https://doi.org/10.22364/atee.2022.40

# Integrating Computational Thinking into Classroom Practice: A Case Study

**Diane Vassallo, Leonard Busuttil**

University of Malta, Malta

## ABSTRACT

Recent educational developments have seen increasing attention attributed to Computational Thinking (CT) and its integration into school curricula. This has brought along a series of challenges for teachers integrating CT into their practice. The study presented in this article explores the journey of a Maltese secondary school teacher in his efforts to integrate CT within the context of a Math club. The teacher participant was recruited from the Malta EU Codeweek summer school, a pilot initiative that stemmed from the EU Codeweek's Train the Trainer programme carried out during summer 2021. The qualitative methodology involved a case study research, with data collected from an online discussion forum, interviews with the participant teacher as well as an analysis of the teaching material developed by the teacher. The results shed light on the CT aspects that were used to scaffold the teaching of mathematical concepts and highlight the challenges and obstacles that the teacher encountered in his integration efforts. The discussion proposes that non-formal learning environments, such as in-break activities, can serve as test-beds for CT integration and emphasises the need for CT to be introduced much earlier on in Maltese schools. Ultimately, this study can substantially help inform further research and practice around the integration of CT in classroom practice.

*Keywords:* Computational Thinking, EU Codeweek, formal and informal learning settings, K-12, Mathematics education

## Introduction

The importance of Computational Thinking (CT), or "the new literacy of the 21st century" (Wing, 2006) cannot be understated in the field of education. As computationally enabled technological advances invade and reshape essential components of our everyday lives, the set of competencies offered by CT are seen to possess the potential of helping our young generations to move from being consumers of technology towards using the technology to create new forms of expression, build new tools and foster creativity (Barr & Stephenson, 2011; Grover & Pea, 2013; Mishra et al., 2013).

CT involves a set of abstract thinking skills that draw on concepts fundamental to Computer Science (Wing, 2006). These skills represent a "universally applicable attitude and skill set" (Wing, 2006, pg. 33) that should be part of the repertoire of every child's analytical ability and thus should constitute a vital part of school learning. This notion has influenced a number of educational movements which have recently attributed increasing attention to CT and its integration into modern curricula.

In fact, the introduction of CT concepts and practices has been formally recognised by many institutions across the world (Duncan et al., 2017; Bocconi et al., 2018; Pears et al., 2017). Malta is no exception, with a strategy underway for all students from Kindergarten to Year 11 to "understand and apply the fundamental principles and concepts of computational thinking" (Catania, 2014, pg 15).

However, despite this increased attention towards CT and the wide range of curriculum strategies and other initiatives, the integration of CT into the curriculum is still facing a range of issues and challenges (Voogt et al., 2015; Angeli & Giannakos, 2020). Including CT practices in and of itself offers little guidance for teachers about what aspects of CT to include in their practices, and how. In this study, the focus is on the integration of CT into classroom practice by exploring the teaching experience of a Maltese secondary school teacher in his efforts to plan, develop and integrate CT within the context of Mathematics lessons as part of an in-break Math club. The research study endeavours to answer the following main research questions:

- What aspects of CT are characterised in the planning and delivery of mathematical concepts?
- What are the major challenges and obstacles experienced in integration efforts?

## Defining CT and its components

Wing (2006) initially highlighted CT as broadly revolving around designing systems, solving problems and understanding human behaviour by drawing on computer science concepts. Later, she refined this definition to encompass the thought processes involved in framing problems and their solutions in ways in which computers could understand and execute (Wing, 2010). Just like proficiency in language aids communication, Lu and Fletcher (2009) define proficiency in CT as a means to "systematically, correctly and efficiently process information and tasks" when dealing with intricate problems.

CT broadly consists of a number of thinking processes which include abstraction, algorithm design, decomposition, pattern recognition, and data representation (Wing, 2006). Similarly, Kalelioglu et al., (2016) developed, from a systematic review of the literature, a framework for CT that focuses on the processes of abstracting and decomposing, analysing data and recognising patterns, algorithmic thinking, implementation, evaluating and generalising. Ultimately, despite the range of views that have emerged over the years about what components truly constitute CT, there seems to be a set of universally accepted CT elements, which include abstraction (Lee et al., 2011; Wang et al., 2014), decomposition (Grover & Pea, 2013), algorithmic thinking (Atmatzidou & Demetriadis, 2016; van Borkulo et al., 2021) and generalization (Angeli et al., 2016; Selby & Woollard, 2013), among others.

## Mathematics and Computational Thinking

The importance of CT skills, and their relevance to various learning and critical problem-solving contexts has been widely supported (Council, 2010; Wing, 2006; Barr & Stephenson, 2011). This is particularly true in Science, Technology, Engineering and Mathematics (STEM) fields (Lee et al., 2020), where research seems to show positive correlations between the use of CT in these areas of discipline (Orton et al., 2016; Weintrop et al., 2016).

The link between CT and Mathematics more specifically, has its roots in the work of Papert (1980) who argued that using programming environments to teach Mathematics allowed students to learn concepts in a more meaningful way. It does seem that recently, the integration of Mathematics and CT has been mainly focussed on programming (Hickmott et al., 2018) or involved a software tool or hardware device (Barcelos et al., 2018). Underlying these integration efforts are beliefs about higher-order skills that are identified as common between the two fields (Barcelos & Silveira, 2016). Weintrop *et al.* (2016) propose a definition for CT in high school Mathematics (and Science) in the form of a taxonomy with the aim to bring current educational efforts up-to-date with the increasingly computational nature of these subjects. Much of these integration efforts have been triggered by the formal acknowledgement of the importance of CT in Mathematics by important entities. The OECD's new Programme for International Student Assessment survey (PISA) have recently introduced aspects of CT into their framework (OECD, 2018), while the Next Generation Science Standards (NGSS) have also listed the use of Mathematics and CT as one of eight distinct scientific practices (NGSS, 2013). These have served to highlight the promising opportunities for fostering CT skills that help promote learning and problem-solving in mathematical activities that are aligned with existing curricula. Recent empirical studies indicate a positive correlation between CT and mathematical achievement (eg. Sáez-López et al., 2019; Psycharis & Kallia, 2017). Other qualitative studies have also portrayed positive results in how CT could be employed to engage students meaningfully towards possibly improving a wide range of mathematical abilities (eg. Pei et al., 2018; Sinclair & Patterson, 2018; Gadanidis, 2017). Despite all this, a scoping review of the literature by Hickmott et al. (2018) indicates that there are still gaps in the knowledge of CT as integrated in Mathematics K-12 education. Among the gaps identified is the lack of empirical studies that offer relevant practices and hands-on advice to educators for bringing together mathematics and CT. This paper addresses these gaps by adding to the list of empirical studies that inform research on the possible methods that can be used to integrate CT into mathematics in an informal school setting.

Moreover, the practice of embedding CT into mathematics lessons is a complex and challenging endeavour, and does not in itself guarantee a successful complement of the use of CT to advance the understanding of the various mathematical topics. In fact, many teachers have a lack of awareness of how CT skills can be incorporated into their teaching practices (Sands et al., 2018; Looi et al., 2020). To complicate things further, teachers have also reported barriers to their integration efforts which have posed further challenges in terms of time management, support from school leaders and access to technology amongst others (Morreale et al., 2012; Pollock et al., 2017).

### The local context

In Malta, plans for integrating CT across the curriculum may be underway (Catania, 2014), however there is very little or no evidence at all in most curriculum content that mentions CT aspects or their integration. One of the known direct references to CT is in the ICT C3 syllabus (this is the compulsory ICT syllabus for years 7 to 11), where a very brief direct mention of CT can be found. There is also very little or no CT content in local teacher education programmes. This points to a scenario whereby CT and its integration largely happens in vacuumed pockets by scattered enthusiast teachers who may have followed specific courses, like the EU Codeweek summer school, as was the case with the participant teacher in this study. In terms of Mathematics, Malta generally places poorly in the league of nearly 80 countries when it comes to PISA testing, especially in Mathematics (Schleicher, 2018). Consequently, the need for the integration of CT as described above, with all its promising aspects and challenges, are seen to be as relevant and much needed in Malta as they are elsewhere.

## Methodology

### Background to the study

In the summer of 2021, academics from University of Malta collaborated with members from the national Maltese Digital Literacy department on the organisation of the EU Codeweek summer school. Recruitment for this initiative happened through calls for participation posted on teachers' groups on Facebook. A total of 20 teachers participated in the initiative, the outcome of which was to guide participants to formulate a plan to integrate CT into their own individual practice for the ensuing academic year. Following the summer school, a call for participation went out to the participants to invite them to collaborate with members from the University of Malta on the implementation of their proposed plan. This was done through a presentation about the proposed research which was carried out during one of the sessions of the EU Codeweek, where information was provided to all participants on what participation in the research would entail. Paul (a pseudonym) was one of the three summer school teachers who opted to collaborate in the study. He was interested in participating and opted into the research after reading further about the project from the information and consent form letter presented to all potential participants. This study thus presents Paul's attempt at integrating CT and Mathematics into his classroom practice over the academic year 2021-2022. His personal ambition was to ultimately enhance the integration of CT across the general mathematics curriculum, however, he decided to initially start on a smaller scale, with a Math club. The reasons for this were multifaceted, involving both issues to do with teacher mastery of CT integration into Mathematics as well as curricular constraints pertaining to the amount of content to be covered for exams, perceived lack of time and other limitations.

### Details of the Math club initiative

The Math club was planned to be Paul's educational space to implement his action plan for CT and Mathematics integration.

A total of 28, 45-minute sessions were held once a week, during break times, between the months of October 2021 and May 2022.

Students, recruited from the middle school in level 6 to level 8 (10 to 12-year olds), were asked to sit for an aptitude test. The invitation to join the club was open to all students, and a total of 20 students showed interest and sat for the test. No grades were allocated for the final outcome. Instead, the scripts were separately vetted by four Mathematics teachers within the Maths department of the school. The result of this vetting process indicated that the academic level of students ranged from average to very high. This information was used by Paul to understand his target audience and inform his planning accordingly. Thus, all students were offered a place on the Math club, with 18 of these initially taking up the offer. After the first few sessions 5 dropped out, leaving a total of 13 students who attended regularly.

The 13 mixed-gender students consisted of five Level 6, four Level 7 and four Level 8 students. They all attended the sessions together and initially worked in groups within their respective grade level. There were however multiple occasions during the Math club sessions where the students collaborated together in mixed grade level groups.

The Math club sessions were meant to provide the students with a space where to engage and indulge in CT in the context of Mathematics. Amongst the topics covered were *number systems, divisibility rules in Mathematics* and *prime factorisation.* Most of the time links were made to Computer Science topics, and programming in Lego, Scratch and Python also featured as part of the activities. While Paul had detailed initial plans, he was flexible throughout and was guided by the students' feedback and progress during the sessions. Paul constantly changed and adapted his plans for the sessions to offer students a more personalised experience that suited their needs and interests, while upholding their motivation. The setting was rather informal, unlike what the students are usually used to in the context of their more formal classroom settings. In fact, the Math club sessions were characterised by less strict rules, more opportunities to be creative and freedom to explore different learning trajectories. Paul employed a project-based approach, with his role shifting more towards a mentor who guides and supports the students rather than the more traditional style that is more predominant in formal lessons within the general school culture. The Math club culminated in a Maths Exhibition, organised by the Mathematics department, where the students had an opportunity to showcase projects they had collaborated on in the club. Furthermore, to reward the students for their hard work and dedication, Paul organised an escape room activity on the school grounds in June 2022, where the Math club participants had the opportunity to flaunt their CT skills to solve puzzles and questions posed by this activity.

## Methods of data collection

In order to answer the research questions, this study was conducted as a single case study (Yin, 2014). This implies an in-depth investigation of the Math club intervention in its real-life context (Creswell, 2013; Yin, 2014). According to Yin (2014), a key strength of the case study research is the opportunity to employ a range of sources of evidence to support the study's construct validity. Unfortunately, due to COVID-19 restrictions, it was not possible for the researchers to physically be present in the classroom, however, this case study findings build on several sources of information, including forum discussions between the teacher and the researchers, semi-structured interviews, the teacher's resources used during the Math club sessions and pictures shared by the teacher of the students working, as well as pictures of artefacts created by the students as part of the projects they were involved in.

The asynchronous discussions, carried out using the Microsoft Teams platform, were active between September 2021 and July 2022. This online space was commonly used by the teacher and the researchers to communicate on a weekly basis. Paul shared his ideas while planning and adapting the sessions and the researchers offered feedback and guidance throughout the design process. A discussion was also generated on a weekly basis that helped sustain a reflective process to evaluate the teaching and learning processes and inform adaptations of the design of future sessions.

The aim of the interviews was to collect in-depth data from the teacher about the progress of the integration process, as well as other aspects of interest that would emerge during the online discussions. The interviews also focussed on aspects identified by the researchers from their analysis of the resources used during the Math club sessions. Two forty-five minute interviews were carried out, one in December 2021 and another in June 2022. This was a time during the COVID-19 pandemic, when major restrictions were in place in Malta, therefore the interviews were held online via the Microsoft Teams platform. Both interviews were recorded with Paul's consent and later transcribed.

The pictures shared by the teacher were instrumental in supporting the other data sources during the process of analysis (Creswell, 2013). More specifically, the pictures of student's work and artefacts were jointly evaluated by the teacher and the researchers as they exemplified how CT was employed in the learning process.

Research ethics for this study was followed very rigorously and an ethics application for carrying out the research was approved by the Faculty Research Ethics Committee, FREC and the University Research Ethics Committee, UREC, at the University of Malta.

### Data Analysis

Thematic analysis offers a flexible method for identifying, analysing and reporting patterns within the data. With the help of the qualitative research software Taguette, thematic analysis (Braun & Clarke, 2006) was used in this study to analyse all the data collected. Transcripts were coded based on two coding schemes: one focussing on the characteristics of CT emerging from Math club sessions, and the other with the aim of identifying challenges and obstacles in the teacher's integration efforts. The six-phase procedure based on Braun and Clarke (2006) involved starting to familiarise with the data, identify initial codes, then subsequently search, review, define and name the emergent themes, and ultimately produce the report.

## Results

Data analysis resulted in the identification of a total of 4 themes and 15 categories, as portrayed in Table 1 and Table 2. The emerging themes shed light on how the teacher translated his understanding of CT into practice to deliver specific mathematical concepts and the challenges met along the way. Primarily, theme 1 in Table 1, referring to the connections established between CT and Mathematics, indicates that prior training about CT was crucial in helping the teacher become more aware of certain specific components of CT. Findings portray how these were then progressively linked to the teaching of Mathematics and subsequently further refined following feedback gained from practical experience. It was also clear that the teacher's own interpretation of CT, which developed and evolved throughout the study, heavily influenced the CT components which ultimately emerged during both the planning as well as the delivery of the Mathematics lessons. Furthermore, analysis of the second theme, about CT characteristics (theme 2, Table 1), indicates that decomposition was the CT component which featured more heavily in the integration efforts, followed by abstraction, pattern recognition and the use of algorithms. Finally, the themes emerging about the challenges and obstacles of CT integration point to a range of barriers met by the teacher. These include amongst others, issues around the context in which the learning was taking place, with informal contexts being identified as being more conductive to the integration of CT into practice over more formal educational experiences. Moreover, issues related to school environment and different methods of teaching were also found to be major contributing factors. The next section discusses these main findings.

*Table 1.* Themes and categories of characteristics of CT emerging from the Math club

| Theme | Categories |
|---|---|
| 1 – CT and Mathematics connection | Teacher experience, Teacher training, EU CodeWeek reflection, Professional development |
| 2 – CT characteristics | Abstraction, Algorithm, Decomposition, Patterns, Students' prior exposure to CT |

*Table 2.* Themes and categories of challenges and obstacles to CT integration

| Theme | Categories |
|---|---|
| 1 – Learning setting | Formal settings, Informal settings |
| 2 – School environment | Curriculum constraints, Time constraints, School management and culture, Students' prior exposure to CT |

## Discussion

### Making the connection between CT and Mathematics

The positive effect of training on CT received during the Malta EU Codeweek Summer School, emerged very prominently from the teacher interviews. Paul in fact recalled how following the training, he had become more conscious of CT and its components. He explains how, prior to the training, he would inadvertently use aspects of CT in his Mathematics classes. However, the training had helped him establish a better understanding of how the different aspects of CT could be translated to enhance his teaching of mathematical concepts more purposefully, as he explains:

> … *the training has helped me put things into perspective, and all the things I had read about before kind of fell into place and made more sense. The practical examples given by other educators during the training was also both very encouraging and enlightening!* (Paul, interview 2).

This highlights the need, as clearly emphasised also across the literature (eg. Angeli & Giannakos, 2020; Caeli & Bundsgaard, 2020), for teacher continued professional development (CPD), to ensure that integration efforts are well-informed and focussed on how best to amalgamate CT skills towards the enhancement of classroom practice. Unfortunately, Paul's CPD experience at his local school rarely met his needs in the classroom as he describes the CPD opportunities within his school as:

> … *being most of the time out of synch with the real demands of the classroom and only superficially addressing tangible needs* (Paul, interview 2).

Targeted CPD could help avoid unwanted situations whereby less experienced teachers might fail to address all relevant CT components in their integration efforts (Maharani et al., 2021) because of a lack of proper training. Ultimately, as identified by another one of the categories of this theme, teacher experience was instrumental in cultivating the link between CT and Mathematics. This clearly emerged during online discussions, where Paul was constantly revisiting and revising his teaching material and his plans for the Math club sessions based on feedback gained as he progressively became more in tune with new and improved ways of how to integrate CT. The analysis of his teaching materials also clearly shows how later versions of his work indicate a kind of greater maturity in his approach to integrating CT based on a better understanding of his own practice and the evolving needs of his students.

Meaningful training and a structured support system, such as that experienced by Paul in this study, are seen here as a crucial strategy that can be extended further in the local Maltese context to ensure better integration of CT across the curriculum. Looi et al., (2020) also recommend involving teachers in co-designing CT enhanced curricula as a very effective way of promoting CT integration. Furthermore, given the importance of both CT as a "universally applicable attitude and skill set" (Wing, 2006, pg. 33), and the essence of teacher training, it is believed to be imperative that teacher preparation programs include elements of CT and how this can be included and integrated in the different subject disciplines (Yadav et al., 2017).

### CT components and Mathematics instruction

Results from the study indicate that the most common CT component that prominently featured in both planning and delivery of various mathematical concepts during the Math club was decomposition. This was followed by abstraction, pattern recognition and the use of algorithms.

Decomposition was the major initial step that was noted as being used at the beginning of every problem explanation. The teacher would explicitly guide the students to

> … *look at the problem and dissect it and break it into smaller problems* (Paul, interview 1).

The prevailing aim at the start of every problem-solving session would be in fact to systematically look at a problem and find ways of decomposing it into a number of smaller, manageable pieces which they would then go on to solve individually. This CT component was also evident in graphical ways in some of the resources the teacher had planned, with visual representations of problems being broken down into smaller pieces. It may seem that the reason for decomposition being the most prominent aspect of CT that surfaced during planning and instruction would be that, as Selby (2015) notes, this is the most difficult aspect of CT. In addition to this, it can be considered as the first step in a structured problem-solving approach, and as The Royal Society (2012) notes, an indispensable skill to master before moving on to other CT skills. It is to be noted that the students who participated in the Math club had little or no background of CT. This, as previously explained, is because CT is not emphasised within Maltese curricula, despite efforts being made for its inclusion. In fact, apart from the ICT C3 syllabus, there is no direct mention of CT anywhere, and it would only feature in lessons where enthusiastic teachers would take their own initiative to integrate CT into their own practice. This may point to the fact that students may not be proficient in CT skills yet, so the need must have been to focus more on decomposition in order to master this before moving on to higher levels of CT skills required for the type of problem solving included in the maths problems presented during the club.

Along with decomposition, abstraction was also a component that the participating teacher used quite frequently in his delivery of mathematical concepts. In accordance with the literature (eg. Chaabi et al., 2019) the teacher considered abstraction as a key skill for both mathematics and CT. For him, abstraction was especially useful when encouraging students to sift details and information given in the problem brief in the process of working towards a solution. Many times, this involved translating the information given into a diagrammatic form which would better portray the problem. As the teacher himself expressed:

> *the sense of abstraction is about re-moving what is not necessary, and representing what you have visually to help in solving the problem* (Paul, interview 1).

On many occasions, especially when problems started becoming progressively more challenging over the course of the Math club, the teacher started introducing the concept of pattern recognition and the idea of

> *finding patterns and finding what is similar and what is repeating* (Paul, interview 1).

A study by Ling & Loh (2020) confirms the positive correlations that exist between pattern recognition and mathematical ability. In fact, in this study, the skill of pattern recognition was used by the participating teacher on multiple occasions as an additional strategy in his quest to help students with their next steps in their problem solving approach.

Finally, algorithmic thinking was the last component of CT that emerged from this study as part of the teacher's integration efforts. Algorithmic thinking was seen to bring all the problem-solving steps that the teacher was promoting with his students in order to come up with a

> *formula that you can apply in general terms, so if you are asked to scale up and say find the sum of all the natural numbers from one to 7 billion, you would be able to do it in a few seconds* (Paul, interview 1).

This highlighted the aspect of generalisation as an important component of CT (Kallia et al., 2021). As also explained in the study by van Borkulo et al. (2021), Paul approached the aspect of generalisation in both plugged and unplugged ways throughout the Math club. In some occasions, he also used the resulting algorithm to program the solution.

Ultimately, our study seems to suggest that, in accordance with the literature (Kallia et al., 2021), learning opportunities that integrate CT into mathematics instruction should highlight aspects of decomposition, abstraction, pattern recognition and algorithmic thinking amongst others. These form part of the problem solving approach that emerged quite starkly in both the planning as well as in the delivery of mathematical concepts in our study. Furthermore, similar to the study conducted by Kallia et al., (2021) problem solving and all the thinking processes involved in it are regarded as common between CT and mathematical thinking. Similar to a study by Niemel et al. (2017), the participating teacher seemed to have a natural pre-disposition to associate CT with problem solving in maths very generally, and his basic underlying notions of CT in mathematics corresponded with his own ways of teaching mathematics (Huang et al., 2021). It can thus be concluded that these problem solving thinking skills were ultimately strategically employed in this study as a way to scaffold the understanding of mathematical concepts (Huang et al., 2021). This highlights the importance of including CT, and more specifically the aspects of decomposition, abstraction, pattern recognition and algorithmic thinking in mathematics instruction. It also highlights the importance of further research to identify other aspects of CT that may have not emerged in our study, but are evident in other studies, like data practices (Kallia et al., 2021), logic and logical thinking (Grover & Pea, 2013), and testing and debugging (Weintrop et al., 2016) amongst others.

## Barriers and Challenges faced by teachers

The fairly successful integration of CT into mathematics education carried out during the lessons for this study, led the teacher to identify a number of challenges and barriers which in one way or another he had to struggle with during his integration efforts. The CT literature supports this aspect as it consistently identifies barriers and challenges to implementation efforts, which include access to resources, concerns with timings and school support (Morreale et al., 2012; Pollock et al., 2017). In this study, the integration experience during the in-break club served to highlight issues encountered during the teacher's formal teaching of mathematics lessons. The main concern encountered seems to highlight a correlation with the context in which the instruction was taking place. In fact, the teacher frequently compared instruction in the Math club to his other mathematics lessons and confessed:

> *I would say I'm more successful, because I am free to push the boundaries further in the Math club, because it is an extra-curricular activity" and also "In the Math club I can afford to scratch their head deeper* (Paul, interview 2).

On the other hand, the formal lessons were characterised with quotes like:

> *I am stressed about the syllabus. I share classes with other teachers and I am concerned when, for whatever reason, I fall behind…and with the whole COVID-19 situation, that has happened quite often lately. There-fore, I always have the syllabus at the back of my mind.* (Paul, interview 2).

It is interesting to note that, unlike findings experienced in other studies (eg. Morreale et al., 2012; Pollock et al., 2017), in this study, the school where the teaching was taking place provided the teacher with enough flexibility to adapt and shape instruction in ways deemed effective by the teacher. Furthermore, the Paul also reported a great degree of support provided by the school in backing these initiatives. Nonetheless, it was evident that the teacher's aim to provide students with opportunities to develop their CT skills and encourage students to internalise these skills to become a natural habit of thinking and part of their general repertoire of problem solving skills, was far more successful in the informal rather than in the formal setting. The main issues, as also identified by (Google Inc. & Gallup Inc., 2016), were those of competing curriculum priorities and the resulting concern over lack of enough time prevailing in the formal setting. Research that focuses specifically on the positive affordances that CT yields in informal settings can be found in the literature (eg. Ehsan et al., 2018, 2019; Rehmat et al., 2020). However, it is argued that, in order to better understand some of the specific barriers and challenges that the integration of CT may be faced with in formal settings, more research is needed to be able to compare and contrast these two important contexts. It is duly acknowledged here that integrating CT only in in-formal settings may lead to the exclusion of some students and thus promote inequitable learning outcomes. It is thus proposed that the use of informal settings may prove to be ideal for teachers as pilot projects, which can then be potentially rolled out to the wider formal setting.

Another challenge which the teacher identified in his integration efforts was the low-level of CT skills that the students were equipped with, compared to their age level. This deterred, to some degree, the progression of the acquisition of the various mathematical concepts, because the acquisition of CT had to come first and this, the teacher felt, resulted in time taken away from purely mathematical instruction to focussing on upskilling the students. This is attributed to the fact that the students have been exposed very little, or none at all to CT competencies, in their previous schooling experiences in the local Maltese educational context. In conclusion, the academic literature clearly confirms that the acquisition of CT skills can be successfully acquired in early childhood (Bati, 2021), and furthermore, this highlights the importance of introducing these very important skills at a much earlier stage in the educational experiences of students.

## Conclusion

This study presented an investigation of the integration of CT into mathematical practice. Results shed light on a range of different aspects that shape the reality of teachers, who like Paul, believe in CT and strive to integrate it into their everyday practice. From a local Maltese perspective, it is argued that even before taking the plunge to integrate CT into Mathematics instruction at a secondary school level, preliminary measures need to be taken to ensure that the proper foundations have been laid out. This refers to both making sure that the students have the basic fundamentals of CT to allow them to thrive, as well as ensuring that robust structures are in place to support teachers in their integration efforts. Following the implications of the learning context presented in this study, it is recommended that informal settings may be ideal for piloting and experimenting with integration efforts until teachers are confident enough and achieve mastery of CT strategies. It is however crucial that integration efforts do not stop at the boundary of informal settings and that every effort should be made to understand, acknowledge and try to overcome the existing challenges in order to transcend into the wider formal settings.

In conclusion, we argue that given the current-socio economic trends and needs emerging from our modern society, CT training should be a core component of teacher-training education as well as an important on-going component of teacher professional development. Finally, it is also strongly recommended that the integration of CT should start early on in the schooling experience, as this would enable students to internalise the skills from a young age and be further empowered to use these through a range of interdisciplinary subjects more meaningfully through-out their learning experiences.

## REFERENCES

Angeli, C., & Giannakos, M. (2020). Computational thinking education: Issues and challenges. *Computers in Human Behavior, 105*. https://doi.org/10.1016/j.chb.2019.106185

Angeli, C., Voogt, J., Fluck, A., Webb, M., Cox, M., Malyn-Smith, J., & Zagami, J. (2016). A K-6 computational thinking curriculum framework: Implications for teacher knowledge. *Educational Technology and Society, 19*(3).

Atmatzidou, S., & Demetriadis, S. (2016). Advancing students' computational thinking skills through educational robotics: A study on age and gender relevant differences. *Robotics and Autonomous Systems, 75*. https://doi.org/10.1016/j.robot.2015.10.008

Barcelos, T. S., Munoz, R., Villarroel, R., Merino, E., & Silveira, I. F. (2018). Mathematics learn-ing through computational thinking activities: A systematic literature review. *Journal of Universal Computer Science, 24*(7).

Barcelos, T. S., & Silveira, I. F. (2016). Computational thinking and mathematics: Possible rela-tionships revealed by an analysis of national curriculum guidelines. *Leadership and Per-sonnel Management: Concepts, Methodologies, Tools, and Applications, 2*. https://doi.org/10.4018/978-1-4666-9624-2.ch037

Barr, V., & Stephenson, C. (2011). Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community? *ACM Inroads, 2*(1). https://doi.org/10.1145/1929887.1929905

Bati, K. (2021). A systematic literature review regarding computational thinking and program-ming in early childhood education. *Education and Information Technologies*. https://doi.org/10.1007/s10639-021-10700-2

Bocconi, S., Chioccariello, A., & Earp, J. (2018). *The Nordic Approach To Introducing Computational Thinking And Programming In Compulsary Education*. Report Prepared for the Nordic@ BETT2018 Steering Group.

Braun, V., & Clark, V. (2006). Using Thematic Analysis in Psychology. *Qualitative Research in Psychology, 3*(2).

Catania, J. (2014). *Computing as a Core Entitlement Framework*. The Ministry for Education, Great Seige Road, Floriana.

Caeli, E., & Bundsgaard, J. (2020). Computational Thinking in Compulsory Education: a survey study on initiatives and conceptions. *Educational Technology Research and Development, 68*(1).

Chaabi, H., Azmani, A., & Dodero, J. M. (2019). Analysis of the relationship between computational thinking and mathematical abstraction in primary education. PervasiveHealth: Pervasive Computing Technologies for Healthcare. https://doi.org/10.1145/3362789.3362881

CollegeBoard. (2017). *AP computer science A: Course and exam description*. AP Central.

Council, N. R. (2010). Committee for the workshops on computational thinking: Report of a workshop on the scope and nature of computational thinking. Washington, DC: National Academy.

Creswell, J. W. (2013). *Qualitative Inquiry & Research Design: Choosing among five approaches* (3rd ed.). In Public Administration. Sage.

Duncan, C., Bell, T., & Atlas, J. (2017). What do the teachers think? Introducing computational thinking in the primary school curriculum. *ACM International Conference Proceeding Series*. https://doi.org/10.1145/3013499.3013506

Ehsan, H., Dandridge, T. M., Yeter, I. H., & Cardella, M. E. (2018, June). K-2 students' computational thinking engagement in formal and informal learning settings: A case study (fundamental). *ASEE Annual Conference and Exposition, Conference Proceedings*. https://doi.org/10.18260/1-2--30743

Ehsan, H., Ohland, C., Dandridge, T., & Cardella, M. (2019). Computing for the Critters: Explor-ing Computational Thinking of Children in an Informal Learning Setting. Proceedings – Frontiers in Education Conference, FIE, 2018-October. https://doi.org/10.1109/FIE.2018.8659268

Gadanidis, G. (2017). Five Affordances of Computational Thinking to support Elementary Mathematics Education. *Journal of Computers in Mathematics & Science Teaching, 36*(2).

Grover, S., & Pea, R. (2013). Computational Thinking in K-12: A Review of the State of the Field. *Educational Researcher, 42*(1). https://doi.org/10.3102/0013189X12463051

Hickmott, D., Prieto-Rodriguez, E., & Holmes, K. (2018). A Scoping Review of Studies on Computational Thinking in K–12 Mathematics Classrooms. *Digital Experiences in Mathematics Education, 4*(1). https://doi.org/10.1007/s40751-017-0038-8

Huang, W., Chan, S. W., & Looi, C. K. (2021). Frame Shifting as a Challenge to Integrating Computational Thinking in Secondary Mathematics Education. *SIGCSE 2021 – Proceedings of the 52nd ACM Technical Symposium on Computer Science Education*. https://doi.org/10.1145/3408877.3432400

Kalelioglu, F., Gulbahar, Y., & Kukul, V. (2016). A Framework for Computational Thinking Based on a Systematic Research Review. *Baltic Journal of Modern Computing, 4*(3).

Kallia, M., van Borkulo, S. P., Drijvers, P., Barendsen, E., & Tolboom, J. (2021). Characterising computational thinking in mathematics education: a literature-informed Delphi study. *Research in Mathematics Education, 23*(2). https://doi.org/10.1080/14794802.2020.1852104

Lee, I., Grover, S., Martin, F., Pillai, S., & Malyn-Smith, J. (2020). Computational Thinking from a Disciplinary Perspective: Integrating Computational Thinking in K-12 Science, Technolo-gy, Engineering, and Mathematics Education. *Journal of Science Education and Technology, 29*(1). https://doi.org/10.1007/s10956-019-09803-w

Lee, I., Martin, F., Denner, J., Coulter, B., Allan, W., Erickson, J., Malyn-Smith, J., & Werner, L. (2011). Computational thinking for youth in practice. *ACM Inroads, 2*(1). https://doi.org/10.1145/1929887.1929902

Ling, M. K. D., & Loh, S. C. (2020). Relationship of creativity and critical thinking to pattern recognition among Singapore private school students. *Journal of Educational Research, 113*(1). https://doi.org/10.1080/00220671.2020.1716203

Looi, C. K., Chan, S. W., Huang, W., Seow, P., & Wu, L. (2020). Preservice teachers' views of computational thinking: Stem teachers vs non-stem teachers. Proceedings of International Conference on Computational Thinking Education.

Lu, J. J., & Fletcher, G. H. L. (2009). Thinking about computational thinking. *SIGCSE Bulletin Inroads, 41*(1). https://doi.org/10.1145/1539024.1508959

Maharani, S., Nusantara, T., As'ari, A. R., & Qohar, A. (2021). Exploring the computational thinking of our pre-service mathematics teachers in prepare of lesson plan. *Journal of Physics: Conference Series, 1783*(1). https://doi.org/10.1088/1742-6596/1783/1/012101

Mishra, P., Yadav, A., Henriksen, D., Kereluik, K., Terry, L., Fahnoe, C., & Terry, C. (2013). Rethinking Technology & Creativity in the 21st Century. *TechTrends, 57*(3). https://doi.org/10.1007/s11528-013-0655-z

Morreale, P., Goski, C., Jimenez, L., & Stewart-Gardiner, C. (2012). Measuring the impact of computational thinking workshops on high school teachers. *Journal of Computing Sciences in Colleges, 27*(6).

Niemel, P., Partanen, T., Harsu, M., Leppänen, L., & Ihantola, P. (2017). Computational thinking as an emergent learning trajectory of mathematics. *ACM International Conference Proceeding Series*. https://doi.org/10.1145/3141880.3141885

Orton, K., Weintrop, D., Beheshti, E., Horn, M., Jona, K., & Wilensky, U. (2016). Bringing computational thinking into high school mathematics and science classrooms. *Proceedings of International Conference of the Learning Sciences, ICLS , 2*.

Papert, S. (1980). Mindstorms Children, Computers, and Powerful Ideas (Second edition). *BasicBooks, 1*.

Papert, S. (1991). Situating Constructionism. In I. Harel & S. Papert (Eds.), *Contructionism* (pp. 1–11). Ablex.

Pears, A., Dagiene, V., & Jasute, E. (2017). Baltic and nordic K-12 teacher perspectives on computational thinking and computing. Lecture Notes in Computer Science (Including Sub-series Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 10696 LNCS. https://doi.org/10.1007/978-3-319-71483-7_12

Pei, C. (Yu), Weintrop, D., & Wilensky, U. (2018). Cultivating Computational Thinking Practices and Mathematical Habits of Mind in Lattice Land. *Mathematical Thinking and Learning, 20*(1). https://doi.org/10.1080/10986065.2018.1403543

Pollock, L., Mouza, C., Czik, A., Little, A., Coffey, D., & Buttram, J. (2017). From professional development to the classroom: Findings from CS K-12 teachers. *Proceedings of the Conference on Integrating Technology into Computer Science Education, ITiCSE*. https://doi.org/10.1145/3017680.3017739

Psycharis, S., & Kallia, M. (2017). The effects of computer programming on high school stu-dents' reasoning skills and mathematical self-efficacy and problem solving. *Instructional Science, 45*(5). https://doi.org/10.1007/s11251-017-9421-5

Rehmat, A. P., Ehsan, H., & Cardella, M. E. (2020). Instructional strategies to promote computa-tional thinking for young learners. *Journal of Digital Learning in Teacher Education, 36*(1). https://doi.org/10.1080/21532974.2019.1693942

Rich, K. M., Yadav, A., & Larimore, R. A. (2020). Teacher implementation profiles for integrat-ing computational thinking into elementary mathematics and science instruction. *Education and Information Technologies, 25*(4). https://doi.org/10.1007/s10639-020-10115-5

Sáez-López, J. M., Sevillano-García, M. L., & Vazquez-Cano, E. (2019). The effect of programming on primary school students' mathematical and scientific understanding: educational use of mBot. *Educational Technology Research and Development, 67*(6). https://doi.org/10.1007/s11423-019-09648-5

Sands, P., Yadav, A., & Good, J. (2018). Computational thinking in K-12: In-service teacher perceptions of computational thinking. In *Computational Thinking in the STEM Disciplines: Foundations and Research Highlights*. https://doi.org/10.1007/978-3-319-93566-9_8

Schleicher, A. (2018). PISA 2018: Insight and Interpretations. OECD, 24(1).

Selby, C. C. (2015, November). Relationships: Computational thinking, Pedagogy of programming, And bloom's taxonomy. ACM International Conference Proceeding Series. https://doi.org/10.1145/2818314.2818315

Selby, C., & Woollard, J. (2013). Computational Thinking : The Developing Definition. ITiCSE Conference 2013.

Sinclair, N., & Patterson, M. (2018). The Dynamic Geometrisation of Computer Programming. Mathematical Thinking and Learning, 20(1). https://doi.org/10.1080/10986065.2018.1403541

The Royal Society. (2012). Shut down or restart? The way forward for computing in UK schools. *Technology*, January.

van Borkulo, S., Chytas, C., Drijvers, P., Barendsen, E., & Tolboom, J. (2021). Computational Thinking in the Mathematics Classroom: Fostering Algorithmic Thinking and Generalization Skills Using Dynamic Mathematics Software. *ACM International Conference Proceeding Series*. https://doi.org/10.1145/3481312.3481319

Voogt, J., Fisser, P., Good, J., Mishra, P., & Yadav, A. (2015). Computational thinking in com-pulsory education: Towards an agenda for research and practice. *Education and Information Technologies, 20*(4). https://doi.org/10.1007/s10639-015-9412-6

Wang, D., Wang, T., & Liu, Z. (2014). A tangible programming tool for children to cultivate computational thinking. *The Scientific World Journal, 2014*. https://doi.org/10.1155/2014/428080

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining Computational Thinking for Mathematics and Science Classrooms. *Journal of Science Education and Technology, 25*(1). https://doi.org/10.1007/s10956-015-9581-5

Wing, J. (2006). Computational Thinking. *Communication of the ACM, 49*(3), 33–35.

Wing, J. M. (2010). Computational Thinking: What and Why? *Thelink – The Magaizne of the Varnegie Mellon University School of Computer Science*, March 2006.

Yadav, A., Stephenson, C., & Hong, H. (2017). Computational thinking for teacher education. *Communications of the ACM, 60*(4). https://doi.org/10.1145/2994591

Yin, R. K. (2014). Case study research: Design and methods (5th ed.). In *Thousand Oaks*, CA: SAGE Publications.

## About the authors

**Diane Vassallo** is a lecturer at the Faculty of Education, University of Malta. She conducts research in the field of Computational Thinking and has a particular interest in Computing education, digital competencies and curriculum design and development.

**Leonard Busuttil** is a senior lecturer at the Faculty of Education, University of Malta. Leonard is involved in the formation of pre-service and in-service Computing educators. His research interests include Computational Thinking, Computing education, design of educational software, game-based learning and human computer interaction.