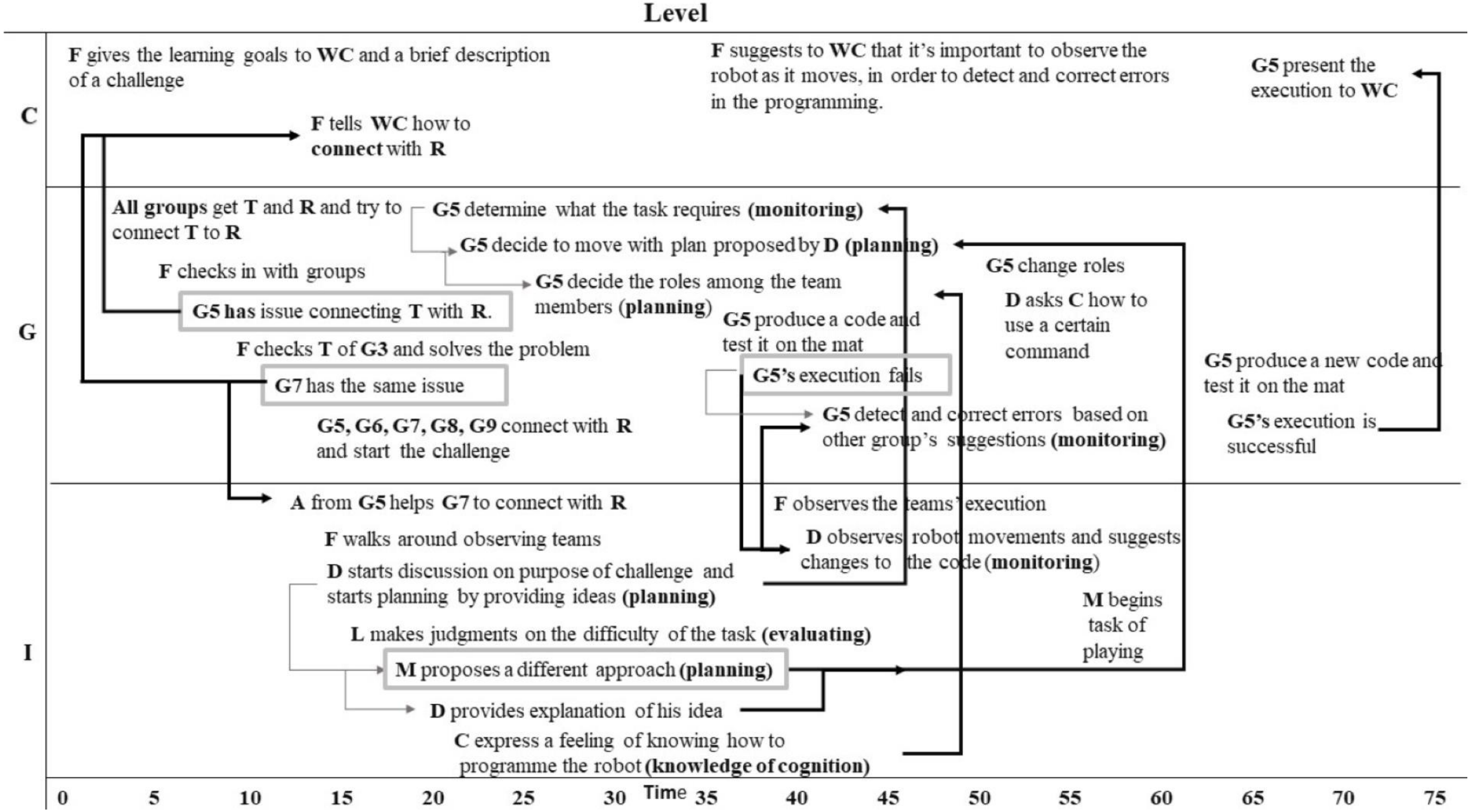


Figure 22: Diagram of the events at the three levels of cognition: community (C), group (G), and individual (I)

7.4 Discussion

This study posits that a critical factor for successfully integrating robotics in education is the curriculum structure. The role of the curriculum structure for successful technology integration remains relatively unexplored in ER. To our knowledge, this is the first time that a study examines this topic, as prior studies focused on the level of guidance in a constructionist learning environment (e.g., Atmatzidou et al., 2018) or compared the social aspects of learning, such as collaboration and social interaction (e.g., Lee et al., 2013).

First, to answer RQ3.1, the common programming errors made during block-based programming were documented. The list can be used by educators and researchers in teaching students how to debug programming errors. It might be useful for primary students to be provided with such a list in the introductory sessions of ER projects in order to generate a hypothesis for debugging and help them learn how to debug. From a constructionist point of view, however, that would not be appropriate; it would be better to let students make the error, recognize it on their own, and come up with inventive ways to solve it, allowing them to engage in an active process of knowledge construction. According to the results of this study, a structured curriculum is needed for students in this age group to be able to come up with inventive solutions to their bugs. Four of the six common errors (i.e., categories 1, 3, 4, 6) were similar to those found in a study with early childhood pre-service teachers conducted by Kim et al. (2018). It seems that the types of errors that novice learners produce in a block-based programming environment tend to be similar, regardless of age.

Subsequent analysis of student errors showed a significant difference in the frequency of errors between the two groups. Students who participated in the unstructured curriculum class made errors far more frequently than students who participated in the structured curriculum class. These results demonstrate the superiority of the instructionist approach as it is more effective in teaching essential aspects of the programming interface and familiarising students with the programming environment's functions. It makes sense; if you are allowed to explore on your own, you will make more errors. The procedure of solving an error (debugging) is considered as a problem-solving situation that students should experience and resolve productively. On the other hand, if students are exposed to too frequent programming errors, this might become a source of frustration that negatively impacts their engagement.

The debugging test results indicated that the structured curriculum condition outperformed the unstructured condition to a statistically significant degree in terms of finding and debugging an error. It can be assumed that the direct instruction (the teacher taking a more instructive role and using worksheets) gave the structured group an advantage in terms of debugging. As the unstructured group students were exposed to more frequent programming errors (higher number of errors), one would perhaps expect them to have become more adept at debugging the errors and therefore score better in the debugging test. This did not turn out to be the case. Repeated errors by the unstructured group did not lead to better debugging. The structured curriculum students were stronger debuggers; notably, though, this was because they had stronger content knowledge, as a result of the direct instruction, and not because they were more skilled at debugging. In summary, the results suggest that students could benefit more from a structured curriculum in order to become better debuggers.

When focusing on engagement, students who participated in the unstructured curriculum group reported statistically significant higher levels of emotional and social engagement than the students in the structured group. This finding is aligned with prior research efforts (albeit not in the ER area), indicating that students who participate in student-centered environments might experience higher levels of emotional engagement compared to those having had teacher-centered approaches (e.g., Wu & Huang, 2007). The higher frequency of errors made by the unstructured curriculum group should have harmed the students' emotional engagement. On the contrary, it seems that their freedom to experiment and explore trumped the frustration caused by the high frequency of errors. Another suggestion is that students saw the errors as a challenge, which positively affected their emotional engagement.

Regarding the higher levels of social engagement in the unstructured curriculum group than the structured curriculum group, this finding is consistent with that of Sullivan and Bers (2013). They showed that using an unstructured ER curriculum was linked to more collaboration than a structured curriculum. Therefore, the unstructured group produced a greater amount of social interaction, which was reflected in their social engagement level. That said, the higher level of social engagement seems not to have had an impact on the students' learning achievement, as it became evident from the debugging test scores and the overall frequency of programming errors made by the two groups.

In consistent with previous empirical studies, this study provided evidence supporting the positive effect of ER activities on students' group metacognitive processes. Going a step further, this study provides empirical substantiation that students who participated in the structured condition were more highly involved in group metacognitive processes than the unstructured condition. This finding extends previous studies' results (e.g., Atmatzidou et al., 2018) by moving from individual metacognition to group metacognition, thus addressing the role of regulated social behaviour during collaborative activities. We posit that the focus on individual regulation of learning is insufficient for understanding learning that takes place in social contexts and, in particular, in CSCL environments. In addition, the study of Atmatzidou et al. (2018) investigated the development of metacognition in the context of ER activities, implementing different modes of metacognitive guidance in the comparison groups. In this study, we demonstrated that metacognitive support could be introduced through the level of structure of the curriculum. According to the results of this study it seems possible to provide metacognitive support for group members in CSCL in the form of a more structured curriculum with a combination of structured and unstructured ER activities. In short, what we suggest in this study is that balance is the key. We suggest a more structured environment at the beginning of each session followed by a challenge which gives students more freedom to explore and investigate solutions in a less structured way.

Furthermore, the results showed that students from the structured curriculum condition produced higher levels of collaboration quality than the unstructured curriculum condition. This outcome is contrary, to some extent, to that of Lee et al. (2013), who found that the unstructured condition was linked with more collaboration than the structured curriculum. It should be noted, however, that Lee et al. (2013) had focused on the amount, as opposed to the quality, of peer collaboration. In their study, both groups ended up with similar quality of the final projects. Therefore, the type of the curriculum did not have an impact on the quality of collaboration and the concepts and skills learned. In contrast, in our study, the type of the curriculum had an impact on the quality of collaboration. As claimed by Dillenbourg (1999), it remains uncertain whether unstructured collaborations can produce interactions that would trigger learning. It seems that our structured curriculum condition triggered more meaningful social interaction than what was seen in the unstructured curriculum condition. It seems possible that the acquired knowledge from the preparatory activities before the session's challenge had a positive effect on the quality of collaboration, which in turn triggered group metacognitive processes. Furthermore, in contrast with our research, which was conducted in an authentic educational setting, the study of Lee et al. (2013) was conducted in a laboratory setting. This fact may justify the different results found in the two studies. In short, these results suggest that designing a structured curriculum with some preparatory activities, combined with guided experimentation at the beginning of each session, would produce a noticeable increase in the collaboration quality among group members.

Surprisingly, no significant differences between the two conditions were identified in the students' perceived group cohesiveness. Students in both conditions had positive perceptions about their group and other group members. Therefore, the "curriculum structure," as an independent variable, seems not to influence group cohesion. As the structured curriculum condition had higher levels of group metacognition and collaboration quality, we expected the same to happen for group cohesiveness, but that was not the case. A possible explanation for this may be that the freedom given to students in the unstructured curriculum condition to experiment and explore the challenge on their own produced a commitment to the work of the group, and this had a positive effect on group cohesion.

Examining group interactions from a more ecological approach (see Figure 22) allowed us first to overview what was happening in the classroom on the individual, group, and community levels of cognition and second, to see the critical role of the individual for the group level. Individual metacognitive contributions that appeared at an individual level had a systemic impact on the group work's progress. Particular metacognitive contributions largely determined group planning. In short, this investigation supports that individual metacognition is the basis for the evolution of group metacognition. These findings provide empirical evidence on prior claims supporting that metacognition is a socially shared phenomenon (e.g., Iiskala et al., 2004).

8 Discussion

The overarching goal of this work was to explore how ER can support students' development of metacognitive thinking and collaborative knowledge construction. This chapter discusses the findings of this work, providing meaningful insights into the use of ER in authentic classroom environments. Specifically, in this chapter, we link the results of the three DBR cycles of work to previous research and present an overview of outcomes and concluding remarks. The chapter includes a summary of the contribution of this work along with directions for future research.

8.1 Introduction

By demonstrating how ER can be used in real educational contexts to support students' metacognitive thinking and collaborative knowledge construction, this work provides theoretical ideas and detailed instructions that can guide educational practice. Based on the overarching goal of the work, a set of research questions were addressed in three DBR cycles. Each of these cycles operates with one another to inform theory and strengthen the design of a theory and practical guidelines on the use of ER as a tool for promoting thinking skills.

Cycle 1 (Chapter 5) described primary school students' patterns of knowledge construction and unravelled the collaborative interactions among students as they engaged in collaboration and co-construction of shared understanding using ER. The results from this first cycle indicate the effectiveness of ER to engage students in collaborative knowledge construction and suggest three conditions under which this process can be promoted. In addition, this cycle helped to unfold the elements of collaborative knowledge construction, identify metacognition as one of the main elements of this process and point out the instrumental role of the technology in supporting students' group metacognitive thinking.

Cycle 2 (Chapter 6) examined how ER can serve the learning process as metacognitive tools, supporting and promoting students' metacognition in the context of elementary STEM education. We explored which elements of metacognition seem to be positively impacted via ER activities and examined students' learning gains in terms of mathematical problem-solving. The findings demonstrated that students developed their metacognitive and mathematical problem-solving skills through ER activities. Furthermore, the regulatory and self-control dimensions (such as planning, monitoring, and debugging strategies) were activated more than the knowledge dimensions. Given the encouraging results, one might suggest that ER activities can be a vehicle to the development of metacognitive skills in elementary education.

Cycle 3 (Chapter 7) focused on revealing the effect of different curriculum structures using ER in CSCL, focusing on (a) the frequency and type of programming errors made by students in block-based programming, (b) their ability to find and debug errors, (c) their engagement in the learning process, (d) their group metacognition, (e) collaboration quality and (f) group cohesiveness. The results showed that the choice of the curriculum structure to technology curriculum design could significantly impact learning. While the type of errors was the same in both curriculum structures, the frequency of errors was different. The unstructured curriculum group produced more errors and scored lower in debugging programming errors. In contrast, the students of the unstructured group expressed higher levels of engagement. Moreover, our findings indicate that a structured curriculum could result in increased group metacognitive processes and higher levels of collaboration quality. Hence, we argue that ER is a useful metacognitive tool whose learning benefits can be maximized through a structured curriculum using pre-designed tasks, in combination with guided experimentation at the beginning of each session.

The following sections of this chapter provide a comprehensive response to each research question and offer a set of implications and useful insights that can help researchers and practitioners use ER effectively to promote students' metacognitive thinking (group and individual), mathematical problem-solving, debugging skills, collaboration quality and engagement.

8.2 Addressing the research questions of this work

Within the chapters of this dissertation, we have addressed the research questions of the work organized in three DBR cycles, as seen in Figure 23.

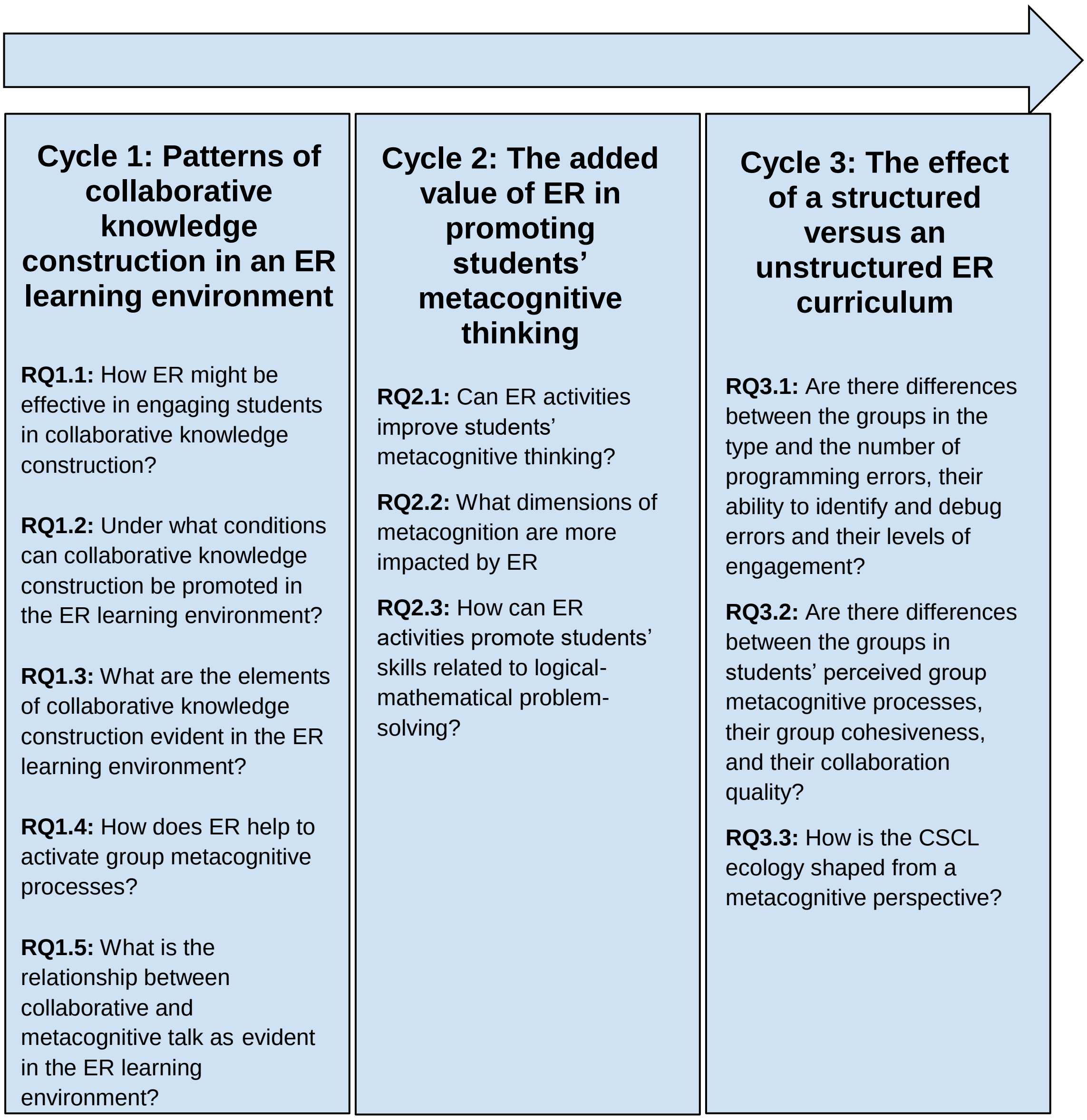


Figure 23: Research questions of the three cycles

8.2.1 [RQ1.1] How ER might be effective in engaging students in collaborative knowledge construction?

We addressed the effectiveness of ER in terms of collaborative knowledge construction in the STEM field. The analysis of qualitative data in Cycle 1 revealed that children experienced high levels of collaborative knowledge construction. Most verbal interaction (over 50%), was coded in higher knowledge construction levels such as KC-3 and KC-4 levels. Students spent most of their verbal interaction in negotiating the meaning, building on previous statements, creating solutions, and testing or modifying their new synthesis against existing knowledge, personal experience, and data, with the prospect of finalizing their synthesis. The increased percentages of the coded interaction to the higher levels of knowledge construction, when compared to previous computer-mediated communication and CSCL studies (Ioannou et al., 2015), lead us to hypothesise that ER might have encouraged knowledge construction at these higher levels, perhaps because of the hands-on experimentation and embodied interaction with the physical robot. A closer look at the chronological diagrams showed that the stage of "Execution of Plan" was tightly coupled with higher levels of knowledge construction. This finding confirms previous evidence about ER promoting collaborative knowledge construction (Chambers et al., 2007). In addition, the analysis of the data demonstrated some features of the technology and teamwork which seem to have a positive effect on the construction of higher levels of collaborative knowledge construction.

8.2.2 [RQ1.2] Under what conditions can collaborative knowledge construction be promoted in the ER learning environment?

This research question was addressed through content analysis of students' discourse and interactions with their peers, the teacher, and the robot during collaborative problem-solving with ER. Students' discourse was coded based on the levels of collaborative knowledge construction. The results demonstrated three elements of ER and teamwork that can promote collaborative knowledge construction. First, the results indicated that when students interacted with the physical robot to execute their plan, they engaged in higher knowledge construction levels. Hence, the physical and embodied interaction with the robot can be considered as a condition (or as an element of the technology) that supports the process of "conversation with the robot," through which students can be involved in the construction of new knowledge. Second, it appears that assigning roles to teammates and serving these roles enabled fair contribution, individual accountability, and social interdependence leading to better quality discourse and knowledge construction. Therefore, fair contribution by teammates adhering to predefined roles is a second condition that is linked to higher levels of knowledge construction. Third, cognitive dissonance is linked to higher levels of knowledge construction. Cognitive dissonance was less often related to the disagreement between the teammates and more often related to the robot's failure to perform the expected outcomes during the execution of a planned strategy. In this case, the students had to reconsider their strategy. The robot and its failure to deliver the expected result was a mediator to discovering cognitive dissonance or inconsistency; the latter was a time-consuming process that teammate struggled to overcome. Nevertheless, when the group overcame this stage, they engaged in higher levels of knowledge construction. Overall, the findings from RQ1.2 demonstrated elements of ER and teamwork that can be used to promote collaborative knowledge construction in an educational learning environment. Educators can use these findings to develop interventions to assist students in engaging in higher levels of knowledge construction using ER.

8.2.3 [RQ1.3] What are the elements of collaborative knowledge construction evident in the ER learning environment?

The results from this research question presents evidence that CSCL activities using ER can engage students in collaborative knowledge construction with prevalent elements of metacognitive processes, questioning, and answering. Indeed, students' discourse demonstrated logical reasoning coupled with metacognitive statements enabling the students to predict and to plan the flow of actions required to solve the problem. Monitoring elements of metacognition seem to be activated in an ER learning environment, engaging students in the process of exploration for the acquisition of knowledge. The large volume of monitoring elements of metacognition can be explained as the ER's value in encouraging procedural knowledge rather than declarative knowledge i.e., student learning by doing and understanding strategies of problem-solving rather than concepts. During the ER activity, intensive collaboration was enacted in the form of questioning and answering while metacognition was enacted in the form of monitoring and planning. Many researchers have identified questioning (e.g., Hmelo-Silver & Barrows, 2008) and reflective thinking (e.g., Baker & Lund, 1997) as important kinds of discourse in knowledge building situations.

8.2.4 [RQ1.4] How does ER help to activate group metacognitive processes?

Investigating the use of ER in an authentic classroom, we observed that metacognitive elements were activated through (a) embodied interaction with the physical robot, (b) transparency, and (c) interactivity. The physical presence of a robot enables students' physical action and simulation of its' expected actions. This seems to encourage expression and personal involvement in the learning process, whilst promoting teamwork, which is vital for the metacognitive process. Also, the transparent software design allowed the students to program and reprogram the robot easily. This opportunity to easily modify their programs enabled students to interact with each other, defend their ideas and build on previous contributions and thus activated group metacognitive processes. Furthermore, the direct interactivity (feedback) coming from the robot's moves in response to students' programming facilitated the group's metacognitive thinking. In fact, when the robot failed to perform the expected outcomes, monitoring and planning elements of metacognition were documented. Metacognition was necessary for students to understand how the tasks were performed and to be able to identify problems, negotiate modifications, and operating changes to solve the problems. Therefore, the embodied interaction with the physical robot, combined with feedback coming from the robot and the interactivity, acted as an extension of students' minds, scaffolding knowledge construction. From this perspective, these results showed that ER could be considered as "scaffolding embedded technological tools" (Chambers et al., 2007).

8.2.5 [RQ1.5] What is the relationship between collaborative and metacognitive talk as evident in the ER learning environment?

Our qualitative dataset, in combination with the use of the chronological diagrams, has provided some initial evidence for a temporal relationship between collaborative and metacognitive talk. Metacognitive and collaborative talk appear to mediate each-other in this CSCL, ER setting. In particular, a pattern of a temporal relationship was observed in our chronological diagrams; metacognitive and collaborative talk followed each other in our chronological diagrams. Most of the time, when one of the two appeared, then the other followed. This finding confirms previous evidence that collaborative talk may mediate the use of metacognitive talk, which in turn is associated with improved learning outcomes (Smith & Mancy, 2018).

8.2.6 [RQ2.1] How does ER help to activate group metacognitive processes?

In accordance with prior empirical studies (La Paglia et al., 2011; Atmatzidou et al., 2018) the results from this research question provided evidence supporting the positive impact of ER activities on students' metacognitive thinking. Our teaching procedure can be considered as a low coercion approach for students' metacognitive training. In contrast with the study of Atmatzidou et al. (2018) in which they found an improvement on students' metacognitive skills only in "strong guidance" groups, we found that metacognition can also take place with a minimal guidance approach. This finding further emphasizes the instrumental role of the technology in supporting students' metacognitive processes. The improvement in students' metacognitive thinking in the experimental group is seen as a collective result of the technology use, group work, teacher's interventions, and the nature of the activities. However, we think that the role of the technology was instrumental since it enabled a spontaneous 3-stages problem-solving process (understanding the problem, planning, executing, and evaluating) which can be considered by itself as a metacognitive learning protocol.

The collection of evidence of students' metacognitive processes by assessing students' judgments of their own performance (calibration), demonstrated that there was a statistically significant increase for students' accuracy on prediction judgments and postdiction judgments from pre-testing to post-testing in the experimental group. The ability to judge one's performance has been conceptualized as an expression of metacognitive monitoring (Boekaerts & Rozendaal, 2010). We, therefore, replicate the previous finding about the positive impact of ER activities on students' abilities to monitor their own learning. Possibly, that is because ER activities are based on procedural knowledge and engage students naturally in the process of exploration for solving a problem; yet further research is needed to fully understand what elements of ER contribute to students' metacognitive thinking.

8.2.7 [RQ2.2] What dimensions of metacognition are more impacted by ER activities?

Further analysis of the data derived from the MAI scale demonstrated that ER activities positively impact more the three regulatory dimensions of metacognition, such as planning, monitoring, and debugging strategies. These subcomponents are related to "regulation of cognition," and ER seems to tackle these aspects of metacognition well. This finding is in line with the work in Cycle 1, showing that students' discourse over ER activities includes a large volume of regulatory and self-control elements such as metacognitive monitoring and planning (see Table 7). In addition, this finding can be considered as crucial knowledge for educators who see their elementary students struggling in solving multi-step problems. Training these aspects of metacognition can help their students become more effective in solving multi-step problems in several disciplines and in general, to become more effective problem-solvers. Since a low level of guidance was applied, this improvement cannot be explained beyond the role of ER as "scaffolding embedded technological tools" (Chambers et al., 2007).

8.2.8 [RQ2.3] How can ER activities promote students' skills related to logical-mathematical problem-solving?

The data derived from student responses to the VisA instrument showed that students' who participated in the ER activities benefited more in mathematical problem-solving. In agreement with the prior work (e.g., Korkmaz, 2018), the results demonstrated a statistically significant increase in students' ability to solve logical-mathematical thinking problems only for the experimental group. It should be noted that our ER activities were not specifically aimed at improving students' abilities in mathematical problem-solving; instead, they were more about STEM and programming concepts. Therefore, students' improvement in solving mathematical problems may have emerged because of the development of metacognition through ER activities, since metacognition is strongly related to problem-solving. It becomes evident that positive results in mathematical problem-solving can be documented via an interdisciplinary approach to ER activities in elementary education, capable of expanding the curricular space (Ioannou et al., 2018).

8.2.9 [RQ3.1] Are there differences between the structured and unstructured ER curriculum groups in the type and the number of programming errors, their ability to identify and debug errors and their levels of engagement?

8.2.9.1 Common errors [RQ3.1a]

The investigation of elementary school students' debugging processes during block-based programming led to a list of six common errors that they often made. The list is discussed in the 7.3.3 section, and only the title of each category is included in this section; (1) error in defining value in block variables, (2) error in selecting the correct sequence of blocks, (3) error in selecting the appropriate block variable, (4) error in matching a motor or a sensor to the port, (5) error in defining conditions and (6) error in recognizing external factors as a cause of program failure.

The list can be used by educators in teaching students how to debug. For example, it might be useful for primary school students to be provided such a list in the introductory sessions of ER projects in order to generate a hypothesis for debugging and help them learn how to debug. From a "productive failure" point of view, however, that would not be appropriate; it would be better to let students struggle and even fail at tasks. Nevertheless, the list of errors can be useful for teachers to build the consolidation phase of discussion around productive failure. Three of the common errors (i.e., defining value in block variables, selecting the sequence of blocks, and defining conditions) in this study were similar to those in other programming studies that did not include block-based programming nor robots (Chiu & Huang, 2015; Liu et al., 2017). Furthermore, four of the six common errors (i.e., defining value in block variables, selecting the block variable, matching a motor or a sensor to the port, and recognising external factors as the cause of programme failure) were similar to those found in a study with early childhood preservice teachers conducted by Kim et al. (2018) in block-based programming with the use of robots. It seems that the types of errors that novice learners produce in programming environments tend to be similar, regardless of age and use of tools like robots.

8.2.9.2 Type and number of programming errors [RQ3.1b]

The data from classroom recordings, tablet screens, and audio recordings and the focus group interviews for the two groups demonstrated that there were no significant differences regarding the type of programming errors. Both groups produced a significant number of errors trying to define a value for a variable. Regarding the number of programming errors, the analysis results revealed that the unstructured curriculum group had a statistically significant higher mean number of errors than the structured group. These results demonstrate the superiority of the structured curriculum in teaching essential aspects of the programming interface and familiarising students with the functions of the programming environment. Another important finding was that the frequency of errors that had to do with knowledge about the programming interface was lower for the structured curriculum group. It seems that an unstructured ER curriculum requires students to have more practice in order to get acquainted with the programming environment. Therefore, these results suggest that learners must have sufficient prior knowledge about the programming interface in order to experience productive failure or learning from failure effectively

8.2.9.3 Differences in their ability to identify and debug errors [RQ3.1c]

The results of the debugging test indicate that the structured curriculum condition outperformed the unstructured condition to a statistically significant degree in terms of debugging. We can assume that teacher guidance (the teacher taking a more instructive role and using worksheets) gave the structured group an advantage in terms of debugging. As the students in the unstructured group were exposed to more frequent programming errors, one would expect them to have become more adept at debugging and therefore score better in the debugging test. This did not turn out to be the case. Contrary to expectations, the failure, in this case, was not productive; repeated errors (failures) by the unstructured group did not lead to better debugging. Students in the structured curriculum condition were stronger debuggers than students in the unstructured curriculum condition; notably, this was because they had stronger content knowledge because of the structured curriculum and not because they were more skilled at debugging. In summary, the results suggest that students of this age (8–9 years old) could benefit more from a structured curriculum to become better debuggers. These results are consistent with the findings of Sinha and Kapur (2019), who found that productive failure with younger students (Year 2 to Year 5) is relatively ineffective. Younger students may have insufficient prior knowledge about cognitive and metacognitive learning strategies to generate solutions on their own.

8.2.9.4 Differences in students' level of engagement [RQ3.1d]

Students who participated in the unstructured curriculum condition reported statistically significant higher levels of emotional and social engagement compared to the students in the structured group. On one hand, this finding confirms the positive effect of ER activities on students' motivation and engagement (i.e., Kim et al., 2015; Ruiz-del-Solar & Avilés, 2004). On the other hand, this finding around engagement levels is aligned with prior research efforts outside of ER, indicating that, irrespective of the study area, students who participate in student-centred environments might experience higher levels of engagement when compared to students having experienced teacher-centred approaches (e.g., Wu & Huang, 2007). Furthermore, one might think that the higher frequency of errors made by the unstructured curriculum group should have had a negative effect on student engagement. On the contrary, it seems that the freedom to experiment and explore trumped the frustration caused by the high frequency of errors. This finding is consistent with that of Lee et al. (2013), who showed that using an unstructured ER curriculum was linked to more collaboration than using a structured curriculum. In Lee et al. (2013), students in the unstructured curriculum group had more free time to explore and could easily share what they learned with their peers leading to a greater amount of social interaction. We can assume that the same happened in the present study; the unstructured curriculum condition produced a greater amount of social interaction, and this was reflected in their level of social engagement.

8.2.10 [RQ3.2]: Are there differences between the structured and unstructured ER curriculum groups in students' perceived group

metacognitive processes, their group cohesiveness, and their collaboration quality?

8.2.10.1 Differences in students' perceived group metacognitive processes [RQ3.2a]

In consistency with the two previous cycles of this dissertation, the results in Cycle 3 provided additional evidence supporting the positive effect of ER activities on students' group metacognitive processes. Quantitative data derived from the pre-post GMS scale showed that students who participated in the structured curriculum group were more involved in group metacognitive processes than the unstructured curriculum group. Therefore, this study proposed that ER is a useful metacognitive tool whose learning profits can be maximized through a structured curriculum using pre-designed tasks, in combination with guided experimentation at the beginning of each session.

The findings of this Cycle extend previous findings (e.g., Atmatzidou et al., 2018) by moving from individual metacognition to group metacognition, thus addressing the role of regulated social behaviour during collaborative ER activities. We support that the emphasis on individual regulation of learning is inadequate to explain learning in social contexts.

Going a step further, Cycle 3 provided empirical substantiation regarding when it is better to provide structure in such environments. Comparing productive failure with direct instruction, our results do not replicate the positive effect of problem-solving prior to instruction found by others (Kapur, 2011; Loibl & Rummel, 2014; Schwartz & Martin, 2004). Contrary to expectations, productive failure, in this case, was not productive. Therefore, the evidence suggests that an unstructured curriculum is not effective in promoting students' group metacognition in the context of ER activities in CSCL.

8.2.10.2 Differences in group cohesiveness [RQ3.2b]

Furthermore, no significant differences between the two groups were identified in the students' perceived group cohesiveness scale. Therefore, the instructional design here seems not to influence group cohesion. A possible explanation for this may be that the freedom given to students in the unstructured ER curriculum group to experiment and explore the challenge on their own produced a commitment to the group's work, which positively affected group cohesion.

8.2.10.3 Differences in collaboration quality [RQ3.2c]

Significant differences between the two groups were identified concerning the quality of collaboration. The video data analysis from two sessions using a Collaboration Quality Rubric showed that students from the structured curriculum condition produced higher levels of collaboration quality than the unstructured curriculum condition. It seems that the structured ER curriculum group triggered more meaningful social interaction than what was seen in the unstructured ER curriculum group. Again, our expectations regarding the benefits of productive failure on student collaboration were not confirmed. It seems possible that the acquired knowledge from the preparatory activities in the instruction phase of the structured ER curriculum group before the session's challenge had a positive effect on the quality of collaboration, which in turn triggered group metacognition. Therefore, the data reported here appear to support the assumption that direct instruction in the case of elementary school students working in groups with ER is more effective than productive failure for developing students' group metacognition. This result is consistent with the outcomes of Sinha and Kapur (2019). They found that productive failure with younger students (2nd-5th graders) might not be the best thing to do as they may have insufficient prior knowledge about cognitive and metacognitive learning strategies to generate solutions on their own.

8.2.11 [RQ3.3]: How is the CSCL ecology shaped from a metacognitive perspective?

Examining group interactions from a more ecological approach enabled us to recognize the critical role of individuals' students, technology, and the problems that emerge from their interactions in forming a collaborative ecology. We also saw the critical role of the individual level for the group level as the individual metacognitive contributions have a systemic impact on the progress of the group work. In short, metacognitive contributions largely determined group planning. The results from this ecological approach suggest that individual metacognition is the basis for the evolution of group metacognition, providing empirical evidence on prior claims supporting that metacognition is a socially shared phenomenon (Iiskala et al., 2004).

8.3 Emerging theoretical ideas

8.3.1 Powerful thinking (or learning to learn as they learn)

Papert (1980) claims that children can recognize different procedures in code, understand when the code does not work as expected, and use debugging strategies to improve it. In our study, during the activities, the children worked with programming concepts and practices to successfully complete their task. The problem-solving tasks require deep engagement and strategy use to successfully manage the completion of the task. The children iteratively organized and documented their code. As described by Papert (1980, p. 28) regarding the Logo environment: “teaching the Turtle to act or to ‘think’ can lead one to reflect on one's own actions and thinking. And as children move on, they program the computer to make more complex decisions and find themselves engaged in reflecting on more complex aspects of their own thinking.” In our study, to come up with a solution, the students had the opportunity to plan, problem solve, code, debug, collaborate, communicate, and reflect on their coding experience using ER. This resulted in the improvement of their metacognitive skills as reflected in Cycles 2 and 3 of our research. In addition, the theoretical idea of powerful thinking emerged in Cycle 1 when the students used several verbal metacognitive contributions in order to come up with a solution to the challenge. This reflection on one’s own actions and thinking, as described by Papert, is metacognitive thinking and it was obvious in students’ discourse in Cycle 1.

8.3.2 Powerful ideas

Papert (1980) identified powerful ideas as an integral part of learning with the computer. He described powerful ideas as central concepts of learning which should be necessary part of constructionist activities. Papert saw the greatest potential of LOGO as an incubator of powerful ideas (Papert, 2000). That is, as a tool to engage children in new ways of thinking and “thinking about thinking” (Papert, 2005). The notion of powerfulness pervades quite explicitly his first book Mindstorms, as an attribute of 1) computers as powerful tools; 2) ideas that grow throughout the engagement with the computer; and 3) children that engage with an activity within the Logo programming language. As such, a “powerful idea” must be personally and epistemologically useful, giving the opportunity to organize a way of thinking, appropriate each time for the specific task, building on previously gained skills and knowledge. Learners need to be highly explorative before they gain expertise; therefore, the task they are required to do needs to be engaging enough in order to commit them to the learning process. In our study, powerful is an attribute of the expertise gained as students engaged with problem-solving using ER. The process of problem-solving with ER brought students in touch with some powerful ideas such as planning a solution, using programming instructions, debugging and so on. The engagement with the task and especially a correct solution to a challenge served as a manifestation of students' progress, as it was tuned with their goals and enhanced their feelings of self-achievement and self-confidence. The use of problem-solving in combination with affordances of ER allowed students to engage in a closer relationship with the knowledge needed for solving the challenge. Students also enhanced their computer literacy by being oriented to use a specific tool and being given time to embrace its use.

8.3.3 Social aspect of ER activities

The "social" dimension refers to the role of collaboration in the coding activity. Students worked in teams of three or four to a given problem using ER. Collaboration and social interaction for a common goal have many benefits, including interacting with others, examining different perspectives, expressing understandings, and interpreting things differently. During the coding activity with ER the students were encouraged to work collaboratively. The process also offered the opportunity to the participants through a debriefing phase to demonstrate their solutions to the whole class and reflect on them. Collaboration was primarily examined between the members of the groups but also among the different teams. In Cycle 1 we found that fair contribution by teammates adhering to predefined roles was linked to higher levels of knowledge construction. We found that collaborative knowledge construction was more evidenced in some groups than others. This case made us hypothesize that lack of within group interaction might have hindered collaborative knowledge construction. We therefore took a closer look at videos and chronological diagrams of all groups to pinpoint patterns of collaboration in relation to collaborative knowledge construction. We found that in three groups all teammates were active participants in the learning process, whilst they participated fairly, adhering to their predefined roles. Instead, members of one group, did not serve their predefined roles and did not participate fairly in the tasks which seems to have led to failure in engaging in collaborative knowledge construction. It therefore appears that, assigning roles to teammates and serving these roles enabled fair contribution, individual accountability, and social interdependence (Johnson et al., 1991) leading to better quality discourse and collaborative knowledge construction.

Furthermore, using a more fine-grained analysis of the phenomenon at the same cycle we found that intensive collaboration was enacted in the form of questioning and answering while metacognition was enacted in the form of monitoring and planning. In Cycle 3 regarding the social aspects of ER activities we found that the structured curriculum condition produced higher levels of collaboration quality than the unstructured curriculum condition. It seems that the structured curriculum group triggered more meaningful social interaction than what was seen in the unstructured curriculum group.

8.3.4 Embodied interaction

Advanced digital technology has been increasingly used to develop environments that support embodied learning. Such environments are designed to develop perceptual and cognitive structures and processes by prompting learners to engage in physical actions. As such ER provide a rich environment for embodied interaction. The physical presence with embodiment seems to be a defining feature of ER. The vision of Papert (1987) for introducing powerful ideas (math and science concepts) through programming was to expand their views “beyond the screen” by targeting on the physical presence of robot. This distinguishes ER from other digital tools such as virtual agents (i.e., animated on-screen characters) and mobile devices. Besides, using virtual environments and visual programming tools such as Scratch, a growing number of educators and researchers have considered ER as a promising field for applying the embodied cognition view, mainly in the context of primary education. For example, Lu et al. (2011) examined how direct and surrogate bodily experiences in a robotic workshop can influence elementary students’ understanding of programming concepts. Participants were asked to act out with their bodies (direct embodiment) or observe the teacher acting out (surrogate embodiment) the robot’s movements and then program the robot to make the same moves. The results indicated that students assigned to the direct embodiment condition comprehended the programming concepts faster. Similarly, Sung et al. (2017) investigated how embodied experiences can affect lower elementary school students' problem-solving skills. Students in the high embodiment condition, were asked to enact the robot's movements through full-body interaction before building and programming the robot, demonstrated better problem-solving skills than those in the low embodiment condition (using hand gestures).

In our study embodied interaction was evident in the three cycles. For example, in Cycle 1 we found that the stage of "Execution of Plan" was tightly coupled with higher levels of knowledge construction. We observed that when students interacted with the physical robot to execute their plan, they often engaged in higher levels of knowledge construction (see Figure 11). Students were engaged in a process of "conversation with the robots," through which they promoted self-directed learning and engaged in the construction of new knowledge.

8.3.4.1 Embodied experimentation

This theme explored examples where children implicated their bodies experimenting possible ideas or solutions to the problems. In Cycle 1, we saw that students used the robot as a mean for experimentation. For example, in Cycle 1 the students started to research the question about where they could set the pen holder to draw a hexagon by adjusting the pen holder in different places on the robot. Then overall experimentation involved their bodies as students held the robot in their hands and were trying to simulate (with their bodies) possible movements of the robot and thinking of possible pen footprints on the paper.

8.3.4.2 Embodied explanation/reasoning

This theme explored examples where students used their bodies when they explained or represented processes in support of communicative and interactional goals. When responding to the robot's actions, students often developed their explanations in an elaborate manner. This elaboration often involved more than one idea and was typically accompanied by visible physical actions. In addition, this elaboration regarding the observed outcomes of an execution of the program, served as a communication channel among group members.

8.3.4.3 Embodied expression of knowledge

This theme encompasses instances when children engaged their body simultaneously with thinking and talking about STEM knowledge. For example, students embodied their explanations of mathematical properties using their feet as a unit for measuring the length or explaining the idea of loop using their fingers to describe the repetition of a sequence of instructions.

8.4 Contributions of this dissertation

This dissertation set up to provide new knowledge and understanding of the use of ER technologies in CSCL settings to develop students' metacognitive thinking. The work contributes to universal knowledge on the use of ER in education. Via a series of interventions, this work offers useful insight into the use of ER as metacognitive tools with which researchers, practitioners, and students can touch upon and unpack new prospects for its use. The analysis, descriptions, and presentation of the findings are significant, drawing attention to this research's implications for researchers and practitioners is equally important. However, this research goes beyond mere identification of ER's technological features; it provides a holistic understanding of how ER's strengths can be used for the benefit of learning.

The dissertation has three main contributions to research and practice. First, it helps to address the noted lack of research on the use of ER in the classroom (Benitti, 2012; Toh et al., 2016). Gaudiello and Zibetti (2016) found that ER learning has substantial positive impacts on the affective, social, cognitive, and metacognitive dimensions of learning and can profoundly transform student and teacher attitudes. However, these effects are not the result of robotics-based activities alone and require the scaffolding provided by a suitable pedagogical approach. Therefore, in this work, new knowledge is provided along with a better understanding of how ER activities can be implemented in authentic classrooms for specific learning purposes by investigating the effect of curriculum structures. Second, the study contributes to the design of ER learning environments and conditions for collaborative knowledge construction in CSCL settings. It provides essential considerations and theoretical guidelines for researchers and practitioners. It also provides a set of implications for classroom orchestration practice and teaching by providing insights into the instructor's and students' roles.

Third, while metacognition is essential in the learning process, an important contribution of this work is to move the discussion about the use of ER further in the direction of its use as a metacognitive tool. While most ER interventions take place in CSCL settings, they do not tend to rely on a CSCL framework. With this work, we push the discussion about metacognition as a social practice, encouraging more empirical research regarding the potential benefits of ER to support this kind of skills in CSCL settings. Therefore, the present work responds to the general need for exploring learning as a social phenomenon by providing additional data to the growing body of research applying sociocultural theories to understand learning.

8.4.1 Implications for researchers

Rapid and widespread new technologies such as ER claim new instructional design forms that lead to effective learning. Yet, computer and technological progress per se cannot improve learning effectiveness. For ER to promote deep learning, their use and adoption need to respond effectively to the needs, expectations, and demands of the curriculum and the real-world. This dissertation explored ER from a social perspective considering the social interaction that occurred in real classroom settings during problem-solving. The positive results that emerged along the three interventions reveal ER's further dynamics as social constructionist tools or as objects-to-share and think-with. Therefore, the use of ER in authentic settings cannot be seen out of a CSCL framework. In addition, the adaptation of coding schemes and frameworks from other CSCL and computer mediated communication fields without the use of ER, and the compatibility of these tools to this study’s setting also demonstrates that ER activities should be seen through a CSCL framework.

Despite the high level of compatibility of the coding schemes into our setting, our research revealed the need for a framework specifically made for the use of ER in real classrooms. Furthermore, the results of this dissertation regarding the effect of different curriculum structures on students’ learning contributes significantly to the research conducted in the design and implementation of this kind of intervention. It has been demonstrated that the curriculum structure is an important variable which defines the learning outcomes of the ER experience.

The research reported in this dissertation supports that the use of ER in CSCL settings can be effective in supporting group and individual metacognition. These results offer a better understanding of features as a learning tool, leading to a new perspective of its use. This dissertation's results contribute significantly to the research conducted in the design and implementation of these interventions. Implementation of research can build on this project's elements and ground the use of ER as a metacognitive tool. Researchers in the fields of learning science and CSCL can draw on the outcomes of this research work and stress a different approach in the use of ER in CSCL settings.

8.4.2 Implications for practitioners

As real classroom environments are complicated and deeply fluid in-nature, ready-made answers to practical problems cannot be given. As noted by Eisner (1991), researchers can offer the findings of their work but are not the ones to give rules of procedures to practitioners; there are no sacred seven steps to effective teaching. This work offers ideas to be shared and discussed, reflected upon, and debated. This study provides the baton to practitioners who need to see the intervention within the lens of their own settings.

This dissertation provides an in-depth and holistic understanding of how ER activities can help students enrich their metacognitive thinking as a key element of collaborative knowledge construction. Specifically, the results from this study show how ER activities can be used in real classrooms for specific learning purposes (i.e., development of group and individual metacognitive skills, debugging skills, and mathematical problem-solving skills). Additionally, our effective implementations of ER activities indicate key elements for designing future curriculum and classroom practices and nurturing new cultures of learning and theoretically and pedagogically aligned task-design.

As it has been shown, there are many advantages to be gained from implementing ER activities in classrooms. Practitioners who are interested in integrating ER activities into their classrooms must be aware of some important issues. First, classroom orchestration is essential for implementing ER activities effectively. The classroom must be designed in such a way that children have space to move comfortably in because a disorganized and uncomfortable class can lead to many problems. The orchestration of classroom activities also encompasses the spatial relationship of tables, chairs and tools, and student dynamics. Teachers must also make decisions about how they combine ER with learning activities. Due to the physicality of the learning activities with robotic technologies, the teachers should make the classroom physical and flexible. Teachers should also be able to use the robotic technologies in the intervention to manage them effectively.

Second, the role of the teacher in ER activities is critical. Teachers, as leaders of the class and mentors, have the responsibility of deciding what directions the activities take. That is, the teacher should encourage students to strive to be the best they can and enjoy the learning experience. The teacher's role is to facilitate, and scaffold students thinking and assist them with hints, prompts, and feedback. Moreover, teachers must be prepared to lead the implementation and to create a positive, playful environment where students are motivated and eager to learn.

Third, this study helped address the noted lack of research on the integration of robotics in the classroom (Benitti, 2012; Toh et al., 2016). Gaudiello and Zibetti (2016) found that learning by robotics has strong positive impacts on the affective, social, cognitive, and metacognitive dimensions of learning and can profoundly transform student and teacher attitudes, but these effects are not the result of robotics-based activities alone and require the scaffolding provided by a suitable pedagogical approach. Therefore, the level of structure that is being used in ER activities is critical as this choice can have a significant impact on students' learning. As both structured and unstructured activities seem to have several advantages and disadvantages, we suggest that teachers should design their curricula using a combination of unstructured and structured curriculum structures, for students to benefit from both. A more structured curriculum at the beginning of the intervention using pre-designed tasks in combination with guided experimentation at the beginning of each session, and an unstructured curriculum with more freedom for students to explore on their own at the later stages of the intervention is suggested. An unstructured curriculum design could engage kids as active participants, giving them a greater sense of control and responsibility for the learning process.

Fourth, ER activities are only one part of the whole learning process and should be based on the class curriculum. In this spirit, the adjustment or adaptation of ER activities should be found in the classroom's dynamic, on students' personal, social, and learning tastes, and their skill levels. To be able to engage all the students in the learning process, activities must include individual, group, and class-wide activities. Teachers must also find a way to motivate students in learning over time. For this reason, the students' roles within the team should change fairly over time. In addition, for the same reason, the activities need to change from session to session and get more challenging and complex as the sessions progress.

8.4.3 Guidelines for designing and implementing ER activities for metacognitive development

This project brought change at a local level while contributing to universal knowledge that can be of value to others. The intended outcomes of this DBR were twofold: 1) to ground the main findings of interventions conducted over three years in constructionism, and 2) to identify reusable design principles that can inform ER coding activities for children and pedagogical tasks. In addition, this study aims to investigate children's learning experiences as they engage in collaborative problem-solving using ER. Analysis of the different data collected from the various instruments over the three-year intervention helped us to explore our ER workshops' effectiveness. We focused on how they enhanced participants' knowledge of basic programming concepts, their metacognitive processes, their coding behavior, and their social interaction and collaboration.

It is essential to have suitable educational designs aiming to promote students' metacognitive thinking with the support of constructionism. Including components like a balance of individual and social involvement and the use of ER, all employed under the common goal of collaborative problem-solving, encourages children's metacognitive thinking and supports collaborative knowledge construction. Engaging children in learning environments that encompasses problem-solving, collaboration, and communication strengthens their sense of competence and confidence, their compassion for others, and their moral character (Bers, 2010). Together with producing growth in students' understanding of computational knowledge and metacognition it is essential to create high levels of motivation and engagement as part of an effective pedagogical design, as revealed in our study.

In summary, the following principles emerging from our DBR cycles of work. These principles shed light on best practices in the design and implementation of ER activities for promoting students' metacognitive thinking as a key element of collaborative knowledge construction in primary education. The emerging principles represent the knowledge gained from the three years of interventions as well as the comparative and thoughtful analysis of the results, also based on the literature:

1. Provide opportunities for sharing and reflection. This may take several forms such as 1) the use of a debriefing phase at the end of each session where children can discuss and exchange ideas, 2) the use of a curriculum with less structure, 3) teacher’s prompts to share and discuss their solutions, 4) the use of a consolidation phase where the student groups can compare, contrast, organise and assemble their solutions into correct solutions.

2. Introduce ER to the whole class and give special attention to the introductory sessions. Often, students do not have the same technological skills or coding experience with ER. Therefore, more precise introductory sessions would help them to avoid mistakes caused by the lack of knowledge of the programming interface. Therefore, with introductory sessions to the whole class the teacher can ensure that students have a common ground of basic knowledge which will make everyone engaged and active.

3. Mobility and flexibility. In cycle 2 and 3, we used tablets instead of computers for programming the robots. We observed that the use of tablets was more functional than the use of computers as it supports students' mobility in the classroom. Without any restrictions from cables, the students could move with their group near the mat while holding the tablet to observe the outcomes of their program. So, the use of tablets instead of computers can facilitate classroom mobility. Classroom flexibility was also important for the effectiveness of the project. Students could change the arrangement of the seats and desks to create more room for their activities. We observed that students moved the seats on the edge of the table or into a classroom corner to create more space for the main activities. Therefore, an ER classroom should: (1) have enough room to conduct the activities; (2) have enough computers or tablets, in order to avoid that only a few children can program; (3) have fewer seats, preferably on the edge of the table, so that they do not hinder interaction with objects and group work. If teachers need more room, other areas of the school (gym, corridors, lobby, etc.) are useful.

4. Provide opportunities for collaboration into and among the groups. Collaboration among team members is an essential part of ER activities. It is necessary to improve this and assure that there is a sense of equality of effort, involvement, and participation between team members. As described in cycle 1, fair contribution by teammates adhering to predefined roles is important for students to produce higher levels of knowledge construction. In addition, as demonstrated in cycle 1 metacognitive talk and collaborative talk seem to have a temporal relation. Therefore, it is important to provide opportunities for collaboration into and among the groups in order to help the enactment of metacognitive thinking.

5. Valuing failure. Failure and unsuccessful attempts are valued as an opportunity to find a solution. During problem-solving, students can learn a lot from the mistakes along the way to the final solution. Therefore, students need to become comfortable working on a solution based on the knowledge they have, perhaps failing, and being able to understand the answer or error they might obtain. The ability to identify a wrong solution is a valuable skill to have as it will empower them to re-examine their solution or look for what knowledge they are missing to come to a solution. ER problem-solving activities fosters linking the knowledge needed with an external artifact, upon which students can reflect and engage in meaningful argumentation in a fail-safe environment. New knowledge is expected to evolve through multiple iterations between the artifact and the actors involved in materializing it.

6. Provide opportunities for embodied interaction with the physical robot. Embodied interaction describes the interplay between the brain and the body and its influence on the sharing, creation, and manipulation of meaningful interactions with technology. To efficiently implement an ER workshop for promoting students' metacognitive skills and collaborative knowledge construction, the tasks should provide opportunities for the students to use their bodies. We support that embodiment within ER activities can serve as an innovative approach to attracting students to computer programming. The synergy between embodied learning and ER through a series of programming activities was evident throughout the three cycles of interventions of this research. One way to give opportunities to students for embodied interaction during ER activities is to use ER activities related for example to math unit such as geometry or measurements. Offering a supportive theme for embodied interaction is a key factor supporting the psychological and sociocultural elements for effective learning. Children become engaged and actively involved in the process of problem-solving with ER.

7. Provide opportunities for cognitive dissonance. In cycle 1, we found that the second level of collaborative knowledge construction (KC-2) “discovery and exploration of dissonance” was less often related to disagreement between the teammates and more often related to the robot’s failure to perform the expected outcomes during the execution of a planned strategy. In short, the robot and its failure to deliver the expected outcome was a mediator to the discovery of cognitive dissonance or inconsistency. We also found that when the group overcame cognitive dissonance, they engaged in higher levels of knowledge construction. Therefore, cognitive dissonance is linked to higher levels of knowledge construction. To provide opportunities for cognitive dissonance we suggest the use of quite difficult activities in which students will not be able to easily come up with a solution with the first attempt. It would be better for them to try and fail hoping to arrive at a mental conflict because of the inconsistency among the robot’s behavior and students’ beliefs. This mental conflict, of course, may prompt students to revise their beliefs or actions to achieve cognitive consistency. In addition, we suggest the use of activities in which students can afford opportunities to generate and explore a wide variety of solutions. The idea to provide opportunities for cognitive dissonance is close to the idea of Kapur to intentionally design failure in ways that are effective for learning. Therefore, we suggest for educators to develop appropriate activities with the use of ER and find a sweet spot where students are challenged yet not frustrated and remain sufficiently engaged in problem-solving with ER.

8. Provide role assignment. The results of cycle 1 showed that teachers should favor role assignment and inner definition of responsibilities; in this way, group members can communicate in a functional manner, avoid the creation of hierarchies, and ensure that there is a sense of equality of effort, involvement, and participation between team members and among teams.

9. Provide structured activities. The results of the study showed that for students of that age a more structured curriculum fosters group metacognitive processes, collaboration quality and debugging skills to a greater extent than unstructured activities. Therefore, we propose an instruction prior to problem-solving (I-PS) approach as more effective for promoting collaborative knowledge construction and metacognition.

8.5 Limitations

Any research project has limitations, which need to be considered. Firstly, the target group in this research consisted only of primary school students, whereas other age groups such as older students or adults are not explored. Moreover, all subjects were primary school students, who attended public schools in Cyprus, thus had or hasn't some competencies and experiences which are determined by the school culture of the country in which they are studying. The results of this study may have been different in schools of another country with a different school culture. It should also be acknowledged that we used only one type of robot in our study. Hence, the use of different robots may have different results.

This type of research leaves many questions unanswered in observed learning and assessment of learning outcomes. As a DBR inquiry, the intervention and its construct are laid open, demonstrating the relationship between theory, technology, and artifact construction in this context. The assumption is that theorized use of ER leads to better instructional design and therefore better learning, yet there is no proven evidence for this here.

In the context of a specific learning domain, there is no single theory that can cover all topics, skills, learning and teaching types. This research made use of an existing learning tool under a certain theory and tested it in a specific context allowing for a set of instructional design elements to emerge. Yet, it is expected that different theories, tools, and tasks should be employed and tailored to the needs of a specific classroom.

Another limitation of this work was the complexity and messiness of the learning environment. As the research was conducted in real-world classrooms where teaching and learning occur, many variables could not be controlled (Collins et al., 2004). For this reason, the study focused only on the variables of interest (i.e., metacognitive, collaboration outcomes) and addressed research questions over the three cycles of this dissertation.

The overarching goal of this work was to explore how ER can support students' development of metacognitive thinking and collaborative knowledge construction. The findings provide strong support for grounding the use of ER under the framework of constructionism for promoting students' metacognitive thinking and collaborative knowledge construction. Yet, it is kept firmly in mind that the proposed instructional guidelines are not a clear-cut map of actions, but it is rather a heuristic-understanding of the intervention for those interested in enacting innovation in their own settings. We recognize that concentrating the investigation in this learning environment can be restricted to these results' replicability and transferability in other learning settings. Nevertheless, by providing a "thick description" of the setting, as proposed by Shenton (2004), the transferability of research findings in identical or comparable settings is increased. By describing the context of the study in-depth within the rich dataset, outside researchers can be supported to make decisions about the fittingness of this study in their settings. The collaborative activities in most cases followed a problem-solving learning approach, during which the teacher only observed the group activities and provided prompts and triggers rather than providing answers to questions. We claim that the setting of this study is realistic, which an outside researcher can decide if the findings of this work might apply to his/her setting. In conclusion, the outcomes of a fruitful implementation of ER activities for students' metacognitive development can be informative despite the limitations presented in this section. These limitations provide space for further research proposed in the following section.

8.6 Future work

Based on the findings presented in the dissertation, some suggestions for future research are presented below.

1. The guidance withdrawal technique. An interesting research question is the degree of integration of the guidance withdrawal technique in the learning process, to avoid the negative consequences of continuous and long-term guidance, without reducing its learning benefits. We propose an in-depth investigation to examine when, how long, and with what rules it should be applied.

2. Exploration of assessment tools for measuring students' development of individual and group metacognitive skills. The research interest in reliable metacognitive tools is intense. One of the most frequently used categories of off-line measures is self-report questionnaires such as the Motivated Strategies for Learning Questionnaire (MSLQ), the Learning and Study Strategies Inventory (LASSI), and the Metacognitive Awareness Inventory (MAI), which was used in this dissertation. In these questionnaires, students are asked to report on their own metacognition. However, these measures do not measure learners' ongoing metacognitive behavior during task processing because they are collected before or after the student processes a learning task (Greene & Azevedo, 2010). This fact causes some severe problems. For example, students must retrieve earlier operations and performance from their long-term memory or differ in their frame of reference as to which situations they have in mind when answering the questions. Therefore, thoughts for future research include focusing on creating on-line measures. These assessment tools will capture metacognition concurrent with the learning behavior giving more insight into the actual use of metacognition affecting learning behavior. Apart from think-aloud protocols, we suggest the development of measures that will assess on-line information about students' metacognition in a fun way for children, such as drawing schemes, taking notes, or clicking a button. We also suggest the development of on-line measures that can assess metacognition or other skills at a group level.

3. Study of the role of the duration of the intervention. One point of interest is the influence that the duration of the intervention may have on the development of students' metacognitive skills. The implementation of the intervention, for a more extended period, will allow exploring the development of metacognitive skills and their consolidation with the intervention.

4. Exploring the development of other learning and life skills. This refers to exploring skills such as critical thinking, computational thinking, creativity, flexibility, and initiative in the context of elementary STEM education in CSCL settings using ER. The evidence for the value of ER activities for developing students' learning skills needs to be more transparent, while exploring life skills is at an early level.

5. Exploring the effect of different curriculum structures on students' metacognitive development. For example, an exciting exploration would be to investigate the effect of productive failure in ER activities on students' metacognitive or other skills. The general idea of productive failure is to develop tasks that students will not be able to solve but require them to call upon their existing knowledge to solve the problem. That knowledge can be of the subject itself, as well as the informal insights students bring from their lives. The students will inevitably fail -as the teacher expects them to- but that failure is framed as part of learning and so is not seen as shameful. This process primes students’ brains to learn the new concept from their instructor after the initial failure.

8.7 Concluding remarks

The value of ER as a learning tool is well presented in the literature. Previous bibliographic and empirical research in the area has demonstrated the positive impact of ER activities on the development of the cognitive, metacognitive, and academic performance of children. Yet, there is indeed a huge gap in research that systematically designs and changes the learning environment over time, collecting evidence of the various changes toward the documentation of conceptual models or design principles that can facilitate a successful integration of ER.

The overarching goal of this work was to explore how ER can support students’ development of metacognitive thinking and collaborative knowledge construction. By adopting the design-based research methodology, it addresses the development of metacognitive skills via ER while it documents design principles for successful ER implementations, based on collected evidence for cycles of work. Through three cycles of DBR, this dissertation provided a comprehensive understanding of how ER activities can be implemented in real learning contexts becoming a vehicle for the development of metacognitive and problem-solving skills. According to this study's findings, the general idea is that children are aware of their learning processes and that ER activities help improve students' collaborative knowledge construction, individual and group metacognition. Findings from this dissertation offer significant insights for researchers and practitioners eager to explore the possibilities of using ER in the classroom. The work clearly demonstrates how robotics can be used as an educational tool in an authentic classroom environment and presents a set of guidelines and implications for its implementation.

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APPENDICES

APPENDIX I: List of relevant publications

Socratous, C., & Ioannou, A. (2018). A Study of Collaborative Knowledge Construction in STEM via Educational Robotics. In J. Kay & R. Luckin (Eds.), Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences (ICLS) 2018 (Vol. 1, pp. 496-503). London, UK: ISLS.

Socratous, C., & Ioannou, A. (2019a). An empirical study of educational robotics as tools for group metacognition and collaborative knowledge construction. In Lund, K., Niccolai, G. P., Lavoué, E., Hmelo-Silver, C., Gweon, G., and Baker, M. (Eds.). A Wide Lens: Combining Embodied, Enactive, Extended, and Embedded Learning in Collaborative Settings, 13th International Conference on Computer Supported Collaborative Learning (CSCL), Volume 2. Lyon, France: International Society of the Learning Sciences.

Socratous, C., & Ioannou, A. (2019b). Using Educational Robotics as Tools for Metacognition: an Empirical Study in Elementary STEM Education. In International Conference of Immersive Learning Research Network (iLRN 2019) (pp. 72-83), Westminster, London, UK. DOI: https://doi.org/10.3217/978-3-85125-657-4-01

Socratous, C. & Ioannou, A. (2020). Common Errors, Successful Debugging, and Engagement During Block-based Programming Using Educational Robotics in Elementary Education. In Gresalfi, M. and Horn, I. S. (Eds.), The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 2 (pp. 991-998). Nashville, Tennessee: International Society of the Learning Sciences.

Socratous, C., & Ioannou, A. (2021). Structured or unstructured educational robotics curriculum? A study of debugging in block-based programming. *Educational Technology Research and Development*, *69*(6), 3081-3100. https://doi.org/10.1007/s11423-021-10056-x

Socratous, C., & Ioannou, A. (2022). Educational robotics in CSCL: evaluating the impact of the curriculum structure on group metacognition, cohesiveness and collaboration quality. *TechTrends* (under review).

APPENDIX II: Approvals by the Centre of Educational Research and Evaluation

ΚΥΠΡΙΑΚΗ ΔΗΜΟΚΡΑΤΙΑ

ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ, ΠΟΛΙΤΙΣΜΟΥ ΑΘΛΗΤΙΣΜΟΥ ΚΑΙ ΝΕΟΛΑΙΑΣ

ΔΙΕΥΘΥΝΣΗ ΔΗΜΟΤΙΚΗΣ ΕΚΠΑΙΔΕΥΣΗΣ

Αρ. Φακ.: 7.15.06.12/4
Αρ. Τηλ. : 22800665
Αρ. Φαξ : 22806335
E-mail : dde@moec.gov.cy

30 Σεπτεμβρίου, 2019

Κύριο
Χρύσανθο Σωκράτους
Αγίας Μαρίνας 21
4194 Ύψωνας

Θέμα: Άδεια για διεξαγωγή έρευνας με μαθητές/μαθήτριες ενός δημοτικού σχολείου της επαρχίας Λεμεσού

Αναφέρομαι στη σχετική με το πιο πάνω θέμα αίτησή σας προς το Κέντρο Εκπαιδευτικής Έρευνας και Αξιολόγησης, που υποβλήθηκε στις 26 Αυγούστου 2019, η οποία στάλθηκε για χειρισμό στις 17 Σεπτεμβρίου 2019, και σας πληροφορώ ότι εγκρίνεται το αίτημά σας για διεξαγωγή έρευνας με μαθητές/μαθήτριες ενός δημοτικού σχολείου της επαρχίας Λεμεσού που εσείς θα επιλέξετε, με θέμα *«Συχνά λάθη, επιτυχής αποσφαλμάτωση και εμπλοκή κατά τη διάρκεια οπτικού προγραμματισμού σε οπτικό περιβάλλον με τη χρήση εκπαιδευτικής ρομποτικής: Σύγκριση δομημένου και μη δομημένου προγράμματος σπουδών στη στοιχειώδη εκπαίδευση STEM»*, την παρούσα σχολική χρονιά 2019-2020. Η απάντηση του Κέντρου Εκπαιδευτικής Έρευνας και Αξιολόγησης σας αποστέλλεται συνημμένα, για δική σας ενημέρωση. Θα πρέπει, επίσης, να παρουσιάζετε το Αναλυτικό Σχέδιο Έρευνας, σε περίπτωση που αυτό σας ζητηθεί.

2. Νοείται, βέβαια, ότι πρέπει να εξασφαλιστεί η άδεια του/της διευθυντή/ διευθύντριας του σχολείου, εκ των προτέρων, ώστε να ληφθούν όλα τα απαραίτητα μέτρα για να μην επηρεαστεί η ομαλή λειτουργία του και αυτό θα πρέπει να γίνει στον μη διδακτικό σας χρόνο. Η έρευνα θα πρέπει να διεξαχθεί με ιδιαίτερα προσεγμένο τρόπο, ώστε να μη θίγεται το έργο των εκπαιδευτικών, το σχολικό περιβάλλον ή οι οικογένειες των μαθητών/ριών και όλες οι δραστηριότητες που θα αναπτυχθούν πρέπει να εμπίπτουν μέσα στο πλαίσιο που καθορίζεται από το Αναλυτικό Πρόγραμμα. Η έρευνα θα διεξαχθεί νοουμένου ότι η απώλεια του διδακτικού χρόνου των μαθητών/ριών θα περιοριστεί στον ελάχιστο δυνατό βαθμό, ενώ για τη συμμετοχή των μαθητών/ριών και τη χρήση συσκευών καταγραφής εικόνας και ήχου χρειάζεται η **γραπτή** συγκατάθεση των γονιών τους. Οι γονείς πρέπει να γνωρίζουν όλες τις σχετικές λεπτομέρειες για τη διεξαγωγή της έρευνας, καθώς και τα στάδια μέσα από τα οποία θα εξελιχθεί. Σημειώνεται, επίσης, ότι τα πορίσματά σας κρίνεται απαραίτητο να είναι ανώνυμα και οι πληροφορίες που θα συλλέξετε να τηρηθούν απόλυτα εμπιστευτικές και αποκλειστικά και μόνο για τον σκοπό της έρευνας.

Υπουργείο Παιδείας, Πολιτισμού, Αθλητισμού και Νεολαίας, 1434 Λευκωσία
Τηλ.: 22800600 Φαξ: 22428277 Ιστοσελίδα: http://www.moec.gov.cy

3. Η παρούσα έγκριση παραχωρείται με την προϋπόθεση ότι τα πορίσματα της εργασίας, θα κοινοποιηθούν μόλις αυτή ολοκληρωθεί, στη Διεύθυνση Δημοτικής Εκπαίδευσης για σχετική μελέτη και κατάλληλη αξιοποίηση.

Χρίστος Χατζηαθανασίου
Διευθυντής
Δημοτικής Εκπαίδευσης

Κοιν.: Π.Λ.Ε. Λεμεσού
Επαρχιακό Γραφείο Παιδείας
: Δρα Μάριο Χαραλάμπους, Ε.Δ.Ε. Φυσικών Επιστημών
Επαρχιακό Γραφείο Παιδείας Λευκωσίας

AT/AT EREVNES

Σχόλια για ερευνητικές προτάσεις

Θέμα έρευνας:	Συχνά λάθη, επιτυχής αποσφαλμάτωση και εμπλοκή κατά τη διάρκεια οπτικού προγραμματισμού σε οπτικό περιβάλλον με τη χρήση εκπαιδευτικής ρομποτικής: σύγκριση δομημένου και μη δομημένου προγράμματος σπουδών στη στοιχειώδη εκπαίδευση STEM.
Κωδικός έρευνας:	114597
Ονοματεπώνυμο Ερευνητή:	ΣΩΚΡΑΤΟΥΣ ΧΡΥΣΑΝΘΟΣ
Διεύθυνση στην οποία υποβλήθηκε:	Διεύθυνση Δημοτικής Εκπαίδευσης
Ημερομηνία υποβολής στο ΚΕΕΑ:	17/09/2019

1. **Σκοπός -ερευνητικά ερωτήματα/υποθέσεις**

   Δεν υπάρχουν παρατηρήσεις.

2. **Χρησιμότητα-αναγκαιότητα της έρευνας**

   Δεν υπάρχουν παρατηρήσεις.

3. **Διαδικασία συλλογής δεδομένων**

   Δεν υπάρχουν παρατηρήσεις.

4. **Δειγματοληψία**

   Δεν υπάρχουν παρατηρήσεις.

5. **Ερευνητικά εργαλεία**

   Δεν υπάρχουν παρατηρήσεις.

6. **Χρόνος απασχόλησης**

   Δεν υπάρχουν παρατηρήσεις.

7. **Χρονική περίοδος έρευνας και αναμενόμενος χρόνος αποτελεσμάτων**

Δεν υπάρχουν παρατηρήσεις.

8. **Θέματα ηθικής και ερευνητικής δεοντολογίας**

Δεν υπάρχουν παρατηρήσεις.

9. **Εισήγηση ΚΕΕΑ**

Η έρευνα να προχωρήσει ως έχει για υλοποίηση	√
Η έρευνα να προχωρήσει για υλοποίηση, νοουμένου ότι θα γίνουν οι αλλαγές/τροποποιήσεις/εισηγήσεις που επισημαίνονται πιο πάνω	
Η αίτηση για έρευνα να υποβληθεί ξανά αφού ληφθούν υπόψη τα πιο πάνω	

2

ΣΥΝΟΠΤΙΚΟ ΔΕΛΤΙΟ ΕΡΕΥΝΑΣ

Κωδ. 114597

Όνομα ερευνητή/ερευνήτριας:
ΣΩΚΡΑΤΟΥΣ ΧΡΥΣΑΝΘΟΣ

Ιδιότητα:
Υποψήφιος διδάκτορας

Μέλη ερευνητικής ομάδας:

1. Άντρη Ιωάννου, Επίκουρη Καθηγήτρια στο Τμήμα Πολυμέσων και Γραφικών Τεχνών του Τεχνολογικού Πανεπιστημίου Κύπρου

2. Παναγιώτης Ζαφείρης, Καθηγητής στο Τμήμα Πολυμέσων και Γραφικών Τεχνών του Τεχνολογικού Πανεπιστημίου Κύπρου

3. Αγνή Στυλιανού-Γεωργίου, Επίκουρη Καθηγήτρια στο Τμήμα Παιδαγωγικών Σπουδών του Πανεπιστημίου Λευκωσίας

Επιστημονικός φορέας:
Τμήμα Πολυμέσων και Γραφικών Τεχνών, ΤΕΠΑΚ, στο πλαίσιο διδακτορικής διατριβής

Διευθύνσεις ΥΠΠ στις οποίες διεξήχθει η έρευνα και σχολική χρονιά:
Δημοτικής, 2019/2020

Ταχυδρομική διεύθυνση ερευνητή/ερευνήτριας:
Αγίας Μαρίνας 21, 4194 Ύψωνας, ΛΕΜΕΣΟΣ

Διεύθυνση ηλεκτρονικού ταχυδρομείου:
chrisanthossocratous@hotmail.com

Τηλέφωνα / τηλεμοιότυπο (fax):
99745088 /

Τίτλος έρευνας:

Common errors, successful debugging, and engagement during block-based programming using educational robotics in elementary education

Λέξεις κλειδιά

Εκπαιδευτική Ρομποτική,Πρωτοβάθμια εκπαίδευση,Αποσφαλμάτωση,Εμπλοκή,Εικονικός Προγραμματ, Educational Robotics,Engagement,Debugging,Elementary Education,Bock-based programming

Σκοπός -ερευνητικά ερωτήματα:

The study aimed to understand the effect of a structured versus an unstructured Educational Robotics (ER) curriculum on student's (a) quantity and type of programming errors in block-based programming, (b) ability to find and debug errors, and (c) engagement in the learning process.

- RQ1: Are there differences between the groups in terms of the type and the number of programming errors?
- RQ2: Are there differences between the two groups in their ability to identify and debug errors?
- RQ3: Are there differences in students' level of engagement between the groups?

Μεθοδολογία:

Data were collected from classroom recordings (one camera in each class), tablet screen, and audio recordings for each team, post-debugging test, post-engagement survey, and focus-group interviews. Tablet screens and discourse of the nine teams were recorded using Mobizen Screen Recorder (see Figure 1).

After the learning experience, students completed a test on debugging, which was developed based on the categories of the common programming errors and was comprised of ten tasks. The test provided students with a scenario with the purpose of the program and a screenshot of the EV3 programming interface with a proposed program with an error. Students had to find the error (by circling the error block or the group of blocks) and describe, writing on the paper, how they could fix it. Each correct task was scored with a total of ten marks (five marks for finding the error and five for a correct proposal to overcome the error). The maximum possible score for the test was 100 marks.

A post-experience survey aiming at evaluating students' engagement was administered. Students' engagement was measured using a 5-point Likert scale with 33 items derived from the Math and Science Engagement Scales (Wang, Fredricks, Hofkens, & Linn, 2016). The scale is comprised of four subscales: (a) Cognitive engagement (e.g., I try to understand my mistakes when getting something wrong), (b) Behavioral engagement (e.g., I keep trying even if something is hard), (c) Emotional engagement (e.g., I enjoy learning new things about STEM), and (d) Social engagement (e.g., I try to understand other people's ideas in STEM class). The four dimensions have internal reliabilities of alpha: .74, .75, .72, .77 respectively.

One week after the learning experience, 16 students participated in semi-structured focus-group interviews (four focus-groups, 50-60 minutes each). The focus-group interviews were organized into two sessions. The first session was contributing to answering RQ1 and enriching our understanding of students' common errors during programming. We used the 40% of the screen recorded data to identify the common programming errors first, and then we designed the first session of the focus-groups based on the common errors derived from the video analysis of the screen recordings. Part of the interviews included questions that prompted students to remember about errors that they have encountered and how they manage to overcome these errors (e.g., What difficulties did you face during programming?, How did you overcome the difficulties?). The second session was aimed at providing additional evidence for students'

engagement (e.g., Do you think robotics activities were useful to you? [Cognitive engagement], How did you feel, while you were working on robotics activities in this class? [Emotional engagement]). The focus-groups data were video-recorded and transcribed for data analysis using a thematic analysis approach. The data analysis was conducted by two researchers, working separately. At the completion of the coding, the inter-rater reliability was assessed to 0.736 (Cohen's Kappa).
We used open coding for the screen-recorded and the audio data. We narrowed our analysis to errors associated with programming; we did not code videos related to assembly. Around 40% of the video was coded by the first researcher, with a second researcher independently coding the same units. Inter-rater reliability between the two raters was found to be high (Cohen's Kappa = .88). Therefore, the first researcher finished coding the complete dataset. The data were analyzed using independent samples t-test to investigate any differences between the two groups on the total number of errors. For the analysis of the data derived from the post-debugging test, and the engagement survey, we also used independent samples t-test.

Συμπεράσματα/Αποτελέσματα:

This study posits that a critical factor for the successful integration of robotics in education is the teaching approach. The role of the teaching approach for successful technology integration remains relatively unexplored in the area of ER. To our knowledge, this is the first time that a study investigates this topic, as prior studies focused on the level of guidance in a constructionist learning environment (e.g., Atmatzidou, Demetriadis, & Nika, 2018), or on the differences on the social aspect of learning such as collaboration and social interaction (e.g., Lee, Sullivan & Bers, 2013); it, therefore, represents a novel extension of prior work in this area.
First, to answer RQ1, a list of the common programming errors during blocks-based programming was produced. The list can be used by educators and researchers in teaching students how to debug programming errors. Four of the six common errors (i.e. #1, 3, 4, 6) were similar to those in a study by Kim et al., (2018) with early childhood pre-service teachers. Therefore, a great similarity appears about the type of errors that novice learners produce regardless of their age. Second, subsequent analysis of students' errors in the two groups showed a significant difference in the number of errors produced. Students who participated in the constructionist class involved in a significantly higher amount of errors than students who participated in the instructionist class. These results demonstrate the superiority of the instructionist approach against the constructionist as being more effective in teaching students essential aspects of the programming interface and make students become familiar with the functions of the programming environment. It makes sense; if you are allowed to explore on your own, you will make more errors. The procedure of solving an error (debugging) is considered as a problem-solving situation which students should experience and resolve productively. On the other hand, if students exposed to too many programming errors, this might become a source of frustration with a negative impact on their engagement.
Third, the results of the debugging test indicated that the structured group outperformed the unstructured group in a statistically significant degree in terms of finding and debugging an error. We can assume that the direct instruction (more instructive role of the teacher and the use of the worksheets) gave this group an advantage in terms of debugging. On the other hand, as the students in the unstructured group were exposed more in programming errors, one would expect to have learned how to debug the errors. The failure in this situation was not productive in terms of debugging. The students of the instructionist condition were stronger debuggers because they have stronger content knowledge, as a result of the direct instruction, and not because they were better at debugging. Summarizing, these results suggest that students could benefit more through an instructionist teaching approach in order to become better debuggers. Fourth, when focusing on the experienced engagement, students who participated in the unstructured curriculum group reported statistically significant higher levels of emotional and social engagement than students of the structured group. This finding is aligned with prior research efforts indicating that students, who participate in student-center environments, might experience higher levels of emotional engagement when compared to teacher-center approaches (e.g., Wu & Huang, 2007). We also found that students of the unstructured curriculum group had a grader level of social engagement than students of the structured curriculum group. This finding is consistent with that of Sullivan and Bers (2013), who showed that using an unstructured ER curriculum was linked with more collaboration than a structured curriculum.

The main finding is that different teaching approaches to technology curriculum design can have a significant impact on various aspects of learning. It is uncertain which method would be the best for enabling the development of students' skills in programming and problem-solving as both approaches seem to have some advantages. Therefore, we suggest that it would be better for teachers to design a curriculum with a combination of teaching approaches such as unstructured and structured activities in order students take advantage of the benefits of both approaches.

Ημερομηνία υποβολής:27/04/2020

APPENDIX III-Informed consent forms

Τεχνολογικό Πανεπιστήμιο Κύπρου

Τμήμα Πολυμέσων και Γραφικών Τεχνών

CYPRUS INTERACTION LAB

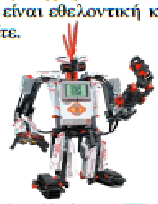
Αγαπητοί γονείς

Ονομάζομαι Χρύσανθος Σωκράτους, και είμαι υποψήφιος διδάκτορας στο Τμήμα Πολυμέσων και Γραφικών Τεχνών του Τεχνολογικού Πανεπιστημίου Κύπρου (ΤΕΠΑΚ) και δάσκαλος των παιδιών σας στο Β' Δημοτικό Σχολείο Αγίου Αθανασίου. Σε συνεργασία με την επίκουρη καθηγήτρια του Τμήματος Πολυμέσων του ΤΕΠΑΚ Δρ. Α. Ιωάννου και μετά από έγκριση από το Κέντρο Εκπαιδευτικής Έρευνας και Αξιολόγησης (ΚΕΕΑ), που υπάγεται στο Υπουργείο Παιδείας και Πολιτισμού (ΥΠΠ), διεξάγω μελέτη στην ερευνητική περιοχή της Εκπαιδευτικής Ρομποτικής.
Σκοπός της έρευνας είναι:
Α) η βαθύτερη κατανόηση των στρατηγικών επίλυσης προβλήματος, που χρησιμοποιούν οι μαθητές, αλληλεπιδρώντας με τα ρομπότ
Β) να εξετάσει κατά πόσο η ρομποτική μπορεί να αποτελέσει ένα διδακτικό εργαλείο που μπορεί να βελτιώσει τις μεταγνωστικές δεξιότητες και τις δεξιότητες αυτορύθμισης των μαθητών.

Η εκπαιδευτική ρομποτική είναι ένα καινοτόμο διδακτικό εργαλείο που στοχεύει στην ενίσχυση και την ανάπτυξη υψηλότερων νοητικών δεξιοτήτων και ικανοτήτων επίλυσης προβλήματος. Αρκετές έρευνες αναφέρουν ότι οι δραστηριότητες εκπαιδευτικής ρομποτικής έχουν θετικά αποτελέσματα στο επίπεδο της συνεργασίας μεταξύ των μαθητών, της ανάπτυξη δεξιοτήτων κριτικής σκέψης, της ανάπτυξης δεξιοτήτων επίλυσης προβλήματος, της δυνατότητας αξιοποίησης της έρευνας στην τάξη και της καλλιέργειας αλγοριθμικής σκέψης. Όσο δε αφορά την ανάπτυξη μεταγνωστικών δεξιοτήτων κατά την υλοποίηση δραστηριοτήτων εκπαιδευτικής ρομποτικής οι έρευνες είναι ακόμα σε αρχικό στάδιο.

Στη μελέτη μας θα χρησιμοποιήσουμε τα ρομποτικά πακέτα Lego Mindstorms EV3 και NXT. Τα παιδιά θα σχεδιάσουν, θα κατασκευάσουν και θα προγραμματίσουν τα ρομπότ στο πλαίσιο της διδασκαλίας μαθηματικών εννοιών. Θα έχουν την ευκαιρία να αναπτύξουν δεξιότητες όπως ή επίλυση προβλήματος, η ομαδική εργασία, η διαχείριση έργου, ο προγραμματισμός, καθώς επίσης και πολύτιμες νοητικές δεξιότητες όπως η αναλυτική και συνθετική σκέψη, η κριτική σκέψη και η δημιουργικότητα.

Για το λόγο αυτό, χρειάζεται να βιντεογραφηθεί η διδασκαλία και οι αλληλεπιδράσεις των παιδιών με τα προγραμματιζόμενα ρομπότ. Αναμένω ότι η ανταπόκριση σας θα είναι θετική. Θα ήθελα να ζητήσω τη συγκατάθεση σας για τη συμμετοχή των παιδιών σας στη μελέτη και τη βιντεογράφησή τους. Το οπτικοακουστικό υλικό, θα φυλαχτεί σε ασφαλές μέρος και θα χρησιμοποιηθεί μόνο για τους σκοπούς της μελέτης, ενώ όλες οι αναφορές για τις συζητήσεις και αντιδράσεις των παιδιών σε επιστημονικά περιοδικά θα γίνουν ανώνυμα. Εάν δημοσιευθούν οποιεσδήποτε φωτογραφίες από τη διαδικασία της ερευνητικής προσπάθειας, τα πρόσωπα των παιδιών θα είναι καλυμμένα. Η συμμετοχή των παιδιών σας στην έρευνα είναι εθελοντική και έχετε δικαίωμα απόσυρσης του παιδιού σας από την έρευνα, οποιαδήποτε στιγμή το επιθυμείτε.


Lego Mindstorms EV3

Σας ευχαριστώ εκ των προτέρων. Χρύσανθος Σωκράτους, Υποψήφιος Διδάκτορας.

Να αποκοπεί

Και να επιστραφεί
Βεβαιώνω ότι είμαι ενήμερος/η και σύμφωνος/η για τη συμμετοχή του παιδιού μου στη μελέτη και τη βιντεογράφηση κατά την αλληλεπίδρασή του με τα προγραμματιζόμενα ρομπότ.

Ονομα Παιδιού Ημερομηνία Υπογραφή Κηδεμόνα

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Επικοινωνία: Χρύσανθος Σωκράτους, chrysanthos.socratous@cyprusinteractionlab.com, 99745088

APPENDIX IV: Assessment tests

Metacognitive Awareness Inventory (MAI)

(Translated to Greek)

1. Κατά διαστήματα αναρωτιέμαι επιτυγχάνω τους στόχους μου.	όχι / μάλλον όχι / δεν ξέρω / μάλλον ναι / ναι
2. Σκέφτομαι αρκετές εναλλακτικές λύσεις σε ένα πρόβλημα, πριν απαντήσω.	όχι / μάλλον όχι / δεν ξέρω / μάλλον ναι / ναι
3. Προσπαθώ να χρησιμοποιώ τις στρατηγικές με τις οποίες έχω εργαστεί στο παρελθόν.	όχι / μάλλον όχι / δεν ξέρω / μάλλον ναι / ναι
4. Ρυθμίζω το διάβασμά μου, προκειμένου να έχω αρκετό χρόνο.	όχι / μάλλον όχι / δεν ξέρω / μάλλον ναι / ναι
5. Καταλαβαίνω τις μαθησιακές δυνατότητες και αδυναμίες μου.	όχι / μάλλον όχι / δεν ξέρω / μάλλον ναι / ναι
6. Σκέφτομαι τι πραγματικά πρέπει να μάθω πριν αρχίσω μια εργασία.	όχι / μάλλον όχι / δεν ξέρω / μάλλον ναι / ναι
7. Ξέρω πόσο καλά τα πήγα μόλις τελειώσω ένα τεστ.	όχι / μάλλον όχι / δεν ξέρω / μάλλον ναι / ναι
8. Θέτω συγκεκριμένους στόχους πριν αρχίσω μια εργασία.	όχι / μάλλον όχι / δεν ξέρω / μάλλον ναι / ναι
9. Επιβραδύνω όταν συναντώ σημαντικές πληροφορίες.	όχι / μάλλον όχι / δεν ξέρω / μάλλον ναι / ναι
10. Ξέρω τι είδους πληροφορίες είναι πιο σημαντικό να μάθω.	όχι / μάλλον όχι / δεν ξέρω / μάλλον ναι / ναι
11. Αναρωτιέμαι αν έχω εξετάσει όλες τις επιλογές κατά την επίλυση ενός προβλήματος.	όχι / μάλλον όχι / δεν ξέρω / μάλλον ναι / ναι
12. Είμαι καλός στο να οργανώνω τις πληροφορίες.	όχι / μάλλον όχι / δεν ξέρω / μάλλον ναι / ναι
13. Εστιάζω την προσοχή μου συνειδητά σε σημαντικές πληροφορίες.	όχι / μάλλον όχι / δεν ξέρω / μάλλον ναι / ναι

14. Έχω ένα συγκεκριμένο σκοπό για κάθε στρατηγική που χρησιμοποιώ.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι
15. Μαθαίνω καλύτερα όταν ξέρω κάτι σχετικό με το θέμα.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι
16. Ξέρω τι περιμένει ο δάσκαλος να μάθω.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι
17. Είμαι καλός στο να θυμάμαι πληροφορίες.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι
18. Χρησιμοποιώ διάφορες στρατηγικές μάθησης, ανάλογα με την περίπτωση.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι
19. Αναρωτιέμαι αν υπήρχε ευκολότερος τρόπος για να κάνω κάτι μετά την ολοκλήρωση μιας εργασίας.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι
20. Ελέγχω πόσο καλά μαθαίνω.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι
21. Κάνω επανάληψη σε τακτά χρονικά διαστήματα για να με βοηθήσει να καταλάβω σημαντικές συσχετίσεις.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι
22. Κάνω στον εαυτό μου ερωτήσεις σχετικές με το θέμα που θα μελετήσω πριν αρχίσω.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι
23. Σκέφτομαι πολλούς τρόπους για να λύσω ένα πρόβλημα και επιλέγω τον καλύτερο.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι
24. Συνοψίζω αυτά που έχω μάθει αφού τελειώσω.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι
25. Ζητώ τη βοήθεια των άλλων όταν δεν καταλαβαίνω κάτι.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι
26. Μπορώ να παρακινήσω τον εαυτό μου για να μάθω όταν χρειάζεται.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι
27. Γνωρίζω τι στρατηγικές χρησιμοποιώ όταν μελετώ.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι
28. Πιάνω τον εαυτό μου να αναλύει τη χρησιμότητα των στρατηγικών, ενώ μελετώ.	όχι — μάλλον όχι — δεν ξέρω — μάλλον ναι — ναι

29. Χρησιμοποιώ τις μαθησιακές μου δυνατότητες για να αντισταθμίσω τις αδυναμίες μου.	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι
30. Στρέφω την προσοχή μου στην έννοια και τη σημασία των νέων πληροφοριών.	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι
31. Δημιουργώ δικά μου παραδείγματα για να κάνω τις πληροφορίες πιο ουσιαστικές.	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι
32. Είμαι καλός κριτής του πόσο καλά καταλαβαίνω κάτι.	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι
33. Διαπιστώνω ότι χρησιμοποιώ χρήσιμες στρατηγικές μάθησης αυτόματα..	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι
34. Σταματώ συχνά για να ελέγξω τι έχω καταλάβει.	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι
35. Ξέρω πότε κάθε στρατηγική που χρησιμοποιώ είναι πιο αποτελεσματική.	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι
36. Αναρωτιέμαι πόσο καλά πέτυχα τους στόχους μου μόλις τελειώσω.	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι
37. Όταν διαβάζω δημιουργώ εικόνες ή διαγράμματα για να με βοηθήσουν να καταλάβω.	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι
38. Αναρωτιέμαι αν έχω σκεφτεί όλες τις εναλλακτικές λύσεις αφού λύσω ένα πρόβλημα.	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι
39. Προσπαθώ να αποδώσω νέες πληροφορίες με δικά μου λόγια.	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι
40. Αλλάζω στρατηγικές όταν δεν μπορώ να καταλάβω.	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι
41. Χρησιμοποιώ την οργανωτική δομή του κειμένου για να με βοηθήσει να μάθω.	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι
42. Διαβάζω προσεκτικά τις οδηγίες πριν αρχίσω μια εργασία.	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι
43. Αναρωτιέμαι αν αυτό που διαβάζω είναι σχετικό με αυτό που ήδη γνωρίζω.	όχι μάλλον όχι δεν ξέρω μάλλον ναι ναι

44. Επανεξετάζω τις υποθέσεις μου όταν μπερδεύομαι.	όχι – μάλλον όχι – δεν ξέρω – μάλλον ναι – ναι
45. Οργανώνω το χρόνο μου για να επιτύχω καλύτερα τους στόχους μου.	όχι – μάλλον όχι – δεν ξέρω – μάλλον ναι – ναι
46. Μαθαίνω περισσότερα όταν ενδιαφέρομαι για το θέμα.	όχι – μάλλον όχι – δεν ξέρω – μάλλον ναι – ναι
47. Προσπαθώ να χωρίσω το αντικείμενο που μελετώ σε μικρότερα τμήματα.	όχι – μάλλον όχι – δεν ξέρω – μάλλον ναι – ναι
48. Στρέφω την προσοχή μου σε γενικές έννοιες και όχι σε λεπτομέρειες.	όχι – μάλλον όχι – δεν ξέρω – μάλλον ναι – ναι
49. Αναρωτιέμαι πόσο καλά τα καταφέρνω, όταν μαθαίνω κάτι νέο.	όχι – μάλλον όχι – δεν ξέρω – μάλλον ναι – ναι
50. Αφού τελειώσω μια εργασία, αναρωτιέμαι αν έχω μάθει όσα θα μπορούσα να μάθω.	όχι – μάλλον όχι – δεν ξέρω – μάλλον ναι – ναι
51. Σταματώ και ξαναμελετώ νέες πληροφορίες οι οποίες δεν είναι σαφείς.	όχι – μάλλον όχι – δεν ξέρω – μάλλον ναι – ναι
52. Σταματώ και ξαναδιάβασα όταν μπερδεύομαι.	όχι – μάλλον όχι – δεν ξέρω – μάλλον ναι – ναι

Visualization and Accuracy Instrument (VisA)

Πρόβλημα 1

Ο Αντρέας και η Μαρία οδηγούν στην εθνική οδό από την Αθήνα στη Θεσσαλονίκη. Ο αυτοκινητόδρομος έχει ένα βενζινάδικο κάθε 55km. Το αυτοκίνητό τους χαλάει μετά το 196km. Ποιο βενζινάδικο είναι το πλησιέστερο, το προηγούμενο ή το επόμενο;

Ερώτηση 1

Πόσο καλά πιστεύεις ότι μπορείς να λύσεις αυτό το πρόβλημα;

Παρακαλώ εξήγησε γιατί...

....

Ερώτηση 2

Σχεδιάστε ένα σχεδιάγραμμα που μπορεί να χρησιμοποιήσεις για να λύσεις το πρόβλημα.

Ερώτηση 3

Λύσε το πρόβλημα

Ερώτηση 4

Πόσο καλά πιστεύεις ότι έλυσες το πρόβλημα;

Πρόβλημα 2

Η Μαρία φυτεύει τριανταφυλλιές κατά μήκος ενός μονοπατιού προς το σπίτι της. Το μονοπάτι έχει μήκος 27m. Φυτεύει μια τριανταφυλλιά κάθε 3m και στις δύο πλευρές του μονοπατιού. Επίσης, φυτεύει τριαντάφυλλα στην αρχή του μονοπατιού (και στις δύο πλευρές). Πόσα τριαντάφυλλα χρειάζεται η Μαρία;

Ερώτηση 1

Πόσο καλά πιστεύεις ότι μπορείς να λύσεις αυτό το πρόβλημα;

Παρακαλώ εξήγησε γιατί..

....

Ερώτηση 2

Σχεδιάστε ένα σχεδιάγραμμα που μπορεί να χρησιμοποιήσεις για να λύσεις το πρόβλημα.

Ερώτηση 3

Λύσε το πρόβλημα

Ερώτηση 4

Πόσο καλά πιστεύεις ότι έλυσες το πρόβλημα;

Πρόβλημα 3

Η περίμετρος των τροχών του ποδηλάτου στη διπλανή εικόνα είναι 80cm. Πόση

απόσταση θα καλύψει το ποδήλατο, αν οι τροχοί γυρίσουν 5 φορές;

Ερώτηση 1

Πόσο καλά πιστεύεις ότι μπορείς να λύσεις αυτό το πρόβλημα;

Παρακαλώ εξήγησε γιατί...

....

Ερώτηση 2

Σχεδιάστε ένα σχεδιάγραμμα που μπορεί να χρησιμοποιήσεις για να λύσεις το πρόβλημα.

Ερώτηση 3

Λύσε το πρόβλημα

Ερώτηση 4

Πόσο καλά πιστεύεις ότι έλυσες το πρόβλημα;

Πρόβλημα 4

Ο Κώστας ετοιμάζει σακουλάκια με γλυκά για το παζαράκι του σχολείου του. Έχει 12 σακουλάκια, 44 καραμέλες και 48 σοκολατάκια. Σε κάθε σακουλάκι βάζει 9 καραμέλες και 8 σοκολατάκια. Πόσα ίδια σακουλάκια είναι δυνατόν να ετοιμάσει;

Ερώτηση 1

Πόσο καλά πιστεύεις ότι μπορείς να λύσεις αυτό το πρόβλημα;

Παρακαλώ εξήγησε γιατί...

....

Ερώτηση 2

Σχεδιάστε ένα σχεδιάγραμμα που μπορεί να χρησιμοποιήσεις για να λύσεις το πρόβλημα.

Ερώτηση 3

Λύσε το πρόβλημα

Ερώτηση 4

Πόσο καλά πιστεύεις ότι έλυσες το πρόβλημα;

Engagement scale

Δεν υπάρχουν σωστές απαντήσεις - περιγράψτε τον εαυτό σας όπως είστε, όχι πώς θέλετε να είστε. Ο δάσκαλός σας δεν θα βαθμολογήσει αυτό.

Ποτέ	Σπάνια	Μερικές φορές	Συχνά	Πάντα
1	2	3	4	5

Γνωστική δέσμευση

1. Κατά τη συμμετοχή μου στις δραστηριότητες ρομποτικής πραγματοποιούσα τις δραστηριότητες και βεβαιωνόμουν ότι ήταν σωστές.

1 2 3 4 5

2. Σκεφτόμουν διαφορετικούς τρόπους επίλυσης ενός προβλήματος.

1 2 3 4 5

3. Προσπαθούσα να συνδέσω αυτό που μάθαινα με αυτά που ήδη γνωρίζω.

1 2 3 4 5

4. Προσπαθούσα να καταλάβω τα λάθη μου όταν έκανα λάθος.

1 2 3 4 5

5. Θα προτιμούσα γράψω απλά την απάντηση από το να κάνω ολόκληρη τη δραστηριότητα (rev)

1 2 3 4 5

6. Δεν μου άρεσε το ότι έβαζα το μυαλό μου να σκεφτεί όταν δούλευα στην τάξη (rev).

1 2 3 4 5

7. Όταν η δραστηριότητα ήταν δύσκολη, μελετούσα μόνο τα εύκολα ζητήματα (rev).

1 2 3 4 5

8. Έκανα ακριβώς ότι μου ζητούσε η δραστηριότητα και όχι περισσότερα από όσα ζητούσε.

Δέσμευση Συμπεριφοράς

9. Κατά τη συμμετοχή μου στις δραστηριότητες ρομποτικής παρέμενα συγκεντρωμένος.

1 2 3 4 5

10. Κατά τη συμμετοχή μου στις δραστηριότητες ρομποτικής προσπαθούσα πολύ για να μάθω πράγματα.

1 2 3 4 5

11. Κατά τη συμμετοχή μου στις δραστηριότητες ρομποτικής προσπαθούσα ακόμα και αν κάτι ήταν δύσκολο.

1 2 3 4 5

12. Κατά τη συμμετοχή μου στις δραστηριότητες ρομποτικής ολοκλήρωνα την εργασία μου εγκαίρως.

1 2 3 4 5

13. Μου αρέσει να μιλάω για την εκπαιδευτική ρομποτική έξω από την τάξη.

1 2 3 4 5

14. Κατά τη συμμετοχή μου στις δραστηριότητες ρομποτικής δεν συμμετείχα στην τάξη (rev).

1 2 3 4 5

15. Κατά τη συμμετοχή μου στις δραστηριότητες ρομποτικής έκανα άλλα πράγματα ενώ έπρεπε να δίνω μεγαλύτερη προσοχή (rev)

1 2 3 4 5

16. Κατά τη συμμετοχή μου στις δραστηριότητες ρομποτικής αν δεν καταλάβαινα κάτι, σταματούσα να προσπαθώ (rev).

1 2 3 4 5

Συναισθηματική δέσμευση

17. Περίμενα με ανυπομονησία τα μαθήματα εκπαιδευτικής ρομποτικής.

1 2 3 4 5

18. Χαιρόμουν που μάθαινα νέα πράγματα.

1 2 3 4 5

19. Ήθελα να καταλαβαίνω τι μάθαινα στα μαθήματα εκπαιδευτικής ρομποτικής.

1 2 3 4 5

20. Αισθανόμουν χαρούμενος κατά τη διάρκεια των μαθημάτων εκπαιδευτικής ρομποτικής.

1 2 3 4 5

21. Συχνά αισθανόμουν απογοητευμένος κατά τη διάρκεια των μαθημάτων εκπαιδευτικής ρομποτικής.

1 2 3 4 5

22. Νομίζω ότι τα μαθήματα εκπαιδευτικής ρομποτικής ήταν ανιαρά. (rev).

1 2 3 4 5

23. Δεν μου αρέσει να κάνω μαθήματα εκπαιδευτικής ρομποτικής. (rev).

1 2 3 4 5

24. Δεν με ενδιαφέρει η εκπαιδευτική ρομποτική.

1 2 3 4 5

25. Συχνά αισθανόμουν κακοδιάθετος κατά τα μαθήματα εκπαιδευτικής ρομποτικής. (rev).

1 2 3 4 5

26. Ανησυχούσα όταν μάθαινα νέα πράγματα για τα μαθηματικά μέσα από τη ρομποτική (rev).

1 2 3 4 5

Κοινωνική δέσμευση

27. Κατά τη συμμετοχή μου στις δραστηριότητες ρομποτικής στήριζα τις ιδέες των συμμαθητών μου.

1 2 3 4 5

28. Κατά τη συμμετοχή μου στις δραστηριότητες ρομποτικής προσπαθούσα να κατανοήσω τις ιδέες/απόψεις των συμμαθητών μου.

1 2 3 4 5

29. Κατά τη συμμετοχή μου στις δραστηριότητες ρομποτικής προσπαθούσα να συνεργαστώ με άλλους που μπορούσαν να με βοηθήσουν.

1 2 3 4 5

30. Κατά τη συμμετοχή μου στις δραστηριότητες ρομποτικής προσπαθούσα να βοηθήσω άλλους που προσπαθούσαν και δεν τα κατάφερναν.

1 2 3 4 5

31. Κατά τη συμμετοχή μου στις δραστηριότητες ρομποτικής δεν ενδιέφεραν οι ιδέες των συμμαθητών μου. (rev)

1 2 3 4 5

32. Κατά τη συμμετοχή μου στις δραστηριότητες ρομποτικής, όταν συνεργαζόμουν με άλλους, δεν μοιραζόμουν τις ιδέες μου μαζί τους (rev).

1 2 3 4 5

33. Δεν μου αρέσει να δουλεύω με συμμαθητές

1 2 3 4 5

Rubric for judging collaboration quality

Session: **Name of the group:**

	Score 1	Score 2	Score 3
Level of discussion	A minimal level of discussion. None or only one student generates detailed statements.	A moderate level of discussion. One student's statements are mostly substantive, and the others vary between detailed and shallow	A substantial level of discussion. Substantive statements of each student build upon those of others, indicating a shared line of reasoning
Elaboration of ideas	Students do not clarify or complete their partners' statements, instead voicing generic responses of agreement.	Statements are discontinuous as each student makes assertions independent from those of others.	Students clarify or complete their peers' statements through expanding, elaborating, restatement, or rebuttal.
The collective nature of decisions	One student decides what to write while the others agree but contribute little.	One student contributes most to what will be written while the others take a smaller, though substantive, role.	Conclusions are jointly constructed with two or more students involved fairly equally in determining what to write.
Use of questions in examining the ideas	None of the students ask why/how type questions, discuss each other's claims, or elaborate in response to questions.	Some students effectively engage in the collaboration process. A few why/how type questions are asked and discussed.	Most students effectively engage in the collaboration process. More than one type of why/how questions is asked and discussed.

	Judgment	Comments and remarks
Level of discussion	1 2 3	
Elaboration of ideas	1 2 3	
The collective nature of decisions	1 2 3	
Use of questions in examining the ideas	1 2 3	

Group metacognition scale (GMS)

Λαμβάνοντας υπόψη τι συνέβαινε στην ομάδα σας κατά τη διάρκεια των συνεργατικών δραστηριοτήτων εκπαιδευτικής ρομποτικής, αναφέρετε το βαθμό που ισχύουν οι παρακάτω δηλώσεις για την ομάδα σας χρησιμοποιώντας την ακόλουθη κλίμακα. (Considering what generally happened in your group during collaborative online activities, please indicate the extent of your agreement/disagreement with the statements by using the following scale)

Α/Α	**Ερώτηση**	**Όχι καθόλου**	**Λίγο**	**Δεν ξέρω**	**Αρκετά**	**Πάρα πολύ**
1	Γνωρίζουμε τις δυνατότητες μας (We know our strengths as learners)					
2	Ξέρουμε πώς να επιλέγουμε πληροφορίες σχετικές με το θέμα (We know how to select relevant information))					
3	Ξέρουμε πώς να χρησιμοποιούμε το υλικό (We know how to use the material)					
4	Ξέρουμε πώς να οργανώνουμε νέες πληροφορίες (We know how to organize new information)					
5	Ξέρουμε πώς να συνδέουμε νέες πληροφορίες με προηγούμενες γνώσεις (We know how to connect new information with prior knowledge)					
6	Σχεδιάζουμε τις δραστηριότητες μας (We plan the activities)					
7	Προσδιορίζουμε τι απαιτεί η δραστηριότητα (We determine what the task requires)					
8	Επιλέγουμε τα κατάλληλα εργαλεία (We select the appropriate tools)					
9	Προσδιορίζουμε τις στρατηγικές που θα χρησιμοποιήσουμε ανάλογα με τη δραστηριότητα (We identify the strategies depending on the task)					
10	Οργανώνουμε τον χρόνο μας ανάλογα με τη δραστηριότητα					

	(We organize our time depending on the task)					
11	Τροποποιούμε την εργασία μας σύμφωνα με προτάσεις/υποδείξεις άλλων συμμετεχόντων στην ομάδα (We modify our work according to other group participants' suggestions)					
12	Κάνουμε ερωτήσεις για να ελέγξουμε την κατανόησή μας (We ask questions to check our understanding)					
13	Ελέγχουμε την προσέγγισή μας και τον τρόπο εργασίας μας για να βελτιώσουμε τα αποτελέσματά μας (We check our approach to improve our outcomes)					
14	Βελτιώνουμε τη δουλειά μας μέσα από ομαδικές διαδικασίες (We improve our work with group processes)					
15	Εντοπίζουμε και διορθώνουμε λάθη (We detect and correct errors)					
16	Κρίνουμε τη δυσκολία μιας δραστηριότητας (We make judgments on the difficulty of the task)					
17	Κάνουμε κρίσεις για τον φόρτο εργασίας (We make judgments on the workload)					
18	Κάνουμε κρίσεις για τα εργαλεία που θα χρησιμοποιήσουμε (We make judgments on the instruments)					
19	Κάνουμε κρίσεις για το τι μάθαμε από τη δραστηριότητα (We make judgments on our learning outcomes)					
20	Κρίνουμε τη διαδικασία ομαδικής εργασίας που ακολουθήσαμε (We make judgments on the teamwork process)					

Group cohesiveness questionnaire

NAME:

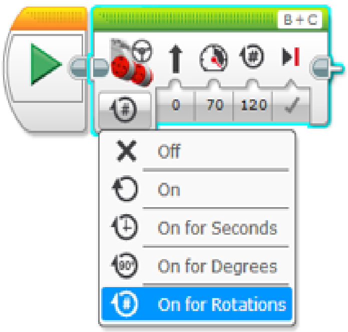
Ερώτηση	Διαφωνώ απόλυτα	Διαφωνώ	Ούτε συμφωνώ ούτε διαφωνώ	Συμφωνώ	Συμφωνώ απόλυτα
Χαίρομαι που ανήκω σε αυτή την ομάδα. (I'm glad I belong to this group)					
Νιώθω άβολα σε αυτή την ομάδα. (I feel held back by this group)					
Είμαι ένα σημαντικό μέρος αυτής της ομάδας. (I am an important part of this group)					
Δεν ταιριάζω με τα άλλα παιδιά αυτής της ομάδα. (I don't fit in with other kids in this group)					
Νιώθω έντονα συνδεδεμένος με αυτήν την ομάδα. (I feel strongly tied to this group)					
Δεν νομίζω ότι η ομάδα είναι τόσο σημαντική. (I don't think the group is that important)					
Νομίζω ότι αυτή η ομάδα λειτούργησε καλά μαζί. (I think this group worked well together)					

Debugging test

Δραστηριότητα 1

Η ομάδα του Γιάννη πρέπει να προγραμματίσει το ρομπότ να κινείται ακριβώς στα 120cm. Έφτιαξαν το πρόγραμμα που φαίνεται στην εικόνα αλλά το ρομπότ τους κινείται πολύ περισσότερο από 120cm. Η περιφέρεια του τροχού του ρομπότ τους είναι 17cm. Πού βρίσκεται το λάθος στο πρόγραμμά τους;

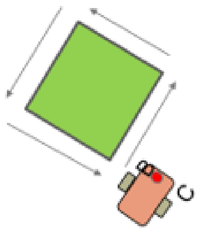
- **Κύκλωσε το λάθος**



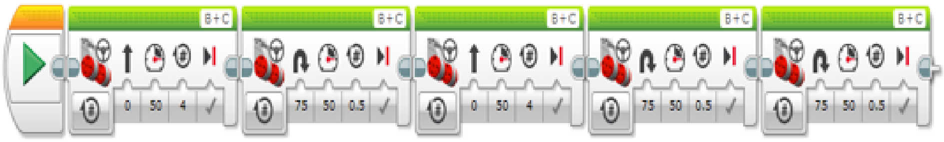
- **Πρότεινε μια λύση στο λάθος (σχεδίασε ή γράψε τη λύση σου με λόγια)**

Δραστηριότητα 2

Η ομάδα του Γιάννη πρέπει να προγραμματίσει το ρομπότ έτσι ώστε να κινείται σε ένα τετράγωνο χωρίς τη χρήση αισθητήρων. Έφτιαξαν το πρόγραμμα που φαίνεται πιο κάτω, αλλά το ρομπότ τους έχασε το τετράγωνο σχήμα στη διαδρομή του. Το πρόγραμμα είναι ενεργοποιημένο στις περιστροφές. Πού είναι το λάθος στο πρόγραμμά τους;



- **Κύκλωσε το λάθος**



- **Πρότεινε μια λύση στο λάθος (σχεδίασε ή γράψε τη λύση σου με λόγια)**

Δραστηριότητα 3

Μια ομάδα έχει προγραμματίσει το ρομπότ της ώστε να κινηθεί προς τα εμπρός για 7 περιστροφές, στη συνέχεια να στρίβει προς τα δεξιά για 1 περιστροφή και να σταματάει. Το αποτέλεσμα στην εκτέλεση του προγράμματός τους δεν ήταν όπως ανέμεναν. Το ρομπότ κινήθηκε προς τα εμπρός για 7 περιστροφές και στη συνέχεια σταμάτησε χωρίς να εκτελέσει τη δεξιά στροφή. Πού είναι το σφάλμα στο πρόγραμμά τους;

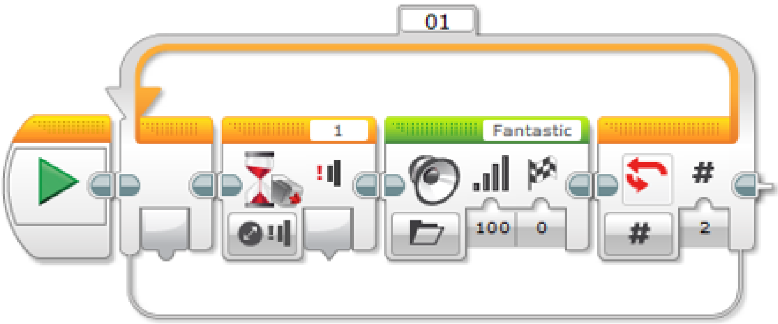
- **Κύκλωσε το λάθος**

- **Πρότεινε μια λύση στο λάθος (σχεδίασε ή γράψε τη λύση σου με λόγια)**

Δραστηριότητα 4

Μια ομάδα προγραμμάτισε το ρομπότ της έτσι ώστε όταν πιέζεται ο αισθητήρας αφής το ρομπότ να λέει "φανταστικό". Πρόσθεσαν επίσης ένα loop στο πρόγραμμα για τη συνεχή λειτουργία του προγράμματος. Όταν η ομάδα εκτέλεσε το πρόγραμμά, μόνο τις δύο πρώτες φορές το πρόγραμμα εκτελέστηκε σωστά. Τις επόμενες φορές που πιεζόταν ο αισθητήρας αφής το ρομπότ δεν αντιδρούσε όπως αναμενόταν. Γιατί το πρόγραμμά τους δεν λειτούργησε σωστά; Πού ήταν το σφάλμα;

- **Κύκλωσε το λάθος**

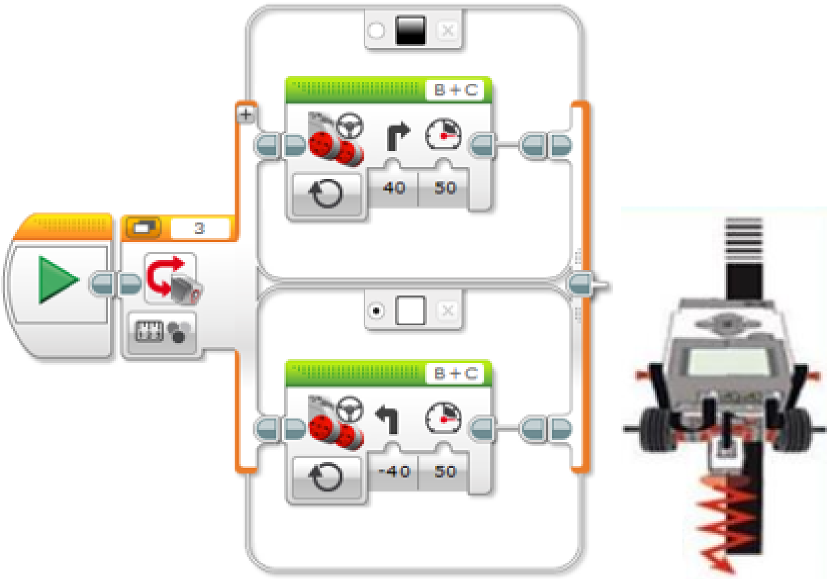


- **Πρότεινε μια λύση στο λάθος (σχεδίασε ή γράψε τη λύση σου με λόγια)**

Δραστηριότητα 5

Μια ομάδα προγραμμάτισε το ρομπότ έτσι ώστε να ακολουθεί μια μαύρη γραμμή. Προγραμμάτισαν το ρομπότ να στρίβει δεξιά όταν βλέπει μαύρο χρώμα και αριστερά όταν βλέπει άσπρο χρώμα. Το ρομπότ κινήθηκε στη γραμμή μόνο για λίγο και μετά σταμάτησε. Έβαλαν τον αισθητήρα χρώματος στη μαύρη γραμμή και εκτέλεσαν το πρόγραμμα. Το ρομπότ έστριψε δεξιά στο λευκό χρώμα και έπειτα γύρισε αριστερά στο μαύρο χρώμα και σταμάτησε. Πού ήταν το λάθος στο πρόγραμμά τους; Γιατί σταμάτησε;

- **Κύκλωσε το λάθος**



- **Πρότεινε μια λύση στο λάθος (σχεδίασε ή γράψε τη λύση σου με λόγια)**

Δραστηριότητα 6

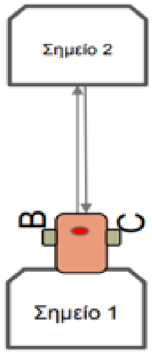
Μια ομάδα προγραμμάτισε το ρομπότ της ώστε να κινείται προς τα εμπρός χρησιμοποιώντας τον αισθητήρας απόστασης. Μόλις ο αισθητήρας απόστασης αναγνώριζε ένα αντικείμενο στα 20cm το ρομπότ θα έπρεπε να σταματάει. Εκτέλεσαν το πρόγραμμά τους, άκουσαν τον ήχο εκκίνησης από το brick αλλά το ρομπότ δεν κινήθηκε καθόλου. Το πρόγραμμά τους φαίνεται στην πιο κάτω εικόνα. Πού βρίσκεται το λάθος;

- **Κύκλωσε το λάθος**

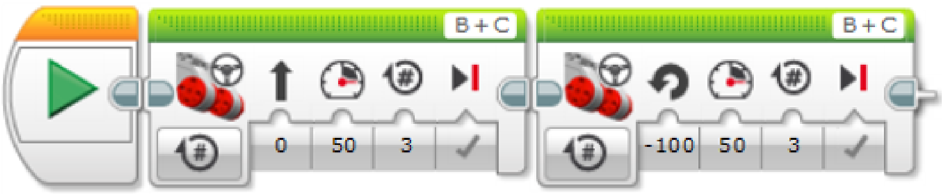
- **Πρότεινε μια λύση στο λάθος (σχεδίασε ή γράψε τη λύση σου με λόγια)**

Δραστηριότητα 7

Μια ομάδα προγραμμάτισε το ρομπότ έτσι ώστε να κινείται προς τα εμπρός για 3 περιστροφές και μετά να επιστρέφει στην αρχική του θέση. Κατά τη διάρκεια της εκτέλεσης, οι μαθητές συνειδητοποίησαν ότι το ρομπότ κινήθηκε προς τα εμπρός για 3 περιστροφές και στη συνέχεια στράφηκε προς τα αριστερά. Ως αποτέλεσμα, το ρομπότ δεν επέστρεψε στην αρχική θέση. Δες το πρόγραμμά τους στην παρακάτω εικόνα και βρες το λάθος.



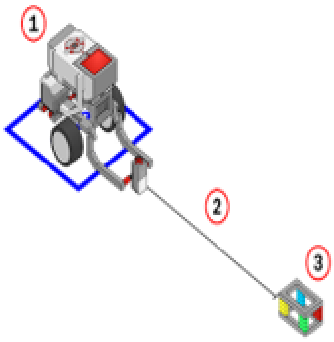
- **Κύκλωσε το λάθος**



- **Πρότεινε μια λύση στο λάθος (σχεδίασε ή γράψε τη λύση σου με λόγια)**

Δραστηριότητα 8

Μια ομάδα προγραμμάτισε το ρομπότ της έτσι ώστε με το πάτημα του αισθητήρα αφής το cargo να ανεβαίνει προς τα πάνω και να κινείται προς τα εμπρός για 5 περιστροφές. Όταν θα έφτανε στο κουτί (σημείο 3) τότε έπρεπε να το πιάνει και να το μεταφέρει στη θέση από την οποία ξεκίνησε το ρομπότ (θέση 1). Η ομάδα έφτιαξε το πρόγραμμα που φαίνεται στην εικόνα και παρόλο που το πρόγραμμά τους φαινόταν σωστό, κάποιες φορές η εκτέλεσή τους ήταν επιτυχημένη και κάποιες φορές όχι. Γιατί νομίζεις ότι συνέβαινε αυτό; Μπορείς να σκεφτείς παράγοντες που επηρέαζαν την ακρίβεια εκτέλεσης του προγράμματός τους;



- **Γιατί συνέβαινε αυτό; Ποιοι παράγοντες μπορεί να επηρέαζαν την ακρίβεια εκτέλεσης του προγράμματός τους;**

....
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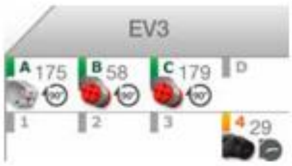
- **Πρότεινε μια λύση στο λάθος (σχεδίασε ή γράψε τη λύση σου με λόγια)**

Δραστηριότητα 9

Μια ομάδα προσπαθούσε να προγραμματίσει το ρομπότ της έτσι ώστε να σταματάει όταν έβλεπε ένα αντικείμενο κοντά του στα 30cm. Έφτιαξε το πρόγραμμα που φαίνεται στην εικόνα αλλά κατά την εκτέλεση του προγράμματος, το ρομπότ συνέχιζε να κινείτε με αποτέλεσμα να χτυπάει στα αντικείμενα χωρίς να σταματάει πουθενά. Γιατί νομίζεις ότι συνέβαινε αυτό; Ποιο ήταν το λάθος στο πρόγραμμά τους;

- **Κύκλωσε το λάθος**



- **Πρότεινε μια λύση στο λάθος (σχεδίασε ή γράψε τη λύση σου με λόγια)**

Δραστηριότητα 10

Η ομάδα του Γιάννη προγραμμάτισε το ρομπότ της ώστε να κινείται προς τα εμπρός για 100cm, να σταματάει για 3 δευτερόλεπτα, να ακούγεται ένας ήχος και ακολούθως να επιστρέφει στην αρχική του θέση. Στην εκτέλεση του προγράμματος το ρομπότ κινήθηκε όπως έπρεπε προς τα εμπρός, σταμάτησε για 3 δευτερόλεπτα χωρίς να ακουστεί κάποιος ήχος από το brick και επέστρεψε στην αρχική του θέση. Ποιο ήταν το λάθος στο πρόγραμμά τους;

- **Σημείωσε στην εικόνα ποια εντολή λείπει**

- **Πρότεινε μια λύση στο λάθος (σχεδίασε ή γράψε τη λύση σου με λόγια)**

Focus group interview protocol

Focus Group Protocol (Nov-25-2019)

Group Number: ___________ Names: ______________

Thank you for your participation in this interview. We would like to hear your ideas and opinions about your experiences during this intervention period**.** The interview will be videotaped but your responses will remain confidential. We don't identify anyone by name in our report. You will remain anonymous. The interview will last 20 minutes. You can choose not to participate. You can interrupt or stop the conversation whenever you want. I want you to do the talking. I would like everyone to participate- only one individual speaking at a time please. There are no right or wrong answers. All student's experiences and opinions are important. Speak up whether you agree or disagree. I want to hear a wide range of opinions.

Engagement questions:

A. Συναισθηματική δέσμευση (Emotional engagement)

1. Πώς σας φάνηκαν τα μαθήματα εκπαιδευτικής ρομποτικής; Σας άρεσαν; Βαρεθήκατε;
2. Τι σας άρεσε περισσότερο; Τι δεν σας άρεσε; Γιατί σας άρεσε; Γιατί δεν σας άρεσε;
3. Νοιώσατε ποτέ απογοητευμένοι κατά τη διάρκεια του μαθήματος; Θυμάστε ποιο ήταν το πρόβλημα;
4. Στην πορεία των μαθημάτων, επιζητούσατε καθόλου τα μαθήματα ρομποτικής; Περιμένατε πότε θα περάσει η βδομάδα για να κάνετε ξανά το μάθημα;
5. Πώς αισθανόσασταν τη μέρα που θα είχατε τα μαθήματα ρομποτικής;
6. Μάθατε νέα πράγματα; Ήσασταν χαρούμενοι που μαθαίνατε νέα πράγματα;

B. Γνωστική δέσμευση (Cognitive engagement)

7. Όταν δυσκολευόσασταν σε μια αποστολή σκεφτόσασταν διαφορετικούς τρόπους προσέγγισης;

8. Προσπαθούσατε να συνδέσετε αυτά που μαθαίνατε με αυτά που ήδη γνωρίζατε από άλλα μαθήματα όπως για παράδειγμα τα μαθηματικά και οι φυσικές επιστήμες;

9. Προσπαθούσατε να καταλάβετε τα λάθη σας;

10. Προτιμούσατε μια εύκολη η μια δύσκολη αποστολή; Γιατί;

11. Κάνατε ακριβώς ότι ζητούσε η άσκηση ή κάποιες φορές ερευνούσατε από μόνοι σας περισσότερα πράγματα από όσα ζητούσε;

Γ. Δέσμευση συμπεριφοράς (Behavioral engagement)

12. Μπορούσατε να παραμείνετε συγκεντρωμένοι κατά τη διάρκεια των μαθημάτων εκπαιδευτικής ρομποτικής; Γιατί νομίζετε ότι συνέβαινε αυτό;

13. Προσπαθούσατε να ολοκληρώσετε την δραστηριότητα ακόμη και αν ήταν πολύ δύσκολη;

14. Μιλούσατε για την εκπαιδευτική ρομποτική έξω από την τάξη; Σας άρεσε να μιλάτε για τα μαθήματα εκπαιδευτικής ρομποτικής;

15. Κατά τη διάρκεια των δραστηριοτήτων κάνατε άλλα πράγματα ή ήσασταν προσκολλημένοι στο μάθημα της ρομποτικής;

16. Κατά τη διάρκεια των δραστηριοτήτων, αν κάτι δεν το καταλαβαίνατε σταματούσατε να προσπαθείτε;

Δ. Κοινωνική δέσμευση (Social engagement)

17. Προσπαθούσατε να κατανοήσετε τις ιδέες/απόψεις των συμμαθητών σας;

18. Σας ενδιέφεραν οι ιδέες των συμμαθητών σας; Ακόμη και αν διαφωνούσατε με αυτές;

19. Συνεργαζόσασταν με άλλους μέσα στην ομάδα ή και με άλλους συμμαθητές σας σε άλλες ομάδες που μπορούσαν να σας βοηθήσουν; Μοιραζόσασταν τις ιδέες σας;

20. Βοηθούσατε άλλους στην ομάδα σας ή σε άλλη ομάδα που προσπαθούσαν και δεν τα κατάφερναν;

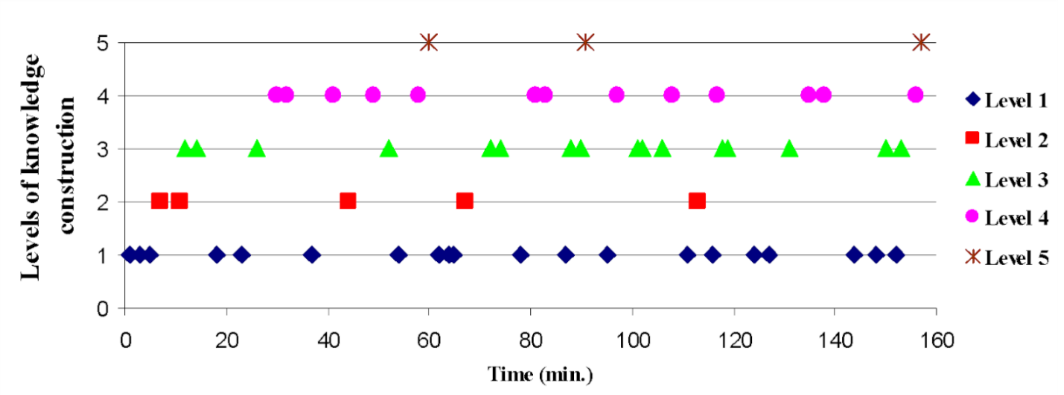
21. Σας άρεσε που εργαζόσασταν σαν ομάδα ή θα προτιμούσατε να εργάζεστε μόνοι σας; Γιατί;

Common errors-bugs questions

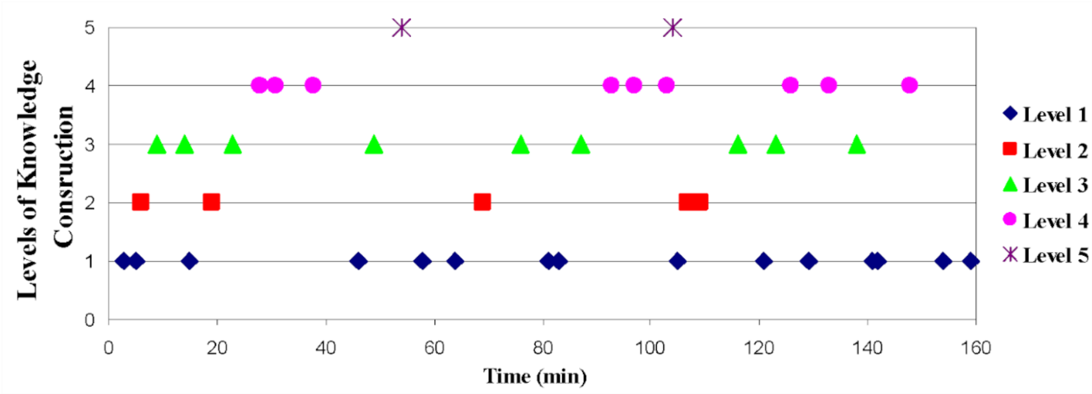
1. Θυμάστε μερικά από τα λάθη που κάνατε στον προγραμματισμό; Ποια ήταν αυτά; Πότε συνέβησαν; Σε ποια δραστηριότητα;
2. Τι κάνατε για να λύσετε το πρόβλημα; Τα καταφέρατε; Πώς τα καταφέρατε; Ζητήσατε βοήθεια από κάποιον άλλο;
3. Ποιο ήταν το πιο συχνό λάθος που κάνατε; Μάθατε να το λύνετε και να προχωράτε;
4. Θυμάστε ποιο ήταν το δυσκολότερο λάθος που είχατε αντιμετωπίσει; Το ξεπεράσατε; Πώς το ξεπεράσατε; Ποιο ήταν το λάθος;
5. Πώς ελέγχατε ή πώς καταλαβαίνατε ότι υπήρχαν λάθη στον προγραμματισμό σας;
6. Πώς αναγνωρίζατε σε ποια εντολή βρισκόταν το λάθος και πώς το ξεπερνούσατε αφού πλέον γνωρίζατε που βρισκόταν;
7. Πώς αισθανόσασταν όταν ξεπερνούσατε ένα λάθος;
8. Πώς αισθανόσασταν σε μια αποστολή που κάνατε συνεχόμενα λάθη και πραγματικά δυσκολευόσασταν;
9. Σε ποιο μέρος της παρέμβασης κάνατε περισσότερα λάθη προγραμματισμού; Γιατί συνέβαινε αυτό;
10. Καταλήξατε σε κάποιον γενικό κανόνα για την αποφυγή αχρείαστων λαθών;
11. Θεωρείτε ότι αν είχατε περισσότερο χρόνο για να γνωρίσετε το περιβάλλον προγραμματισμού του EV3 θα κάνατε λιγότερα λάθη; Γιατί;
12. Θεωρείτε ότι θα ήταν το ίδιο ελκυστικό το μάθημα ρομποτικής χωρίς τα λάθη προγραμματισμού;
13. Μάθατε κάτι μέσα από αυτά τα λάθη; Τι μάθατε;

APPENDIX V: Qualitative results

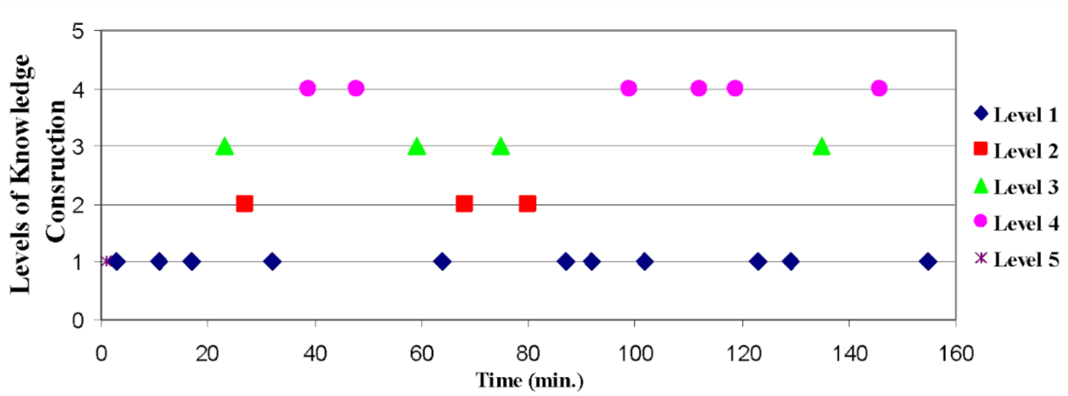
Coding results- Cycle 1



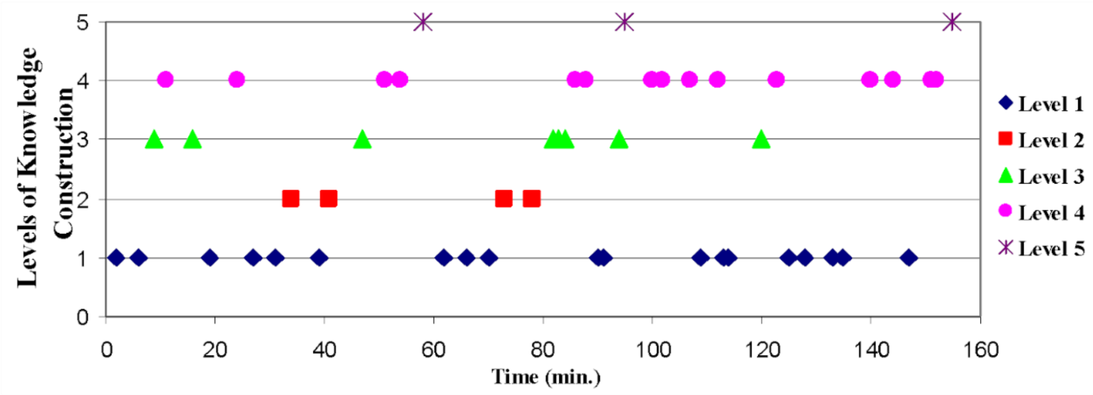
Chronological Visual of Group 1



Chronological Visual of Group 2



Chronological Visual of Group 3

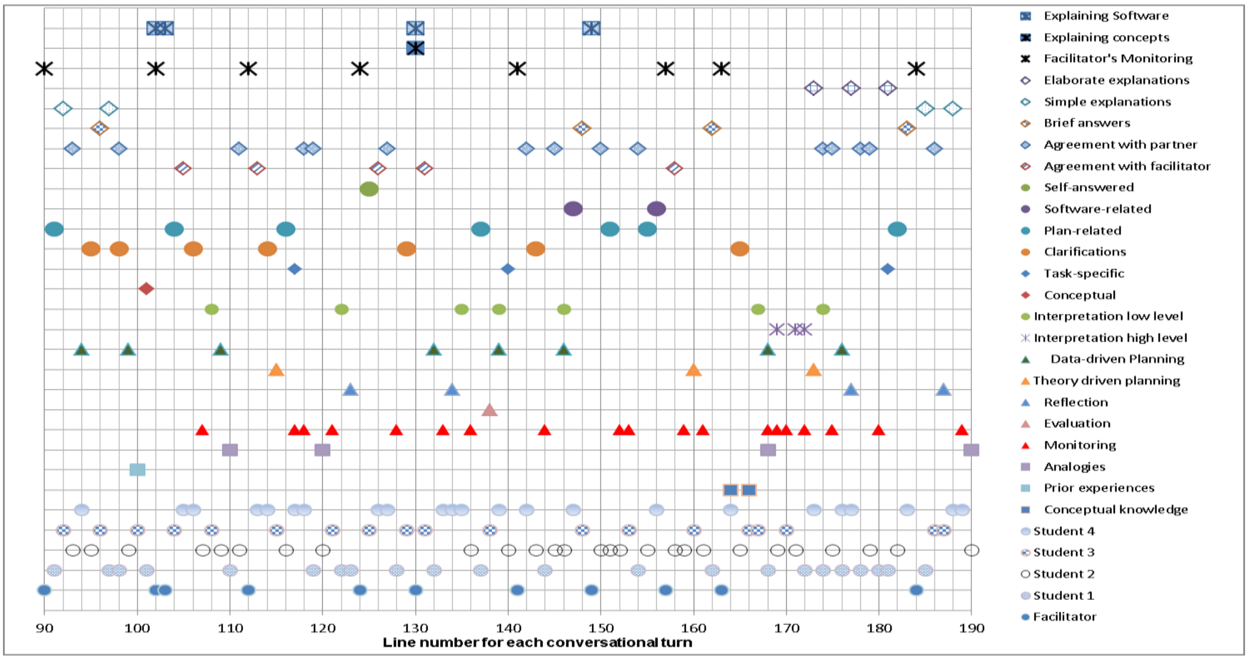


Chronological Visual of Group 4

Major categories and subcategories frequencies

Coding categories	**N (%)**	**Coding categories**	**N (%)**
Knowledge	***29 (5.2%)***	***Collaboration***	***355 (63.9%)***
Conceptual knowledge	5 (0.9%)	Conflict	26 (4.8%)
Prior experiences	4 (0.7%)	Conceptual	3 (0.6%)
Analogies	20 (3.6%)	Task-specific	23 (4.1%)
Metacognition	***134 (24.1%)***	Questioning	*126 (22.7%)*
Monitoring	74 (13.3%)	Clarifications	30 (5.4%)
Evaluation	4 (0.7%)	Plan-related	44 (7.9%)
Reflection	19 (3.4%)	Software-related	22 (4%)
Total planning	37 (6.7%)	Self-answered	5 (0.9%)
Theory-driven Planning	2 (0.4%)	General	2 (0.4%)
Data-driven Planning	33 (5.9%)	Facilitator	23 (4.1%)
Unjustified	2 (0.4%)	Responses	135 (24.3%)
Interpretation	***38 (6.8%)***	Agreement with facilitator	20 (3.6%)
High-level	7 (1.3%)	Agreement with peer	71 (12.8)
Low-level	31 (5.5%)	Brief answers	24 (4.3%)
		Simple explanations	16 (2.9%)
		Elaborate explanations	4 (0.7%)
		Facilitator's input	68 (12.1%)
		Monitoring	41 (7.4%)
		Explaining concepts	3 (0.4%)
		Explaining Software	24 (4.3%)

CORDTRA diagram of students' contributions.



APPENDIX VI – Statistical results

Descriptive statistics– Cycle 2

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Mean	Structured Curriculum Group	16	3.7891	.52185	.13046
	Unstructured Curriculum Group	19	3.6908	.45903	.10531

Independent Samples Test -Cycle 2

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Mean	Equal variances assumed	.269	.608	.593	33	.557	.09827	.16578	-.23902	.43556
	Equal variances not assumed			.586	30.223	.562	.09827	.16766	-.24403	.44058

Non-parametric Mann-Whitney U Test-Cycle 3

Ranks

	Group	N	Mean Rank	Sum of Ranks
TOTAL_ALL	Structured Curriculum Group	4	7.50	30.00
	Unstructured Curriculum Group	5	3.00	15.00
	Total	9		

Test Statistics[a]

	TOTAL_ALL
Mann-Whitney U	.000
Wilcoxon W	15.000
Z	-2.481
Asymp. Sig. (2-tailed)	.013
Exact Sig. [2*(1-tailed Sig.)]	.016[b]

a. Grouping Variable: Group

b. Not corrected for ties.

APPENDIX VII: Curriculum vitae

Chrysanthos Socratous

Personal Details

Name	Chrysanthos Socratous
Email	chrysanthos@cyprusinteractionlab.com

Education

09/2017 – present **PhD Candidate**

Department of Multimedia and Graphic Arts, Cyprus University of Technology, Limassol, Cyprus. **Dissertation title:** Collaborative knowledge construction and metacognition in CSCL via educational robotics

MA in Pedagogical Sciences (specialisations: Information and communication technology (ICT) in education), Faculty of Philosophy, School of Philosophy and Education, Aristotle University of Thessaloniki, Thessaloniki, Greece GPA: 9.20 out of 10 (09/2004 – 06/2008)

BA in Primary education, Faculty of Education, School of Primary Education, Aristotle University of Thessaloniki, Thessaloniki, Greece, GPA: 8.92 out of 10 (09/2004 – 06/2008)

Professional Experience

09/2008 – 2011 Primary school teacher

Adamantios Private School, Pylaia, Thessaloniki

09/2012- current Primary school teacher

Public primary schools, Limasol, Cyprus

Research Related Activities

(A) Research Interests

My general research interests are on the use of ER in CSCL settings for the development of higher-order thinking skills.

More specifically my research interests are:

- Computer-Supported Collaborative Learning

- Educational Technology Integration

- Problem-based Learning

- Learning Design

(B) Research Lab Affiliation

09/2017 – present Cyprus Interaction Lab, Lab Member

Honours and Awards

12/2018 Scholarship from the Youth Board of Cyprus for supporting research on youth related issues.

11/2017 Full scholarship from the Cyprus Scholarship Foundation (IKYK) for PHD studies.

11/2008 Full scholarship from the Cyprus Scholarship Foundation (IKYK) for MA studies.

6/2008 Excellent Graduate Student, Award from the Department of Primary Education, Aristotle University of Thessaloniki, Thessaloniki, Greece.

Teaching

(A) Overview of Teaching Experience

Since 2008 I have been working as a teacher in private and public elementary schools in Greece and Cyprus. All these years, new technologies were an integral part of my teaching.

(B) Pedagogical Approach

My pedagogical philosophy is underpinned by social constructivism and constructionism (Papert, 1980; 1991; 1993). I believe that learning can happen most effectively when people are collaboratively active in making tangible objects in the real world or in the world of the computer. In this sense, ER and constructionism are connected with experiential learning. In my classroom I endeavour in engaging students in challenging authentic real-life situations using educational robotics.

Publications

A. Articles in Refereed Journals

Socratous, C., & Ioannou, A. (2021). Structured or unstructured educational robotics curriculum? A study of debugging in block-based programming. Educational Technology Research and Development, 69(6), 3081-3100.

Socratous, C., & Ioannou, A. (2022). Educational robotics in CSCL: evaluating the impact of the curriculum structure on group metacognition, cohesiveness and collaboration quality. TechTrends (under review).

B. Articles in Refereed Conference Proceedings

Socratous, C., & Ioannou, A. (2018). A Study of Collaborative Knowledge Construction in STEM via Educational Robotics. In J. Kay & R. Luckin (Eds.), Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences (ICLS) 2018 (Vol. 1, pp. 496-503). London, UK: ISLS.

Ioannou, A., Socratous, C., & Nikolaedou, E. (2018, September). Expanding the Curricular Space with Educational Robotics: A Creative Course on Road Safety. In European Conference on Technology Enhanced Learning - ECTEL 2018 (pp. 537-547). Springer, Cham.

Socratous, C., & Ioannou, A. (2019). Using Educational Robotics as Tools for Metacognition: An Empirical Study in Elementary STEM Education. In International Conference of Immersive Learning Research Network (iLRN

2019) (pp. 72-83), Westminster, London, UK. DOI: https://doi.org/10.3217/978-3-85125-657-4-01

Socratous, C., & Ioannou, A. (2019). An empirical study of educational robotics as tools for group metacognition and collaborative knowledge construction. In Lund, K., Niccolai, G. P., Lavoué, E., Hmelo-Silver, C., Gweon, G., and Baker, M. (Eds.). A Wide Lens: Combining Embodied, Enactive, Extended, and Embedded Learning in Collaborative Settings, 13th International Conference on Computer Supported Collaborative Learning (CSCL), Volume 2. Lyon, France: International Society of the Learning Sciences.

Socratous, C. & Ioannou, A. (2020). Common Errors, Successful Debugging, and Engagement During Block-based Programming Using Educational Robotics in Elementary Education. In Gresalfi, M. and Horn, I. S. (Eds.), The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 2 (pp. 991-998). Nashville, Tennessee: International Society of the Learning Sciences.

C. Conference Presentations and Proceedings (refereed extended abstracts)

Socratous, C., Ioannou, A., & Stylianou-Georgiou, A. (2018, April). An Empirical Study of Educational Robotics as Tools for Metacognition and Collaborative Knowledge Construction. Paper presented at the annual meeting of the American Educational Research Association, NY, New York.