Bebras-inspired Computational Thinking Primary School Resources Co-created by Computer Science Academics and Teachers

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ABSTRACT

This paper describes our process of creating computational thinking (CT) resources for primary school teachers in Ireland. The National Council for Curriculum and Assessment has proposed a revised primary mathematics curriculum with an emphasis on CT skills and problem solving, and some teachers would like to introduce it already on an informal basis. However, CT is not yet part of teacher training. Our motivating question has been: how can teachers without a computer science background deliver CT at primary level in Ireland?

Our process involves third-level computer science academics co-creating resources with in-service and pre-service teachers during workshops. The resources comprise a workbook and lesson plans. Our resources are based on tasks from the International Bebras Challenge, a well-known large-scale international CT contest with a reasonably gender-neutral profile of school-age participants. The workbook consists of ten Bebras tasks, each followed by a page of original activities on the theme of the task. A set of ten lesson plans accompanies the workbook.

Each lesson plan has information about how to use the corresponding workbook activities in the classroom, where the activity might fit into the existing curriculum, categorisation of the task in terms of eight CT topics, differentiation, and extension activities. This paper explains our process of workshop planning, workbook creation, and lesson plan co-creation. Preliminary evaluation of our process uses teacher feedback.

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CCS Concepts

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1 Introduction

Delivery of computer science as an examinable school subject is at an early stage in schools throughout Ireland. In 2020, computer science was introduced as a Leaving Certificate (formal end of high school state exam) subject. Initially, twenty secondary (second level/high school) schools piloted computer science as a Leaving Certificate subject nationally, and it is now open to all secondary schools. Additionally, a short course in computer programming which requires 100 hours of student engagement, has been available since 2017 for the Junior Cycle (a formal state exam after three years in high school). However, despite these subjects in secondary school there is no formal computer science curriculum in primary-level schools. In 2017, the National Council for Curriculum and Assessment (NCCA) proposed a revised primary mathematics curriculum with an emphasis on CT skills and problem solving [1]. Currently, the NCCA is undertaking a public consultation process in relation to a Draft Primary Curriculum Framework [2], which although not recommending computer science as a full primary-level subject, acknowledges that there are demands for computer programming and

computational thinking (CT) to be included. These demands are motivated by the perceived needs of students in the modern world, and by some evidence, requiring broader investigation, that an early introduction to CT can be advantageous for students, building confidence in dealing with complexity and with open-ended problems [3]. Teachers at primary level in Ireland currently have no formal computer science training to prepare them to deliver these topics.

The motivating question for the work reported in this paper is "How can primary–level teachers who have no training in computer science successfully teach introductory CT concepts in the classroom?". Through a project funded by the Science Foundation Ireland (SFI) Discover Programme, we have developed CT teaching materials that support primary-school teachers with no formal computer science training. The co-creation used in the generation of a workbook and lesson plans, that build upon Bebras tasks, is described in detail in this paper. We use this co-creation and partnership approach because, although we are experts in teaching computer science in a university and higher-level secondary school context, we have no knowledge or experience of how to do it in a primary school context. A further important consideration is where computer science topics fit into a new primary curriculum. In a report from the NCCA [4], mathematics and science were identified as being the most appropriate locations for the integration of these topics into the curriculum, with teachers identifying the potential for integration across other subjects also. This matches the feedback we have received through our interaction with teachers.

2 Related Work

At its core, computer science is a science of problem solving, supporting other subjects in the STEM family. This emphasis on domain-independent problem solving is why computer science is such a cross-cutting STEM subject: almost any scientific domain can make use of CT to analyse the efficiency and effectiveness of existing solutions, in order to discover improved solutions. As an approach to problem solving, CT is the process of finding and analysing solutions to problems that can be automated with a computer. Denning suggested that CT has been around since the 1950s as algorithmic thinking, referring to the use of an ordered precise set of steps to solve a problem and where appropriate to use a computer to do this task [5].

Many learning theories have been proposed over the last 100 years. The recent inclusion of digital resources in education has forced educators to reconsider these theories in the modern world. Some of these theories and their proposers might not subscribe fully to the CT teaching practice proposed here, but modern teaching tends to draw from many of these theories. Western educational systems are largely based around Piaget's idea of cognitive constructivism – students' progress through a series of stages from sensorimotor to formal operational. Vygotsky added a more social dimension to learning in 1978, with the notion of social constructivism [6]. In terms of computing, perhaps the most significant concept of learning came from Seymour Papert [7]. Papert is credited as concretising CT in 1980 [8], where he felt that CT could come about as a result of his constructionist approach to education, in which the social and affective dimensions are as important as the technical content. Through these dimensions, students construct computational artifacts that make CT an interdisciplinary tool for learning other disciplines [7]. It is since the contribution of Jeanette Wing in 2006 [9], who popularised the term CT and brought it to the international community's attention, that more focus has been placed on CT within education.

It has been shown that problem-solving skills can be extended and transferred [10] and that as a result students' analytical skills can be improved [11, 12]. Similarly, students' self-efficacy for computational problem solving, abstraction, debugging, and terminology can be increased [13]. One especially interesting finding is that exposure to CT can be used as an early indicator and predictor of academic success since CT scores have been found to correlate strongly with general academic achievement [14]. One form of CT resource, Bebras tasks [15], has been used in developing a testing tool to measure CT attainment skills in students [16].

The Bebras Computing Challenge [15] is an international contest that aims to promote computer science and CT among school students of all ages using fun and motivating puzzles referred to as tasks. Participants are usually supervised by teachers and the challenge is performed at schools [15]. These tasks allow teachers and students to work in a constructivist manner, building new knowledge and problem-solving skills based upon the foundations of previous learning. These tasks have proven to be remarkably inclusive across gender and culture. The tasks have been designed to be fun and appealing, appropriate for the contestants' age, and with solutions that should take on average three minutes per task [17]. During November 2021, over 2.5 million students from 36 countries took part in the challenge with the main aim of Bebras being to get students all over the world excited about computing [18]. Unique among international computer science competitions is Bebras' approximately equal gender balance (e.g. Ireland in November 2020: 44% female, 40% male, 16% unknown [19]).

Bebras tasks are a useful tool to reach out to teachers, students, and parents to encourage them to engage with CT for three reasons. Firstly, they are co-created by academics and teachers to be sound from both computer science and pedagogic perspectives and are accompanied by a paragraph about the computer science behind the task. Secondly, they require no computer science/CT expertise or technical knowledge/preparation on behalf of the teacher. Thirdly, they have proved to be engaging for children independent of age and gender, and are suitable as a whole-class activity, as justified in the previous paragraph. While not the only paradigm and set of resources that exists, Bebras tasks nonetheless can form a part of many different approaches to teach CT at primary level. As such, we believe there is sufficient interest in the community in an experience report that uses Bebras tasks, in particular, one that uses the same co-creation with schoolteachers, introduced below, that the international Bebras community itself strives for during task creation.

Our co-creation with in-service and pre-service teachers mirrors other co-creation situations. Co-creating content through including 'students as partners' and the co-creation of learning and teaching resources has become extremely popular and has been embedded in many curricula to date [20, 21, 22, 23]. One perceived benefit of students being involved in the curriculum co-creation process is that students can begin to think and practice differently with students often experiencing a shift in their metacognitive understanding of learning [21, 24]. Co-creating motivates students by increasing their sense of ownership and engagement in the teaching and learning process [21]. Bovill [25] states that "co-creation and partnership share many values and characteristics, and both envisage learning and teaching as things done with students not done to students". Co-creation and partnership share many common values, including shared respect, shared decision-making, negotiation, valuing all perspectives, and shared responsibility [25].

3 Workshops

Our activities included a combination of on-site and in-person Continuing Professional Development (CPD) workshops for primary and secondary school teachers. The aim was to provide mentoring but also a peer-learning opportunity where teachers can help each other to give them confidence to deliver Bebras-style problems in a classroom setting. Bebras tasks were chosen for teachers to allow them to teach fundamental CT skills. Initially, we ran two workshops at our university in a face-to-face setting with approximately 20 teachers and four third-level mentors in each. Teachers worked in groups of 4-6, progressing through the CT tasks and discussing how to generate and plan lessons for the tasks to be delivered in the classroom. The approach used in these workshops was a co-creation and partnership approach with teachers working together. Each group had teachers from both primary and secondary school, ensuring the groups had teachers who taught different age groups and subjects, thus bringing different experiences and ideas to the group.

The CPD in-person workshops were moved to an online setting due to the onset of Covid restrictions. We ran eight online workshops. This meant that we lost the face-to-face aspect of these workshops and the hands-on activities that we had planned. Working in an online setting did however allow us to reach a larger geographical spread of teachers, who perhaps would not have been able to attend in-person workshops. We used an established teleconferencing environment to run the on-line workshops, with break-out rooms to facilitate smaller-group work. A subset of Bebras CT tasks was chosen that illustrated a range of CT topics and were provided in PDF format to all participants in advance of the workshop. Document templates were prepared in advance of all workshops, with questions for each group to answer together during the workshop. These documents facilitated and promoted group discussion regarding the use and applicability of the CT tasks in a classroom setting. A third-level mentor was available to each break-out room. Lesson plan templates were provided in electronic form, and our teleconferencing environment supported collaborative answering of the questions in these documents in real-time.

The workshops (both in-person and on-line) began with an overview of how the workshop would run followed by an introduction to CT and its associated concepts. An overview of how and where CT links with education was then presented to the participants and then they were introduced to Bebras tasks which are the basis of our materials. Participants were then divided into smaller groups and presented with several Bebras tasks that they were asked to analyse and solve. Once this was completed, the entire group of participants and the workshop hosts came together to discuss these tasks and solutions along with where participants felt such tasks might fit in the curriculum, and what age groups they were appropriate for. This process was repeated with a second set of Bebras tasks. Following a short break, a third group session occurred where the participants were again put into smaller groups and asked to design a lesson plan for one of the Bebras tasks that they had worked through earlier, with occasional input from third-level mentors. During the first workshop a lesson plan template was co-created with all participants (see Figure 1). In this and each subsequent workshop, the groups worked with this template on compiling lesson plans for the Bebras tasks, before presenting their ideas to the whole group in the final part of the workshop.

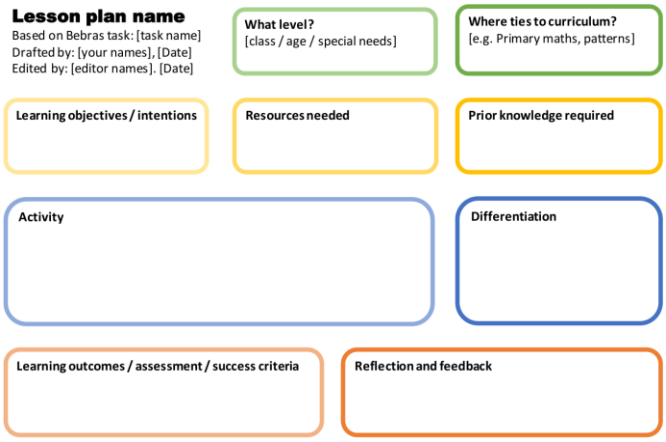

Figure 1: Co-created lesson plan template

Participants were asked to answer pre-workshop and post-workshop questionnaires. In-person workshop participants were also asked to fill in questionnaires after each activity during the workshop. Answering the questionnaires was voluntary. Almost all participants from the in-person workshops answered the questionnaires (21 responses in the first workshop and 16 in the second workshop). For the online workshops it was challenging to get questionnaires answered: we got a total of 27 pre-workshop questionnaire responses and 3 after-workshop responses from the online workshops. In total, 84 teachers participated in the workshops.

4 Workbook

As part of our vision, we wanted to create a workbook for primary schools to provide a coherent set of CT activities. The workbook has 10 lessons that can be easily delivered by a teacher, without any background in computer science, in the classroom over a term. Teachers may wish to allocate different amounts of discretionary time to CT (as there is no official allocation in the timetable), so each lesson supports durations of anywhere between 20 minutes and one hour. Teachers attending our workshops will have been introduced to Bebras tasks and may have used them in an ad hoc manner in their classrooms (e.g., Fun Fridays, or our highly popular seasonal tasks available on our website [26]). Some of the feedback from teachers on Bebras tasks that inspired the development of the workbook were suggestions for future resources such as:

- *"Ability-appropriate booklets."*
- *"Having series/sets of problems, with indexing by curriculum area."*
- *"Include differentiation type tasks to phase up skills + extend problems."*

The workbook provides extension activities to the Bebras task concept. It allows teachers a more structured way to introduce CT to their students. The workbook consists of ten Bebras or Bebras-inspired tasks, each followed by a page of original activities on the theme of the task. A set of ten lesson plans accompanies the workbook (described in the following section). We usually develop teacher resources in electronic form, but teachers had expressed an interest in a printed (hardcopy) workbook for several reasons, including breaking the reliance on IT-infrastructure, the quality of which varies widely from school to school. Having something tactile also gives a sense of ownership to the students and affords them the possibility to take questions home to work on with their parents.

The number of Bebras tasks in the workbook was selected to afford the right amount of content to support CT activities for one school term. Although we envisage most teachers will progress through the workbook linearly, sections can be selected arbitrarily from the workbook without difficulty. This allows the workbook to be used in less structured scenarios, such as after-school science clubs. The range of tasks in the workbook introduces students to the breadth of CT, while providing links to further online content. The workbook is aimed at 3rd to 6th class students (~8- to 12-year-old students), with tasks rated by difficulty using a three-point scale. The scale was verified and fine-tuned by pre-service teachers (explained in Section 5). Our original activities following each Bebras task in the workbook [27] have a lot of variety. Some pages contain up to six further instances of the same task in increasing order of difficulty, some require students to design their own task instance, some test their understanding of the CT concept behind the task, and some exercise their artistic imagination.

5 Co-created lesson plans

Thanks largely to the network we had established during recent years, we had extensive contacts with teachers and teacher trainers at both primary and secondary level. Through our workshops, we discovered an enthusiasm and a need for co-creating materials for teaching CT to students. We quickly realised that the co-creation process was key to generating lesson plans that would be useful and effective in classrooms nationwide. The co-created materials foster abstract thinking, numeracy, and literacy amongst students as they engage with CT in a constructivist manner [28].

As outlined above, our co-creation process began with in-person and online CT workshops for teachers. During our workshops, we discuss the suitability of the materials for various levels in the classroom, explore avenues to provide extension activities, and flesh out lesson plans for the most appropriate Bebras tasks. While we delivered the material on CT for these workshops, it is worthwhile noting that the discussion of appropriateness for the classroom, the extension activity exploration, and the lesson plan design were teacher-driven exercises. Time was a constraint for our workshops, so once they had concluded, our team edited the draft lesson plans.

Outside of the workshops, we also took the opportunity of working with Maynooth University Froebel Department of Primary and Early Childhood Education pre-service primary school teachers to design and improve lesson plans and to refine the problems themselves. In advance of working with the pre-service teachers, the workbook pages had been largely completed by third-level computer science academics, and each task was categorised in terms of eight CT topics. These topics were abstraction, algorithms, decomposition, evaluation, generalisation, logic, pattern recognition, and representation. The lesson plan template co-created during the aforementioned teacher workshops was the starting point, along with draft lesson plans from workshops. The lesson plan co-creation process proceeded in the following fashion. The pre-service teachers worked together in a room during scheduled meetings with a third-level mentor, and also singly and in pairs at other times, and for each lesson plan worked with us to determine:

- the difficulty level of each task and activities for 8- to 12-year-old students,
- how a teacher can use the activities in the classroom,
- where the activities fit into the curriculum in the absence of CT officially being in the curriculum,
- how to differentiate the activities for a range of abilities, and
- what extension activities are possible.

Co-creation of teaching materials has a number of benefits such as teacher buy-in (from an increased sense of ownership) to a better relevance to the curriculum (in terms of the day-to-day practitioners being involved in course material design). Another benefit relates to our stated goal of facilitating teachers without a computer science background to deliver CT at primary level in Ireland. By involving teachers in the co-creation process we get to informally induct a new generation of teachers into the discipline of CT. In addition, the cohort of teachers that we have had working with us to date has comprised a large number of pre-service teachers who each typically would work in many schools during their early careers, expanding the potential reach of our co-

created material. Working with pre-service teachers was a learning experience, albeit a smooth and productive one, resulting in a set of teacher-friendly lesson plans. As we report in the next section, the student teachers that took part in the co-creation process found it valuable and enjoyable.

6 Evaluation

Our workshop evaluation took the form of a combination of written questionnaires and dictated verbal conversations (feedback, suggestions, and shared ideas) that influenced our choices while preparing the CT workbook and accompanying lesson plans. Our workbook lesson plan co-creation evaluation took the form of a written questionnaire.

6.1 Evaluation of the co-creation process of lesson plans for the CT workbook

Feedback from three pre-service teachers that participated in workbook lesson plan co-creation is shown below, consisting of all answers to the free-form questions "How did you find the process of co-creating computational thinking lesson plans (how interesting/valuable/challenging)?" and "Do you have any other feedback about co-creating CT lesson plans?"

- "I found that it was good to work with others while creating the lesson plan as everyone brought their own ideas. We could suggest ideas and get feedback before ultimately agreeing on what would work best. Some people had areas that they were stronger in so there was a good balance, and we could focus on our preferred areas."
- "Working with peers also took some pressure/ intimidation of a big project like this away. You didn't have to have all the answers or ideas yourself; you could put an idea out into the group and work to develop it together."
- "I really enjoyed working collaboratively on a project with my peers."
- "The process of co-creating computational thinking lesson plans was extremely valuable as it allowed me to gain an insight into the value of computational thinking in education and how it can be applied in the classroom."
- "The nature of the work meant it felt very much like a team-based pursuit and that we were 'working with' rather than 'working for', this led to the process being quite enjoyable and made adapting the tasks for use in the classroom in a creative manner much easier."
- "I would also recommend this project to any if my peers. It was really enjoyable and asked you to think in a different way. It also gave us an insight to how the new maths curriculum might look/ be delivered especially regarding critical thinking."

These comments (above) show that co-creation of lesson plans for the CT workbook was found to be a valuable experience for pre-service teachers. We also found that it was a productive way of creating useful resources for teachers who did not have a computer science/CT background.

- "It was challenging at times to know what would work best for some of the lesson plans especially when everyone wasn't there to discuss things in person. However, I found the face-to-face sessions valuable, and I gained insights that will assist me in my own teaching."

This comment indicates that facilitating in-person meetings at the start of the co-creation process was found to be valuable, particularly for discussions and sharing ideas.

- "I think the process was well set up, and the goals of the process clearly outlined."

This comment informed us that it was important to plan the co-creation framework carefully and to provide a clear structure for the lesson plans. To make the production of lesson plans as effective as possible, clear goals needed to be explained.

- "I thought the ability to share the document and work independently when the hours suited/ became available was really helpful. Especially when you are in a full-time course, finding an hour here and there to work together rather than a set time every week was a factor that I think encourages participants."
- "The use of the shared documents was efficient as it meant that while we may have been working remotely, the collaborative element of the project was not lost."

These comments convinced us that finalising lesson plans required suitable and reliable tools for online collaboration. This was appreciated by the participants.

6.2 Can teachers successfully deliver CT materials in the classroom without prior computer science training?

Our workshop participants reported that they had very little prior knowledge of CT and most participants had not taught CT in the classroom before. However, after the workshop, the participants reported that they were very likely to teach CT to their students and use the CT materials provided. This can be seen in the mean outcomes (of 21 participants) of the questionnaire answers from our first in-person workshop below (scale: *1=not at all, 2=slightly, 3=moderately, 4=very much, 5=extremely much*), shown next.

Before workshop:
Q: Do you have prior knowledge of computational thinking? 2.2
Q: Have you taught computational thinking in the classroom? 1.7
After workshop:
Q: How likely are you to teach computational thinking to your students? 4.7
Q: How likely are you to use some of the materials in your classroom? 4.8
Q: How useful was the workshop for your teaching? 4.5
Q: How useful are the workshop materials for your teaching? 4.6
Q: How much do you think you will include computational thinking into your teaching? 4.1
Q: Do you think that it is difficult to teach computational thinking to students? 3.1

The following feedback was received from three pre-service teachers after the workbook lesson plan co-creation to the

question "How comfortable would you be to deliver these CT lessons in the classroom yourself?" (all feedback included).
- *"It was challenging at first to get into the mindset of the computational thinking but once we did it was a great experience."*
- *"I would be comfortable delivering the lessons myself. I would make sure I was comfortable with the CT problems themselves and understood how to complete them. Therefore, I think the best support is providing the teacher with the solution and explanation to the problem. Providing ideas for teaching them and extension activities are also helpful."*
- *"Very comfortable. All the lessons provided were easy to deliver and understand."*
- *"I also shared some of the charts as challenges with other teachers who thought they were a great engaging activity that really asked the children to think independently."*
- *"I would feel quite comfortable delivering the plans as the explanations of the tasks are quite thorough."*

Our conclusion is that Bebras-style CT materials can be an effective way to give teachers an introduction to CT. By initially solving Bebras tasks together in groups, teachers can gain confidence to later try out the CT materials in the classroom. By observing that there are often multiple ways to solve each task, teachers understand that Bebras tasks can lead to lively discussions where the teacher is a facilitator or even a participant, which is a more comfortable role to have when bringing new teaching material to the classroom. After two years of running our workshops and lesson plan co-creation activities with teachers, we are confident that our approach can support teachers without former computer science training to deliver novice-level CT materials confidently and successfully in the classroom.

6.3 Where to teach CT in the absence of computer science in the curriculum

The mathematics and science curricula were identified as being the most appropriate locations for the integration of CT concepts into the curriculum [9]. This is also the feedback teachers have given us, while identifying the potential for integration across other subjects also. For example, 18 out of 21 participants in our first workshop responded that they will be teaching CT as part of their mathematics allocated time. They also reported uses for Bebras-style CT materials in science, literacy, coding, first foreign language, and numeracy support curricula.

7. Conclusions and future work

We have organised ten teacher training workshops over the past two years with 84 teacher participants who collectively have distributed our CT materials to 7,145 students. The ideas and suggestions brought up during workshop discussions and workshop feedback inspired the co-creation of a Bebras-style CT workbook and lesson plans for primary schools. In addition, they have inspired us to provide other CT resources including 52 seasonal, and Irish language CT tasks. These CT resources have been distributed via our public website and have been used by over 14,000 students and 250 teachers in Ireland. Our CT workbook and lesson plans for teachers will be available for teachers to download from our website, and our funding also allows for 10,000 printed copies to be sent free-of-charge to primary schools in Ireland. We will seek follow-up feedback from teachers who have used our resources in the classroom and seek the necessary approvals to gather student feedback.

The process of generating CT workbooks, inspired by teacher feedback during our CT workshops, and with subsequent input from pre-service teachers (problem selection, difficulty tuning, and generation of lesson plans) has convinced us of the value of embracing a fully co-creational approach to generating primary school CT material. The teacher discussions and feedback received have given a clear indication that there is a need for CT teacher training in both primary and secondary level schools in Ireland. We have also received suggestions to develop our workshops through a more collaborative, co-creative approach. We plan to do this via CoCoA [29], our new project funded from the national SFI Discover Programme, to enable us to bring teachers together with CT experts to co-create, adapt, and evaluate new material for the classroom to facilitate teamwork, develop communication and related language skills, and promote problem-solving skills through physical activity. Co-created learning materials will include lesson plans, resource books, and a suite of active games to encourage physical activity, communication, and teamwork.

We will follow a peer-learning format where teachers can constructively collaborate to develop confidence delivering CT material, through (a) group evaluation of existing lesson plans and resources, (b) working in small teams to solve Bebras tasks and generate feedback, and (c) working with us to co-create teaching resources. In particular, we will continue to co-create teaching materials through collaboration with in-service and pre-service teachers, such as lesson plans, CT workbooks, and CT resource books with exercises that students complete at home with their parents. In the absence of CT in the primary school curriculum in Ireland, the developed resources will allow teachers to practice fundamental CT skills in a sound, effective, interesting, and engaging pedagogical manner, across multiple subjects in the school curriculum.

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