An Empirical Study of Educational Robotics as Tools for Group Metacognition and Collaborative Knowledge Construction

Chrysanthos Socratous, Cyprus Interaction Lab, Cyprus University of Technology, chrysanthos@cyprusinteractionlab.com
Andri Ioannou, Cyprus Interaction Lab, Cyprus University of Technology, Research Center on Interactive Media, Smart Systems and Emerging Technologies (RISE), andri@cyprusinteractionlab.com

Abstract: The affordances of Educational Robotics (ER) for advancing teaching and learning has become a widely researched topic. This study aims to identify the major components of collaborative knowledge construction in an ER learning environment and to investigate the mediating role of ER as mindtools to support group metacognition. Data analysis involved a micro-level examination of students' discourse, interaction with the technology, peers and the facilitator, using fine-grained analysis of video and audio recordings. The results made evident that metacognition, along with questioning and answering, were prevalent elements of collaborative knowledge construction around ER. We support that ER can be used as a learning tool and can be effective in supporting group metacognition through immediate feedback, openly accessible programmability and students' embodied interaction with the physical robot. Beyond the instrumental role of ER for supporting metacognitive processes in CSCL settings, the study provides initial evidence for a temporal relation of metacognitive talk to collaborative talk in group problem-solving.

Introduction

The use of Educational robotics (ER) in educational contexts to support teaching and learning has become an extensively researched topic. ER is constructible and programmable high-tech devices which can be employed in education as constructivist learning tools to support teaching and learning through hands-on activities. ER too early earned an influential role as a research field, motivating the attention of many schools, and universities, both from an instructive and a research point of view. Jonassen (2000) first introduced the theoretical background and the motivation for the integration of robotic technologies as cognitive tools which can improve and enrich the educational process. According to Gaudiello and Zibetti (2013), two features of ER are linked to their high educational potential; "transparency" and "interactivity." "Transparency" refers to the openly accessible programmability of the robot whilst, "interactivity" refers to the immediacy of the feedback given by the robot when a student programs and executes the commands (Gaudiello & Zibetti, 2013).

Many studies have focused on exploring the affordances of ER in promoting several transversal skills such as problem-solving (e.g., Atmatzidou, Demetriadis & Nika, 2018), collaboration (e.g., Ardito, Mosley & Scollins, 2014), and computational thinking (e.g., Bers, Flannery, Kazakoff & Sullivan, 2014; Constantinou & Ioannou, 2018). Still, ER as metacognitive tools have been considered only recently (e.g., La Paglia, Caci, La Barbera & Cardaci, 2010; Gaudiello & Zibetti, 2013) and the research evidence is inconsistent. Further investigation in the area is needed to fully understand the potential of ER in supporting students' metacognitive processes and especially socially-mediated metacognitive processes in CSCL settings.

We present an empirical investigation of ER in a CSCL experience aiming at engaging students in collaboration and co-construction of shared understandings in the mathematics domain. In this work, the whole experience around using the robot is seen as a metacognitive experience that assists students to become more aware of their process of thinking and learning. We aim to unfold the elements of collaborative knowledge construction, identify details of the metacognitive processes during students' interaction with the robot and their peers, and document the educational potential of ER as tools for supporting group metacognition. Specifically, the research questions of this study are the following:

1. What are the elements of collaborative knowledge construction in an ER learning environment?
2. How does ER help to activate group metacognitive processes?
3. What is the relationship between collaborative talk and metacognitive talk in ER learning settings?

In the following lines, we present the theoretical framework of the study, findings from previous empirical studies, methodology, and findings from the present investigation along with discussion of the implications of this work.

Theoretical framing

 © ISLS

Metacognition

Whilst, over the past years various theoretical models of metacognition have evolved, researchers agree that metacognition consists of three or at least two fundamental processes. According to Schraw and Moshman (1995), metacognition can be divided into a knowledge component (knowledge of cognition) and a skill component (regulation of cognition). Other researchers have expanded this model suggesting a three-tier model of metacognition namely, metacognitive knowledge, metacognitive judgments and monitoring, and self-regulation and control (Pintrich, Wolters, & Baxter, 2000). More recently Efklides (2011) proposed a complex interplay between the task level, the person level (where metacognitive knowledge and skills are located) and the interaction level (where metacognitive experiences take place).

There are already some studies examining the use of ER to promote metacognition at the individual level. For example, a study by Keren and Fridin (2014), examined how ER can assist the teaching of geometric thinking and promote children's metacognitive development. Findings from the study showed that students' performance on geometric thinking and metacognitive tasks were improved because of their participation in ER activities. Also, to investigate the process of constructing and programming robots as metacognitive tools, La Paglia et al. (2010) found that ER may be conceptualized as a novel metacognitive setting that motivates learners to monitor and control their own learning actions. Gaudiello and Zibetti (2013) tried to identify and classify the heuristics that are applied by elementary school students while they interact with and control ER technologies. The results demonstrated three main types of heuristics: (a) procedural-oriented, (b) declarative-oriented, and (c) metacognitive-oriented. Atmatzidou, Demetriadis, and Nika (2018) investigated the development of students' metacognitive skills in ER activities when the facilitators performed different levels of guidance (low and high) in different age groups. The results suggested that strong guidance had a positive impact on students' development of metacognitive thinking skills independently of their age and gender.

Group metacognition

There is a recent shift in the literature towards the study of group metacognition rather than metacognition as an individual endeavor. Yet, research on metacognition in group (e.g., CSCL) situations is not well developed, despite group learning being commonplace in schools and other learning environments (Smith & Mancy, 2018). Despite the limited research on group metacognition, some findings suggest that metacognition is mediated and socially shared among group members in collaborative activities (Goos, Gailbraith & Renshaw, 2002) and that group metacognition can be considered as an extension of individual metacognition into group interactions. Also, researchers agree that metacognition in group situations consist of students' monitoring, reflecting and controlling of one-another's knowledge and actions. In CSCL research, the potential role of CSCL tools for supporting group metacognition has not been examined to date. As Järvelä and Hadwin (2013) explained, the potential role of CSCL tools for supporting the planning, monitoring, and regulation of collaborative learning processes has been virtually ignored. In this work, we see ER as CSCL tools that can promote students' metacognitive thinking. Most of ER activities are collaborative learning activities, yet, there are virtually no studies in the CSCL literature that examine the impact of ER on the development of group metacognition as an essential part of group work.

Methods

Participants

The participants were 14 students (6 male and 8 female) in Grades 4, 5 and 6 (aged 9-11 years old) in a public primary school in Cyprus. The students worked in 4 groups of 3-4 students each. Each group was formed with different genders and abilities (i.e., mathematical, technological and problem-solving abilities) to allow different discourses and problem-solving approaches to develop. The participating students had no previous experience in robotics.

Procedures

There were two weeks of introductory activities to help students get familiar with the EV3 kit. These activities were followed by three 80-minutes sessions of STEM-related problem-solving tasks. Students should program a robot using a tablet, which was connected to the robot via Bluetooth. Each group was tasked with the following programming problems.

- Program a robot to move from its starting position, through a maze, to the finish position
- Program a robot to move along the outside of the flags without touching them
- Program a robot to draw a hexagon

Students in groups could adopt any approach they wanted to come to a solution. The teacher acted as a facilitator assisting the whole procedure e.g., assessing progress, examining understandings, monitoring group work, and suggesting attention to data. When the groups completed their tasks, a debriefing phase took place. In this case, the groups demonstrated their approach in addressing the problem and answered questions asked by the facilitator and the students of other groups.

Data collection and analysis

Verbal contributions were recorded via audio recorders next to each group. A camera was also placed in the room to record the overall student interaction and technology use.

To answer RQ1, the audio data were transcribed verbatim and analyzed using a fine-grained analysis. 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 theme of the discussion or when a different kind of discourse appeared, these were parsed into extra coded units. Generally, a conversational turn had more than one coding units. 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. 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.

To answer RQ2 and RQ3, 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, Jordan, Liu, and Chernobilsky (2011) and later applied in varied CSCL settings by Ioannou (2011), Ioannou, Brown and Artino (2015), and Socratous and Ioannou (2018). CORDTRA was examined in combination with excerpts of students' discourse to identify details of metacognitive and collaborative processes and the role of the technology.

Findings

What are the elements of collaborative knowledge construction? (RQ1)

Knowledge

As presented in Table 1, the students rarely referred to prior conceptual knowledge or experience of knowledge (5.2%). Not surprisingly, the students made comparisons and links referring to observations of previous actions in the same task.

Metacognition

The students used a larger amount 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

Students 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

Collaboration category included three subcategories: conflict, questioning and facilitator's input. Conflicts within groups were few and appeared mostly at early stages of the task. When conflicts appeared, they were more often related to 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. 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 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 1: 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%)

How does ER help to activate group metacognitive processes? (RQ2)

To answer RQ2, we examined an integrated view of an episode, using the CORDTRA diagram of Fig. 1. On 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 use of the robot when students tried to solve the "Draw a hexagon" challenge. Combining the diagram with discourse excerpts helped to understand student's interactions across time. We zoomed into an episode in which the students work on solving the "draw a hexagon" challenge (lines 90-190).

ER activating group metacognitive processes through embodied interaction

For the activity, students should combine mathematical knowledge, experience with ER (i.e., introductory lessons), and programming skills to solve the problem. 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 pen holder on the robot. 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 mean for experimentation by adjusting the pen holder in different places on the robot. Students seemed to recognize the significance of where they should adjust the pen holder; this important discussion moved students' thinking forward. The 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. 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. Thus, it appears that ER, through embodied interaction, served as a tool for experimentation, activating group metacognitive processes and collaborative knowledge construction.

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 manage 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.

ER activating students' group metacognitive processes through interactivity and transparency

In lines 160-176 of the CORDTRA diagram, students went through an exploration in which 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 and, with the teacher's assistance, they managed to connect their mathematical knowledge and programming skills with a real-world condition. A student influenced by the introductory robotics lessons used a flowchart describing the required moves of the robot to draw a hexagon (line 168). Then, they decided to program the robot to turn 120º, as much as the internal angle and observed their robot turning much more than they 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). 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 various possibilities and proposed a solution to the problem. After that, student 4 contributes a more 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 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 on the paper the correct angle (line 174). Student 2 built on the 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 paper to find the angle"). The other group members acknowledged this contribution and developed a solution to the problem.

The transparency features of ER 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, and 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 solution. The students identified gaps in their knowledge and collectively discussed, elaborated, and improved their solution. Regulatory statements that were produced due to the interactivity and transparency features of the robot 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 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	4 different triangles. So, multiplies by 180º each equal 720º
Student 1	Divide by 6 angles of a hexagon *(thinking)*. Equals 120º. So, we will program the robot to move forward and then turn 120º for 6 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 wrongly. Let's check it.
Student 3	Or, the sensor is not working
Student 2	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 turn 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 of the internal angle. So its 180-120 = 60.

Student 4 Yes, that is. The robot must turn as much as the supplementary of the internal angle, only 60º not 120º.

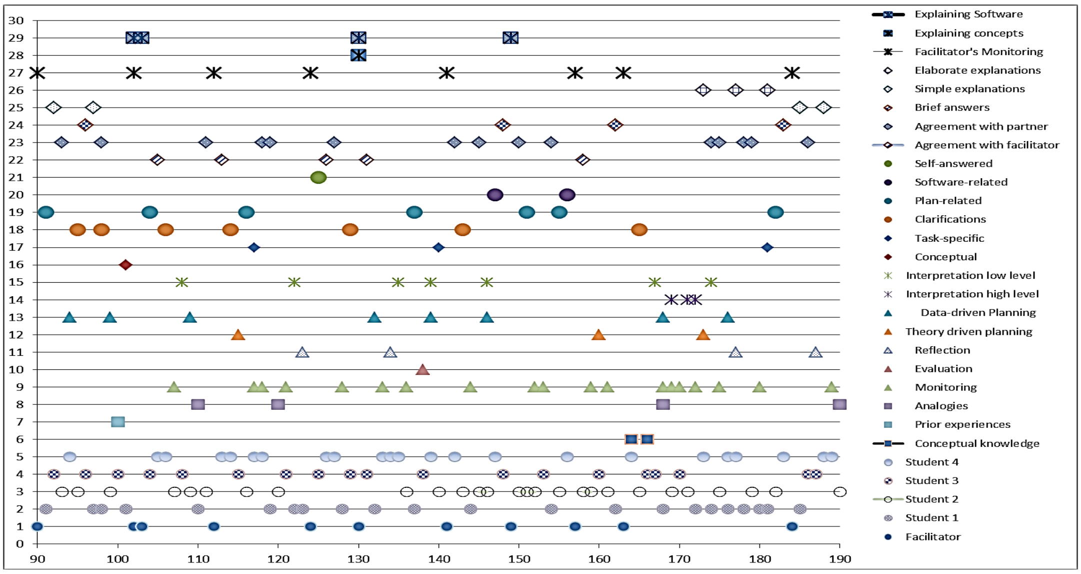

Figure 1. CORDTRA diagram of students' contributions.

What is the relationship between collaborative talk and metacognitive talk? (RQ3)

Both 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 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 and so, he proposed a trial and error plan. Student 3 ignored Student's 1 plan highlighting that with two sensors, it would be easier for the robot to detect the flags. When they failed, Student 3 accepted 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 (Fig. 1), 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.

Discussion

The study 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. 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, Carbonaro, Rex & Grove, 2007; Socratous & Ioannou, 2018). 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, whilst supporting teamwork which is important 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 elements 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 coming from the robot, acted as an extension of students' mind, 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 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 fully maximize their effectiveness in group problem-solving CSCL tasks.

Conclusions

Coding and plotting student's discourse around an ER experience in CSCL settings can shed light on the value to the technology for collaborative knowledge construction and group metacognition. In this work, fine-grained analysis of student's discourse made evident that metacognition, along with questioning and answering, are prevalent elements of collaborative knowledge construction in ER activities. What is more, the role of the technology seems to be instrumental; namely, the embodied interaction, direct feedback and openly accessible programmability enabled by the robot were tightly coupled with group metacognitive processing and overall collaborative knowledge construction. In conclusion, this work extends the evidence on the value of ER integration in learning environments and CSCL activities. The study contributes 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. Future work should extend on the nature of the problem, the teacher's scaffolding, the students' roles and the characteristics of the technology which might further endorse collaborative knowledge construction and metacognition in CSCL settings.

References

Ardito, G., Mosley, P., & Scollins, L. (2014). We, robot: Using robotics to promote collaborative and mathematics learning in a middle school classroom. *Middle Grades Research Journal*, *9*(3), 73.

Atmatzidou, S., Demetriadis, S., & Nika, P. (2018). How Does the Degree of Guidance Support Students' Metacognitive and Problem Solving Skills in Educational Robotics? *Journal of Science Education and Technology*, *27*(1), 70-85.

Baker, M., & Lund, K. (1997). Promoting reflective interactions in a CSCL environment. *Journal of computer assisted learning*, *13*(3), 175-193.

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education*, *72*, 145-157.

Chambers, J. M., Carbonaro, M., Rex, M., & Grove, S. (2007). Scaffolding knowledge construction through robotic technology: A middle school case study. *Electronic Jrl for the Integration of Technology in Education*, *6*, 55-70.

Constantinou, V., & Ioannou A. (2018). Development of Computational Thinking Skills through Educational Robotics. In European Conference on Technology Enhanced Learning - ECTEL. Retrieved December 2018 from http://ceur-ws.org/Vol-2193/paper9.pdf

Efklides, A. (2011). Interactions of metacognition with motivation and affect in self-regulated learning: The MASRL model. *Educational psychologist, 46*(1), 6-25.

Gaudiello, I., & Zibetti, E. (2013). Using control heuristics as a means to explore the educational potential of robotics kits. *Themes in Science and Technology Education, 6*(1), 15-28.

Goos, M., Galbraith, P., & Renshaw, P. (2002). Socially mediated metacognition: Creating collaborative zones of proximal development in small group problem solving. *Educational studies in Mathematics*, *49*(2), 193-223.

Harel, I., & Papert, S. (Eds.). (1991). *Constructionism.* Westport, CT, US: Ablex Publishing.

Hmelo-Silver, C. E. (2003). Analyzing collaborative knowledge construction: Multiple methods for integrated understanding. *Computers & Education, 41*(4), 397-420.

Hmelo-Silver, C. E., & Barrows, H. S. (2008). Facilitating collaborative knowledge building. *Cognition and instruction*, *26*(1), 48-94.

Hmelo-Silver, C. E., Jordan, R., Liu, L., & Chernobilsky, E. (2011). Representational tools for understanding complex computer-supported collaborative learning environments. In *Analyzing interactions in CSCL* (pp. 83-106). Springer US.

Ioannou, A. (2011). Online collaborative learning: The promise of wikis. International Journal of Instructional Media, 38(3), 213-223.

Ioannou, A., Brown, S.W., & Artino, A.R. (2015). Wikis and forums for collaborative problem-based activity: A systematic comparison of learners' interactions. The Internet and Higher Education, 24, 35-45.

Järvelä, S., & Hadwin, A. F. (2013). New frontiers: Regulating learning in CSCL. *Educational Psychologist*, *48*(1), 25-39.

Jonassen, D. H. (2000). *Computers as mindtools for schools: Engaging critical thinking.* Prentice Hall.

Keren, G., & Fridin, M. (2014). Kindergarten Social Assistive Robot (KindSAR) for children's geometric thinking and metacognitive development in preschool education: A pilot study. *Computers in Human Behavior*, *35*, 400-412.

La Paglia, F., Caci, B., La Barbera, D., & Cardaci, M. (2010). Using robotics construction kits as metacognitive tools: A research in an Italian primary school. Studies in Health Technology and Informatics, 154, 110–114.

Pintrich, P. R., Wolters, C. A., & Baxter, G. P. (2000). 2. assessing metacognition and self-regulated learning.

Schraw, G., & Moshman, D. (1995). Metacognitive theories. *Educational psychology review*, *7*(4), 351-371.

Smith, J. M., & Mancy, R. (2018). Exploring the relationship between metacognitive and collaborative talk during group mathematical problem-solving–what do we mean by collaborative metacognition?. *Research in Mathematics Education*, *20*(1), 14-36.

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.

Acknowledgments

This work is part of a project that has received funding from the European' s Horizon 2020 research and innovation programme under grant agreement Nº739578 and the government of the Republic of Cyprus through the Directorate General for European Programmes, Coordination and Development.