



Fostering 21st Century Competences through Computational Thinking and Active Learning: A Mixed Method Study¹

Francisco Buitrago-Flórez

Universidad de los Andes, Bogotá, Colombia, sicks@uniandes.edu.co

Giovanna Danies

Universidad de los Andes, Bogotá, Colombia, g-danies@uniandes.edu.co

Silvia Restrepo

Universidad de los Andes, Bogotá, Colombia, srestrep@uniandes.edu.co

Carola Hernández

Universidad de los Andes, Bogotá, Colombia, c-hernan@uniandes.edu.co

Traditionally, cognitive skills in mathematics and language have been described as key indicators for success. However, the social, technological, and economic changes that have occurred in the 21st century have made critical thinking, creativity, communication, and collaboration, key competences to face the challenges of a rapidly changing world. In this study, we developed a Computational Thinking (CT) curriculum based on student-centred pedagogical strategies to enhance these four competences. This curriculum was designed under the socio-cultural vision of learning, in which individuals interact in communities to build significant knowledge. An embedded mixed-method approach was implemented to evaluate improvements in competence development both in quantitative and qualitative ways in a sample of 42 students. The results indicate an encouraging increase in skills related to the competences of interest thanks to the implementation of a student-centred pedagogical curriculum based on CT. Additionally, by designing the curriculum under socio-cultural ideas of education the results show that the students and the teacher were able to form a community to facilitate teaching and learning.

Keywords: competences development, computational thinking, problem-based strategies, student-centred education, active learning

¹ This research article was elaborated using unpublished information enclosed in a dissertation developed by the first author Francisco Buitrago-Flórez, which was developed as a requirement to obtain the degree of Doctor of Philosophy.

INTRODUCTION

Multiple studies regarding life-learning and learning to learn identify four competences that make a measurable contribution to desirable outcomes in educational achievement, relationships, employment, health and well-being; this applies to all individuals, not only to those in a specific trade, occupation, or walk of life (Bates & Morgan, 2018; Ontario Ministry of Education., 2016; Tang, 2019). These competences are commonly known as the 4Cs, representing Critical thinking, Creativity, Communication and Collaboration (P21 association, 2017). Computational Thinking (CT) is one of the fields with a high potential to develop such competences. Jeannete Wing (2016) defines CT as ‘the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent’ (Wing & Stanzone, 2016). Curzon et al., (2014) highlight five essential skills related to CT that are worth developing in students at any stage of education: abstraction, decomposition, algorithmic thinking, debugging, and generalization.

The concept and definition of CT have been discussed and researched in recent years, particularly because CT can be used as a tool to develop highly complex skills in students ranging from K-12 to bachelors’ programs and beyond (Bocconi et al., 2016; Buitrago-Florez et al., 2020; Curzon & Mcowan, 2017; Wing, 2006). Nevertheless, most strategies have focused on developing these skills in relation to computer programming and digital literacy (Buitrago-Florez et al., 2017) and no pedagogical approach has yet involved the development of these CT skills in the enhancement of the four key competences (Garcia-Peñalvo, 2018).

On the other hand, current pedagogical research provides teachers at any stage of education the means to develop competences in an effective manner. Vygotsky’s (1978) socio-cultural perspective of education claims that learning is a complex problem that is the product of different activities, contexts and socio-cultural factors involving the learner. Buitrago-Florez et al. (2020), describe the development of the skills as a social process in which the learner’s path is embedded in activities of individuals in a particular context. Along this path, the student enters in a community of practice as a member who gets involved in participation (actively interacting and creating identity in the community) and reification (transforming abstract information into real artefacts), progressively becoming an expert in ideas, values, beliefs, languages, skills and competences (Wenger, 1998). By performing participation and reification students would be able to build significant learning as a process of recontextualization. As described by van Oers (1998), recontextualization can be seen as the process in which the actions and meanings of a person become less and less determined by the aspects from the context in which the actions or concepts were originally learned. Therefore, under the socio-cultural vision of education learning is not seen as a process of ‘transfer’ itself as described in other perspectives of education but, is defined as the process in which students are able to recontextualise actions and concepts from an original situation to new defiant scenarios.

Consequently, the learning process can be seen as the travelling of the learner from the periphery to the centre of a community of practice, transforming the practitioner into a fully equipped individual who displays high levels of recontextualization (Hernández et al., 2015). This vision of education puts the students at the centre of their own active learning process, and teachers as the providers of guidance that facilitate the learners' journey (Radford, 2008). Additionally, students are engaged in reflection and conscious awareness processes, which allow them to understand what they may have done wrong or right in order to avoid future pitfalls, as they understand the learning objectives of the activities they perform (Agouridas & Race, 2007).

Considering the benefits of CT and the socio-cultural vision of education previously described, the purpose of this study is to report the results of a mixed-method research in the implementation of a competence development course through CT.

METHOD

Course Development

The entire course curriculum was aligned with the student-centred Problem Based Learning (PBL) approach, which allows students to engage in a problem case or scenario to define and truly understand the learning objectives of the activities (Capon & Kuhn, 2004). As stated by Wood (2003), the true benefits of PBL rely on how students are able to appropriate the problem's situation to increase their knowledge, skills and competences, rather than solving de problem per se. There are several studies that explain and validate PBL in depth (Capon & Kuhn, 2004; Ribas, 2004, 2009; Wood, 2003), in which the PBL strategy is summarised in seven implementation steps. However, the activities carried out in this course did not fully follow the PBL guidelines, but were designed and implemented to integrate the use of the five key skills related to CT, in combination with a set of interactions in which students could consciously enhance the skills of critical thinking, creativity, communication and collaboration in problem-based scenarios.

Participants in the Research Study

The participants in the course were all the students belonging to 11th grade in a private school in Bogotá, Colombia. Every year, this school implements a standard curriculum in all stages, mostly based on traditional teacher-centred strategies in combination with laboratory practices in some disciplines. A total of 42 native Spanish-speaking students (19 females, 23 males), between 16 and 18 years old participated voluntarily in the course. All the participants manifested their willingness to participate by signing a consent form that had been previously approved by both, the school and the university ethics committees. Furthermore, students dedicated 48 class hours (one class hour = 45 minutes), distributed in approximately 10 weeks from late February to early June of 2018, in a time frame that was previously dedicated to preparing students for a national test that took place at the beginning of February. The school agreed to provide the facilities and time since they are interested in exploring non-traditional strategies for teaching and learning towards a future school curriculum reform.

In the first activity, students attended a lecture in order to become familiarised with CT and competence concepts, as well as with the description of the first PBL exercise. Later, students were given a 720-pieces Lego brick box and instructed to build a 15-20 Lego brick structure. Then, they were told to develop an algorithm, meaning a step by step set of instructions so that another student could build the Lego structure they designed, by using the same set of Lego bricks. Afterwards, students were organised in pairs and started testing the couple's algorithm and to debug it in real time. This implied that if a student found an error in the algorithm, the designer was able to fix it right away. Once all the students were able to build the structures, they were instructed to modify the algorithm so that a blindfolded mate could assemble it, and later they did the same process of testing and debugging in real time. Finally, the students went through a reflection process in which they described the difficulties they had, and how they were able to solve them. They also established a relation between the exercise and the use of CT skills, communication and creativity, which were the learning objectives of the activity. The total time provided for this activity was 12 class hours.

In the second activity, the students teamed-up in groups of three and were given the following problem situation: they had to design, assemble and test a structure able to hold an impact of 300 Newton's force from a handmade catapult, which they had to build as well. Teams were subsequently equipped with the 720-pieces Lego brick box, popsicle sticks, springs, rubber bands, strings, metal balls, cardboard and clay. Later, students brainstormed in their groups about the possible learning objectives of this activity, considering CT skills, concepts, and characteristics of the 4C's. Finally, students fully engaged in the development of the structure. The teacher was in charge of constantly monitoring the activities of the groups and pointing out the exact moments in which the groups displayed critical thinking, creativity, communication and collaboration. At the end of the activity the groups showed their final products to the other students. The total time provided for this activity was 14 class hours.

The third PBL activity consisted in the construction of a Rube-Goldberg machine, which is a set of deliberately complex contraptions in which a series of devices that perform simple tasks are lined together to produce a domino effect (Rankin et al., 2008). The students were grouped in teams of four and first they dedicated some time to understand the Rube-Goldberg machine, recognise the materials and define the learning objectives as they did in the second exercise. They were given the materials previously used in the activities 1 and 2 and additional supplies like plastic containers, motors, electronic kits, batteries, light bulbs, pulleys, among others. Later, the students brainstormed on the development of the Rube-Goldberg machine and made a sketch before starting the construction process. Subsequently, they fully engaged in the development of the machine for about 12 class hours and the groups showed their machines to the other students at the end of the activity. The teacher monitored the activity making students aware of the moments they exhibit the 4Cs and students developed a new reflection process in which they described difficulties, strategies to solve them, and an association between the activities carried out and the 4Cs. The total time provided for this activity was 20 class hours.

Evaluation Design and Data collection

Since social phenomena are extremely complex, different kinds of methods are needed to understand them in depth (Green et al., 2011). Therefore, this proposal was evaluated by using a mixed-method data analysis, in order to maximise the power of the information collected, as well as to strengthen the overall evaluation. The research design used in this study collected information with open-ended and close-ended approaches, in line with the embedded mixed method strategies described by Creswell (2009). Moreover, this research was mainly qualitative in nature (QUAL-*quan*), since it was our purpose to understand the experience of the participants of the course supported by the gathering of quantitative data of a specific point of research (in this case critical thinking) Tashakkori and Teddle (2002). On the one hand, written reflections from students, notes from the field diary of the teacher, and perceptions from a focus group allowed a qualitative analysis of perception for all competences. Guide questions for the written reflections and the focus group are available in Supplementary material 1.

On the other hand, a pre/post-test based on multiple-choice questions implemented to gather information about critical thinking was analysed quantitatively (Supplementary material 2). The tests comprised 13 CT questions from validated sources such as www.code.org and <https://teachinglondoncomputing.org/> to inquire about the use of CT key skills. Both tests included six questions related to theoretical aspects of CT (1 point each) and seven questions related to analytical aspects of abstraction, algorithmic thinking, decomposition, debugging and generalization (2 points each), for a total score of 20 points. We doubled the value of analytical questions as these represent the active use of CT skills. We decided to use such set of questions given that these skills are considered fundamental for problem solving, a major characteristic of critical thinking (Curzon & Mcowan, 2017).

The evaluation process of this study follows the guidelines of Bamberger (2012), who conceives evaluation as ‘the systematic collection, analysis, and interpretation of information about human phenomena (commonly, social and educational programs) in order to make judgments about their quality and effectiveness – judgments which are then used for decision- making, accountability, improvement, critique, and social betterment, among other uses’ (p. 10). Therefore, the techniques used for data collection in this study provide enough data for a triangulation process, in order to establish valid conclusions from the evaluation method (Oliver-Hoyo & Allen, 2006). As such, reflections allowed students to explain personal experiences and internal thought activities (Agouridas & Race, 2007). The teachers’ field diary offered notes and reflections from another point of view with an extensive amount of extra details from students, who perceive activities and learning processes in a different way (Merriam & Tisdell, 2015). Lastly, the focus group provided a dynamic interaction between the participants who contributed to a deep discussion via a logical sequence of open-ended questions (Lecanda & Garrido, 2003). Furthermore, a pre/post-test allowed us to measure through descriptive and comparative statistics the students’ progress regarding the performance in CT skills and problem solving. Following the evaluative approach

described above, all 42 students participated in the pre/post tests and in two written reflections throughout the course. Additionally, 12 students were randomly selected at the end of the course to provide narrative data in the focus group.

FINDINGS AND DISCUSSION

The aforementioned research design was used to establish whether the curriculum proposed effectively addressed student-learning outcomes and expected perceptions regarding the 4Cs. This section summarises the analyses of the pre/post tests for critical thinking as well as the qualitative data collected in relation to the four competences.

Critical Thinking / Problem Solving

The information related to problem solving was classified based on the perception of the students regarding their ability to solve problems in the PBL activities throughout the course, in combination with the pre-test/post-test progression analysis. At the beginning of the course, the students struggled with the use of the five key skills related to CT to formulate solutions, reporting that these were abstract for them. Nevertheless, as students developed the problem-based exercises and reflected about their practice, they recognised the usefulness of the CT skills in problem solving.

Data from reflections demonstrate that students were able to identify specific moments in which they used the skills in particular actions in the three PBL exercises (Table 1). This is consistent with Wenger (1998) proposal that learning is a process resulting from participation and reification in specific communities. As students interacted with their peers and the teacher throughout the course, they were able to get involved in a learning community in which the level of expertise and understanding of CT concepts, language, symbols and artefacts increased over time.

Table 1

Categories formed from associations between actions and CT skills in the second reflection. The numbers in parentheses indicate how many students state a specific relationship between a CT skill and an action made during the activities of the course.

CT Skill	Action
Abstraction	<ul style="list-style-type: none"> • Modifying the instructions of the algorithm so a blindfolded student could be able to assemble the Lego structure (23) • Imagining the instructions for building the Lego structure while blindfolded (14) • Imagining how materials could be used to create the catapult and the Rube-Goldberg machine (18) • Sketching the designs for the Rube-Goldberg machine (12) • Looking for alternatives for issues regarding the assembling of the catapult and the Rube-Goldberg machine (9)
Algorithmic thinking	<ul style="list-style-type: none"> • Making the step by step in the Lego activity (39) • Debugging and re-thinking the steps of the assembling process of the catapult and the structure (13) • Designing the steps of the Rube-Goldberg machine (25)
Decomposition	<ul style="list-style-type: none"> • Dividing the assembling of the Lego structure into different groups of actions to facilitate the process while blindfolded (40) • Dividing the assembling of the catapult and the structure into different processes in the second PBL exercise (23) • Subdividing the assembling of each of the steps of the Rube-Goldberg machine into different steps (16)
Debugging	<ul style="list-style-type: none"> • Fixing errors in real time while another student assembled the Lego structure (35) • Making an auto-evaluation of the instructions for the Lego structure (6) • Testing the resistance of the structure to the impact of the catapult (21) • Testing each of the steps of the Rube-Goldberg machine (7) • Testing the functioning of the Rube-Goldberg machine as a whole (13)
Generalization	<ul style="list-style-type: none"> • Re-contextualizing instructions from the first algorithm in the second one during the Lego activity (16) • Using ideas from a physics class to build the catapult (18) • Using ideas from the second exercise in the third exercise (16)

Additionally, in the focus group the students agreed on the fact that being exposed to a CT lecture at the beginning of the course was interesting. However, the application of the CT concepts and skills explained, was difficult to understand. In the terms of Wenger (1998), they were unable to reify just by attending and listening. Nevertheless, as students became participants of the learning community, they had the opportunity to engage multiple processes that allowed them to experience situations and reify CT skills and concepts. For example, a student recalled:

St11: 'This (course) was very interesting for me because I was able to see clearly how the skills worked in the process of building the catapult and the structure. Additionally, when I did the reflections, I was able to think more deeply how the skills were used, and I was very surprised to see that in fact I used them all'.

This quote supports data from the field diary of the teacher, who described that students recognised the value of reflecting about the learning process. Being reflective creates a relation between knowledge and reality by internalizing successful practices and

experiences, which subsequently contributes in the creation of an identity in the learning community that empowers the student in the learning process (Roth & Lee, 2004).

Moreover, participants were asked in the second reflection to extrapolate the use of the CT skills to everyday life situations. Students were able to choose one out of three situations: making a cooking recipe, learning to drive and developing a monograph. The data shows the ability of participants to propose a CT approximation via recontextualization of the concepts seen, indicating a powerful increase in the levels of problem solving in students (Table 2). Most students chose the development of a monograph, which is a choice consistent with the socio-cultural idea that situations in context allow students to build knowledge effectively (Roth, 2009), given that all students had to develop a monograph as a degree requirement before the development of this course.

Table 2

CT skills used to approach an everyday life situation. The numbers within parentheses refer to how many students chose a specific situation.

Situation	Skill approach
Cooking recipe (3)	<ul style="list-style-type: none"> • Abstraction to consider the elements that can be used, as well as which ones should be avoided so that another cook can be able to understand them or replace them with ease. • Algorithmic thinking to develop a step-by-step set of instructions for the recipe. • Decomposition to divide the recipe into different activities. • Debugging to test the recipe and find potential issues. • Generalization to develop new recipes from the original.
Learning to drive (4)	<ul style="list-style-type: none"> • Abstraction to understand the parts and functioning of the vehicle. • Algorithmic thinking to create a set of steps for specific actions like parking, starting the vehicle and setting up mirrors. • Decomposition to divide complex situations and solve them while learning. • Generalization to use previous experiences and incorporates them in the driving process.
Monograph development (32)	<ul style="list-style-type: none"> • Abstraction to understand the problem as a whole and propose a solution. • Abstraction to formulate the research question. • Abstraction to decide what kind of information is useful and which is not. • Abstraction to answer the research question according to the results obtained. • Algorithmic thinking to develop a step-by-step approach to develop the research. • Decomposition to divide the work into parts to ease the process. • Decomposition to divide the monograph into sub-topics to increase coherence in the development. • Debugging to check for errors and solve them. • Debugging to develop experiments and get results. • Generalization to use approaches from previous experiences in the school.

Furthermore, quantitative data show a notorious increase in pre-test/post-test performance in CT concepts and skills to solve specific questions (Figure 1).

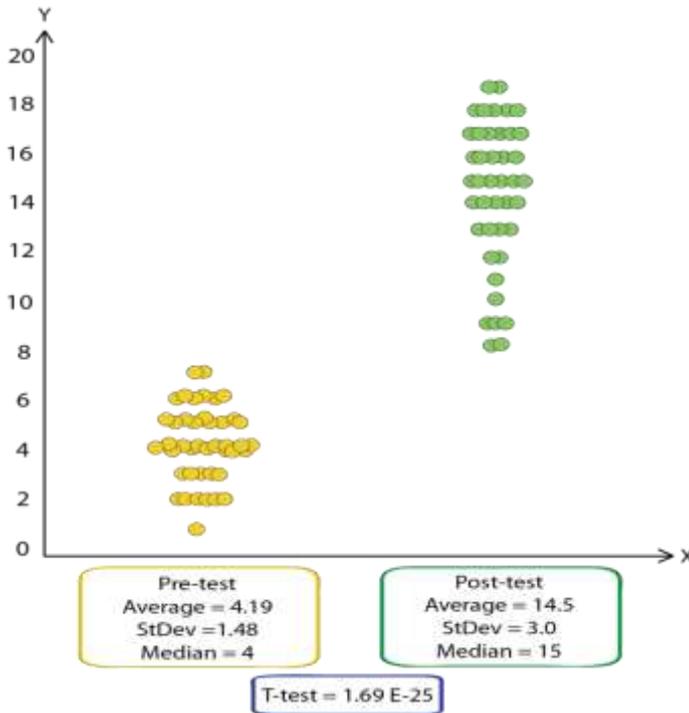


Figure 1

The pre-test/post-test performance in CT concepts and skills to solve specific questions

Figure 1. Pre-test and post-test data representation. In the pre-test, the average of correct answers over 19 possible marks was 4.19, with a standard deviation of 1.49, a highest score of 7 and a lowest score of 1. In comparison, the post-test results show an average of correct answers of 14.5, with a standard deviation of 3.0, a highest score of 19 and a lowest score of 8. Furthermore, the population showed a normal distribution and the T-test showed a significant difference accordingly with a P-value of 1.7×10^{-25} .

These results were somehow expected, since various entries in the field diary of the teacher mention that during the course most students manifested they had struggled with math throughout their school education. Several studies highlight a strong correlation between performance in math and how students can elaborate in computational thinking. A robust mathematical thinking comes with high levels of abstraction and algorithmic skills that lead to a rapid progression in CT through computer programming courses (Bocconi et al., 2016; Buitrago-Florez et al., 2017; Curzon et al., 2014; Kong, 2018). Nevertheless, traditional teacher-centred education hinders the students' progress in mathematical thinking since participation and reification processes are extremely restricted, resulting in low performance in math skills (Skovsmose & Borba, 2004). Therefore, the results of this study confirm the benefits of including student-centred pedagogical strategies for skill enhancement. As described by Hernández et al. (2015)

these strategies effectively allow students to actively participate and reify in a learning community.

Ultimately, both qualitative and quantitative results show that by the implementation of a CT/student-centred cross-curricular approach, these students were able to understand and use CT skills to solve a wide range of problems. As proposed by the Partnership for 21st century competence development (P21, 2011) students improve their critical thinking competence when they display a good performance in: (1) identifying significant information and concepts to create better solutions, (2) analysing how parts of a whole interact with each other to produce outcomes in complex systems, and (3) solving different kinds of familiar and non-familiar problems in conventional and innovative ways. Hence, our results show that students not only improved in CT, but the curricular approach was also a major contribution to their critical thinking competence.

Communication

Analysis from narrative instruments indicate that students recognise that the problem situations they faced throughout the course challenged them in terms of assertive communication. According with entries from the field diary of the teacher, students struggle with complexity of CT language in some situations of dialogue, a common issue in teaching and learning CT (Angeli & Giannakos, 2019). The teacher expressed however, that students rapidly start to interact with each other by using CT language, expressing situations in terms of abstraction, algorithmic thinking, decomposition, debugging and generalization to be able to listen, transmit and understand ideas from their peers in complex scenarios. This increase in language skills is the result of discussions encouraged by students to clarify, analyse and evaluate their work (Hernández et al., 2015). A students' perception from the focus group validates these ideas:

St7: 'I think we improved a lot over time thanks to being exposed to problem situations all the time, it is not easy to make others understand what one imagines building, for example the catapult. However, by communicating information in terms of the skills seen in the course, it was easier to understand each other'.

Furthermore, students claimed in several opportunities that at the beginning they failed to communicate ideas because they thought some aspects were somehow logical, being the opposite for other students. Nevertheless, as consigned in the field diary of the teacher, as they continued in the process of learning they became reflective and were able to identify these issues and solve them. For example, one student described:

St2: 'The Lego activities, I think, helped us realise that communication is not easy for all. One takes for granted some things that seem logical; nevertheless, these are not logical for others. Once I was able to debug this issue, it was easier to transmit instructions to my peers'.

Data from reflection two allowed us to group into six different subcategories the moments in which students stated communication was critical to accomplish specific actions throughout the course: (1) converting ideas into a clear set of steps in the Lego

exercise, (2) guiding verbally the blindfolded partner to bypass issues in their algorithms, (3) making other students understand different uses for the materials provided, (4) making others understand abstract ideas for solving the problems related to exercise two and three, (5) discussing ideas and reach agreements for assembling structures associated to exercises two and three, and (6) making others understand issues and debugging processes throughout the course. Perspectives enclosed in these categories are a direct product of being part of a problem-based pedagogical strategy. As proposed by Capon and Kuhn (2004), it is not the same a person that studies by listening to the teacher who is in charge of transmitting knowledge than a person that studies by discussing several topics for an extended period of time. Likewise, the constant communication between all members of the learning community formed in this course helped students to recontextualise CT symbols and language, encouraging effective communication among the students.

Collaboration

Since all the exercises were carefully designed to be developing by interacting with peers in teams, it was expected that valuable information on collaboration competences would be gathered from the narrative instruments. From the teacher's perspective, students started the course with several issues in effective teamwork, spending a lot of time interacting to take group decisions. However, throughout the progress of the course students successfully developed strategies to take decisions and debug teamwork issues through discussions. Five subcategories regarding specific moments in which students appreciated the fact that they had to improve their collaboration practices are: (1) taking into account and integrating all ideas proposed to solve a specific situation, (2) dividing big steps into sub activities with assigned roles and subsequently conducting a debugging process by all members of the teams, (3) appreciating different points of view to find errors in the different exercises, (4) helping other members of the team to understand problems and encourage them to propose potential solutions, and (5) collaborating in the assembling process of the structures in exercises two and three. These data show that our problem-based strategy provided scenarios that enabled students to create a community space in which multiple perspectives were considered and discussed, showing an increase in collaborative process skills and respect for others (Ribas, 2004).

Students also struggled to collaborate with each other in order to understand and facilitate the development of the activities they proposed to tackle the problem situations. Nevertheless, students highlighted several times the accompaniment of the teacher as critical. In multiple occasions the teacher intervened in the groups to facilitate understanding and suggest actions based on observations that were consigned in the field diary as the students worked in the exercises. As recounted by a student:

St12: 'For me (collaboration processes) were evident in the development of the (Rube-Goldberg) machine. This was an extensive and very difficult job, impossible to do individually. We had to request for the teacher's guidance and increase our tolerance to work as a team and finish the activity'.

In the development of this course the success of the teacher in the guidance process is a result of previous training in student-centred strategies. Problem-based approaches rely on the capacity of the teacher to understand its role as a supervisor. In this approach, a teacher better resembles a person that aids a less experienced member of the community in the integration of knowledge and actions (Hernández et al., 2015). This role is by all means different from being a transmitter of concepts or a project leader. As Northedge (2002) discusses, a teacher involved in student-centred strategies must be able to go outside the specialised language and engage students with terms that are familiar to them, until the learner reaches mastery in language.

The teacher also had to intervene in all the groups to provide guidance about the difference between teamwork and group work. At the beginning of the second activity teams tried to divide assignments individually, nonetheless, they understood very soon that by implementing that sort of strategies they would expend too much time and would face several issues in the development of the activities as a whole. One student described her experience as:

St9: 'I think these exercises were amazing because here (in the school) we don't usually do that kind of activities as a team, teachers mostly assign tasks in groups, which we divide individually and are joined later. Here we had to unite and think as a team to successfully develop the activities under the times provided'.

This phenomenon can be explained by the enrolment as passive entities that traditional teacher-centred strategies provoke in students (Roth, 2009). Nonetheless, those sorts of perspectives highlights the way in which, in terms of Johnson, Johnson, and Smith (1991), group accountability and responsibility was reliant on individual accountability and responsibility in this course, being the former a necessary principle for cooperative group learning in communities of learning. Ultimately, students were able to recontextualise characteristics and notions of effective teamwork via reflection, displaying an improvement in their performance as a team.

Creativity

Students were very conscious that this competence was ground base in order to developed strategies to solve situations they confronted. Six subcategories were formed given the analysis of the students' perception considering the instants when they stated that creativity surfaced: (1) imagining different uses of Lego bricks to form a structure in the first exercise, (2) imagining ways to explain how to assemble the Lego figure to the blindfolded partner, (3) proposing solutions to issues in real time while the blindfolded partner assembled the Lego structure, (4) imagining non-conventional uses for materials in exercises two and three, (5) proposing, testing and debugging different types of solutions in exercises two and three, and (6) understating the learning objectives facilitate imagining multiple alternative solutions very fast. Consequently, the data allowed us to conclude that our curriculum design triggers elements of newness, innovation and novelty; inasmuch as problem-solving situations derives in tools and techniques that make the process fun. As proposed by Awwang and Ishak (2008), engaging and collaborative environments creates a positive experience that helps the

adoption of new ideas that lead to processes of recontextualization of CT concepts and skills for problem-solving. An opinion, product of the interaction in the focus group, reinforced these data:

St11: 'I believe creativity was very present. For example, when I did the algorithm in the Lego activity it was very difficult for me, I had to do several attempts and imagine several ways to develop the exercise'.

Additionally, entries in the filed dairy of the teacher mention two interesting phenomena. On the one hand, students constantly expressed their surprise as they came up with innovative solutions. In different dialogues with the teacher they claimed that this sort of situations, in which they had to be creative, were very rare in their everyday curriculum. This idea is an undoubtedly product of traditional education, being the teacher the 'transmitter' and the students passive 'receptors', thus preventing students to build their own knowledge and depleting creativity as school continues over time (Roth, 2009). On the other hand, students stated that being aware of the learning objectives and understanding explicitly the reasons why they did each of the exercises, allowed them to create solutions and debug more straightforwardly. This is a direct result of interacting with problem-based strategies, in which a central axis of learning is to establish and understand deeply the learning objectives throughout the process (Ribas, 2009).

Study Limitations

This study describes the ways in which students were able to form a learning environment for the enhancement of CT competences in a single course. As the results are the product of an embedded mixed approach, not all of the competences were evaluated through quantitative and qualitative instruments, being critical thinking, the only competence subjected to quantitative analysis. Although through students' reflections and perceptions from the focus group we can be optimistic that participants improved in skills related to the 4Cs, we are fully aware that rubrics for communication, collaboration and creativity progress can be developed in order to quantitatively support narrative data. Nevertheless, we consider that the perception of students must be the core in assessment of student-centred strategies, as processes of negotiation of meaning are not always easy to quantify.

Furthermore, students were asked at the end of the focus group about issues and potential improvements for the development of future CT courses. The participants were emphatic in two critical points: teacher assistance and time. Regarding the former, students expressed that more than one teacher or the presence of class assistants could facilitate the process, given that in several cases the teacher could not guide all the questions that emerged in the groups at specific moments. In regard to the latter, students claimed that the CT course should last the whole academic year, so that they could obtain additional benefits and even apply strategies learned in other school subjects, such as the monograph they had to develop previous to the implementation of the CT course. Overall, we perceive students' perceptions as appropriate. Formation of large communities of learning often requires more than one expert member to guide processes, as well as additional time to provide profound interactions among members.

We consider nonetheless, that despite these limitations the data collected shows promising results that are encouraging for teachers and administrators interested in student-centred strategies for the development of competences.

CONCLUSION

Creating and implementing mixed assessment tools and evaluation strategies that facilitate systems to evaluate performance while hearing students' voices is critical in understanding learning experiences. Results from this study show that the students and the teacher were able to form what we would call a 'computational thinking learning community', in which the students increase their level of expertise in critical thinking, communication, collaboration and creativity through CT. Evidence showed that most of the students displayed recontextualization by designing and implementing solutions to the problem situations presented in the course; by associating specific moments in which CT skills were present in their practices; by extrapolating CT benefits to tackle everyday situations; and by increasing problem-solving performance quantitatively measured. Therefore, by increasing their ability to solve problem situations the students enhanced their critical thinking competence. Furthermore, students showed recontextualization and reflection upon skills such as listening, dialoguing, clarity, friendliness, open-mindedness, respect, role assignment, failure response, tolerance, curiosity and imagination. Consequently, we can argue that our curriculum proposal creates a learning environment that effectively fosters four 21st century competences (critical thinking, communication, collaboration and creativity), which are of great importance for every individual belonging a knowledge-based society (Chalkiadaki, 2018).

Moreover, data analysis demonstrates how reflection processes allow the students to build meaningful knowledge. As argued by Kolmos et al., (2004), many researches in the educational field consider that reflection is a key step to perceive and emphasise the relevance, quality and depth of what is learned in pedagogical environments. Hence, as expressed by Hernández et al. (2015), being reflective denotes an interaction between the reality and an individual who shapes it according to his/her own practices, thoughts and interpretations. Therefore, in the curriculum design here exposed the reflection processes became a form of participation in a specific learning community, increasing processes of recontextualization which ultimately leads to the building of knowledge to be easily implemented in schools and higher education.

Without the systematic implementation of pedagogical strategies to create a sense of community and identity, students enrolled in traditional teacher-centred classes in schools and universities can easily get a feel of insignificance and may be discouraged to learn. The efforts described in this study combined a focus on CT concepts with personal development that is very valuable, given that educational systems must pay attention to how the students' individual growth relates to social necessities (Sá & Serpa, 2018). We are aware that setting specific expectations that connect recontextualization with key competences is defiant but is a way to respond to the changing demands of a globalised world by preparing students for future challenges. Accordingly, active pedagogical strategies such as the approach described in this research project could be used as a starting point in schools and universities for

competence development. This will produce an important effect in experience, skills and concepts acquisition, worth using to maximise the 4Cs and other competences in later courses throughout the curriculum.

REFERENCES

- Agouridas, V., & Race, P. (2007). Enhancing knowledge management in design education through systematic reflection practice. *Concurrent Engineering: Research and Applications*, 15(1), 63-76. <https://doi.org/10.1177/1063293X07076267>
- Angeli, C., & Giannakos, M. (2019). Computational thinking education: Issues and challenges. *Computers in Human Behavior*, 106185. <https://doi.org/10.1016/j.chb.2019.106185>
- Awwang, H., & Ishak, R. (2008). Creative thinking skill approach through problem-based Learning: pedagogy and practice in the engineering classroom. *World Academy of Science, Engineering and Technology*, 16, 635-640. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.306.7430&rep=rep1&type=pdf>
- Bamberger, M. (2012). *Evaluation for equitable development results*: UNICEF Evaluation Office. http://www.clear-la.cide.edu/sites/default/files/Evaluation_for_equitable_results_web.pdf
- Bates, C., Morgan, D. (2018). (2018). Literacy leadership: The importance of Soft Skills. *The Reading Teacher*, 72(3), 412-415. <https://doi.org/10.1002/trtr.1755>
- Bocconi, S., Chiocciariello, A., Dettori, G., Ferrari, A., & Engelhardt, K. (2016). Developing computational thinking in compulsory education – Implications for policy and practice. *EUR 28295 EN*. <https://doi.org/10.2791/792158>
- Buitrago-Florez, F., Casallas, R., Hernandez, M., Reyes, A., Restrepo, S., & Danies, G. (2017). Changing a generation's way of thinking: teaching computational thinking through programming. *Review of Educational Research*, 87(4), 834-860. <https://doi.org/10.3102/0034654317710096>
- Buitrago-Florez, F., Danies, G., Tabima, J., Restrepo, S., & Hernández, C. (2020). Designing a socio-cultural approach for teaching and learning Computational Thinking. *Nordic Journal of Digital Literacy*, 15(2), 106-124. <https://doi.org/10.18261/issn.1891-943x-2020-02-03>.
- Capon, N., & Kuhn, D. (2004). What's so good about Problem Based Learning? *Cognition and instruction*, 22, 61-79. https://doi.org/10.1207/s1532690Xci2201_3
- Creswell, J. (2009). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*: 3rd ed. Thousands Oaks, CA:Sage.
- Chalkiadaki, A. (2018). A Systematic Literature Review of 21st Century Skills and Competencies in Primary Education. *International Journal of Instruction*, 11(3), 1-16. doi.org/10.12973/iji.2018.1131a

- Curzon, P., Dorling, M., Ng, T., Selby, C., & Woollard, J. (2014). Developing computational thinking in the classroom: a framework. *Computing at School (CAS) Releases*. <https://eprints.soton.ac.uk/369594/>
- Curzon, P., & Mcowan, P. (2017). *The power of computational thinking: games, magic and puzzles to help you become a computational thinker*: World Scientific Publishing Europe.
- French Academy of Sciences (FAS). (2013). Teaching computer science in France, tomorrow can't wait. *Institut De France - Academie des Sciences*. http://www.academie-sciences.fr/pdf/rapport/rads_0513gb.pdf
- Fullan, M., & Langworthy, M. (2014). *A rich seam: How new pedagogies find deep learning*: London: Pearson.
- Garcia-Peñalvo, F. (2018). Computational thinking. *Revista Iberoamericana de Tecnologías del Aprendizaje*, 13(1), 17-19. <https://doi.org/10.1109/RITA.2018.2809939>
- Green, J., Bouce, A., & Ahn, J. (2011). *A values-engaged, educative approach for evaluating education programs: A guidebook for practice*. Illinois, IL: University of Illinois Publications.
- Hernández, C., Ravn, O., & Valero, P. (2015). The Aalborg university PO-PBL model from a socio-cultural learning perspective. *Journal of problem based learning in higher education.*, 3, 16-35. <https://doi.org/10.5278/ojs.jpblhe.v0i0.1206>
- Johnson, D., Johnson, R., & Smith, K. (1991). *Active Learning: cooperation in the college classroom*: Edina, MN: Interaction Book.
- Kolmos, A., Fink, F., & Krogh, L. (2004). The Aalborg PBL model. *Aalborg University Press*. <http://www.en.aau.dk/about-aau/aalborg-model-problem-based-learning>
- Kong, S. C., Chiu, M. M., & Lai, M. (2018). A study of primary school students' interest, collaboration attitude, and programming empowerment in computational thinking education. *Computers & Education*, 127, 178-189. <https://doi.org/10.1016/j.compedu.2018.08.026>
- Lecanda, R., & Garrido, C. (2003). Introducción a la metodología de investigación cualitativa. *Revisa te psicodidáctica*, 14, 5-40. <http://www.redalyc.org/articulo.oa?id=17501402>
- Merriam, S. B., & Tisdell, E. J. (2015). *Qualitative Research: A Guide to Design and Implementation*: Wiley.
- Northedge, A. (2002). *Organizing excursions into specialist discourse communities: A sociocultural account of university teaching.*: Wiley Online Library.
- Oliver-Hoyo, M., & Allen, D. (2006). The Use of Triangulation Methods in Qualitative Educational Research. *Journal of College Science Teaching*, 35, 42-47. <http://www.nsta.org/publications/news/story.aspx?id=51319>

Ontario Ministry of Education. (2016). *21st century competencies: Foundation document for discussion, phase 1: Towards defining 21st century competencies for ontario*. Ministry of Education of Canada.

P21. (2011). Framework for 21st century learning. *Partnership for 21st competencies development*. <https://www.battelleforkids.org/networks/p21>

P21 association. (2017). Partnership for 21st century learning. <https://www.battelleforkids.org/networks/p21>

Pellegrino, J. W., & Hilton, M. L. (2012). *Education for life and work: Developing transferable knowledge and skills in the 21st century*. National Research Council. Committee on Defining Deeper Learning and 21st Century Skills, Board on Testing and Assessment and Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Qualls, J., & Sherrel, B. (2010). Why computational thinking should be integrated into the curriculum. *Journal of computer science colleges*, 25, 66-71. <https://dl.acm.org/citation.cfm?id=1747148&dl=ACM&coll=DL>

Radford, L. (2008). *The ethics of being and knowing: towards a cultural theory of learning*: Sense Publishers.

Rankin, Y., Gooch, A., & Gooch, B. (2008). The impact of game design on students' interest in CS. *GDCSE conference 08*, 59-63. <https://doi.org/10.1145/1463673.1463680>

Ribas, A. (2004). Las líneas maestras del aprendizaje por problemas. *Revista interuniversitaria de formación de profesorado*, 24, 79-96. <http://www.redalyc.org/pdf/274/27418106.pdf>

Ribas, A. (2009). *Aprendizaje basado en problemas en la educación superior (Problem based learning in higher education)*. Colombia: Editorial Universidad de Medellín.

Roth, W. M. (2009). *The Gap Between University and the Workplace. Examples from Graphing in Science*. In O. Skovsmose, P. Valero, & O. Ravn (Eds.), *University Science and Mathematics Education in Transition* (pp. 133–155): Springer.

Roth, W. M., & Lee, S. (2004). Science education as/for participation in the community. *Science Education*, 88, 263-291. <https://doi.org/10.1002/sce.10113>

Sá, M., & Serpa, S. (2018). Transversal Competences: Their Importance and Learning Processes by Higher Education Students. *Education Sciences*, 8, 1-12. <https://doi.org/10.3390/educsci8030126>

Skovsmose, O., & Borba, M. (2004). *Research Methodology and Critical Mathematics Education*. In Valero, P & Zevenbergen, R (eds.), *Researching the Socio-Political Dimensions of Mathematics Education* (vol. 35, pp. 207-226), Kluwer Academic Publishers, Boston (doi:10.1007/1-4020-7914-1_17). Dordrecht: Kluwer.

Tashakkori, A., & Teddle, C. (2002). *Handbook of mixed methods in social and behavioral research*: Thousand Oaks, CA: Sage.

Tang, K. (2019). Beyond Employability: Embedding Soft Skills in Higher Education. *The Turkish Online Journal of Educational Technology*, 18(2), 1-9. <https://doi.org/10.21153/jtlge2019vol10no1art794>

van Oers, B. (1998). The fallacy of detextualization. *Mind, Culture and Activity*, 5(2), 135 - 142. https://doi.org/10.1207/s15327884mca0502_7

Vogler, J., Thompson, P., Davis, D., Blayne, M., Finley, P., & Yasseri, D. (2018). The hard work of soft skills: augmenting the project- based learning experience with interdisciplinary teamwork. *Instructional Science*, 46, 457-488. <https://doi.org/10.1007/s11251-017-9438-9>

Vygotsky, L. (1978). *Mind in society*: Cambridge, Ma.: Harvard University Press.

Wenger, E. (1998). *Communities of practice: Learning meaning and identity*: Cambridge university press.

Wing, J. (2006). Computational thinking. *Commun. ACM*, 49(3), 33-35. <https://doi.org/10.1145/1118178.1118215>

Wing, J., & Stanzione, D. (2016). Center for computational thinking. *Communications of the ACM*, 59, 10-11. <https://doi.org/10.1145/2933410>

Wood, D. (2003). ABC of learning and teaching in medicine Problem Based Learning. *BMJ*, 326, 328-330. <https://http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1125189/>

Supplementary Material

Supplementary material 1 available at https://www.dropbox.com/s/z7wc31dafaxd6xg/2.%20IJI_Supplementary%20material%201_FBF.docx?dl=0

Supplementary material 2 available at https://www.dropbox.com/s/uz30xve4ep6owoy/3.IJI_Supplementary%20material%202_FBF.docx?dl=0