A Computational Thinking Obstacle Course Based on Bebras Tasks for K-12 Schools

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ABSTRACT

This paper describes an unplugged computational thinking (CT) resource for primary and secondary schools developed from Bebras tasks. In Ireland, CT is not part of the primary school curriculum or mandatory in secondary schools. However, the National Council for Curriculum and Assessment is in the process of revising the primary school curriculum to include aspects of CT. Our aim for creating this CT Obstacle Course is to introduce teachers (and pupils) without formal computer science training to the subject of CT. This is done in a manner that informs and motivates, and gives them the confidence to deliver CT materials in the classroom. We also want to find out from teachers how useful and important this type of resource is for developing problem-solving skills, and if our unplugged activity can support learning at various skill levels.

Our CT Obstacle Course includes 14 Bebras tasks for primary schools and an additional 6 Bebras tasks for secondary schools. The activity is suitable for indoors and outdoors and is completed in groups, promoting teamwork and communication. We have delivered it to 146 primary school classes during 38 school visits between May 2021 and June 2022. It has been undertaken by 3,445 pupils and 195 teachers and other school staff. This paper describes our CT resource in detail, and reports teacher feedback from primary schools.

CCS CONCEPTS

• Computational thinking • K-12 education

KEYWORDS

Computational thinking, Bebras tasks, K-12, unplugged

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1 INTRODUCTION

The PACT team at Maynooth University Department of Computer Science has been promoting computational thinking (CT) teaching at pre-undergraduate level since 2012. Our motivation is two-fold. Firstly, we believe that all students are well-served by having a knowledge of CT concepts, in the same way that all students have a broad introductory knowledge of other science subjects. Secondly, we recognise that the traditionally low progression rates of undergraduate computer science students can be addressed by better preparing them prior to their arrival in university. Part of this challenge is to strengthen their pathway to university by ensuring they have encountered CT in a meaningful way at primary and secondary school level.

Though long established in other countries, computer science is only a recent addition as a recognised subject in the Irish school system. Currently, computer science is an examinable subject on the Leaving Certificate (a formal state exam for 17-18 year olds), having been introduced on a pilot basis in 2020, and now open to all schools. Targeted at a slightly younger age-level, a short course in programming (100 hours of pupil engagement) was also introduced in 2017. This is available for the Junior Cycle (a formal state exam for 15-16 year olds). This is the earliest point at which pupils can formally encounter computer science in the school system in Ireland, with no computer science introduced at primary school level. There has been some discussion of addressing the demand for CT and programming at this primary school level, notably via the National Council for Curriculum and Assessment (NCCA) [15, 17]. Although not recommending computer science as a full primary level subject, the NCCA recognises the need for these topics to be taught at that level.

One of the most significant challenges in getting CT into the primary school classroom is teacher training. At primary level, there is no such formal training for teachers. The NCCA recommends [16] that mathematics and science are the most appropriate locations for introducing these new topics into the classroom with teachers being encouraged to explore integrating them into other subjects. Until there is teacher training and exposure to what is, in the Irish educational context, a relatively new topic, CT is unlikely to find its way into the primary school curriculum. The challenge then is "*how to introduce teachers (and pupils) to CT in a manner that informs and motivates them to do more in the area*?". Drawing upon the work of the long-established Bebras community, we leverage and adapt its refined CT materials to inform and educate teachers and pupils about CT. One resource we have designed and delivered, which has been very successful with schools and teachers that have little or no CT exposure, is the CT Obstacle Course. Our goal in this study was to deliver the CT Obstacle Course event to students and teachers by visiting at least 25 schools and 100 different classes (approximately 2,500 pupils and 100 teachers). In this paper, we discuss the motivation, design, and delivery of this resource. We also discuss the results of teacher feedback that indicate that the resource helps us achieve this goal of informing and empowering teachers to introduce more CT into the classroom.

2 RELATED WORK

Computer science is a science of problem solving, supporting other subjects in the STEM domain, and beyond, along with supporting countless industry domains. At its core, computer science, places an emphasis on domain-independent problem solving skills and techniques allowing computer science to be such a cross-cutting STEM subject. The computer science concept of CT describes the thought processes involved in understanding a problem and designing a set of instructions to solve that problem that a human or computer can follow. Further, CT can be used by almost any scientific domain to analyse the efficiency and effectiveness of existing solutions, in order to discover improved solutions. 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 [6].

Papert is credited with concretising CT in 1980 [20], 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. He felt that through active and deliberate effort, pupils could create meaningful computational artefacts that would help them to transfer their CT knowledge to other contexts and domains [14]. However, it was the contribution of Jeanette Wing in 2006 [23] which brought more focused attention to the term CT and brought it to the international community's attention.

Lodi [13] analysed the many definitions and discussions around CT and proposed a broad classification of the elements of CT found in many of these works. This classification can be represented by four categories. The first category is Mental Processes, which looks at the strategies used to solve problems, for example, decomposition and pattern recognition. The second category is Methods, which deals with approaches commonly used by computer scientists, such as automation, analysis, and representation. The third category is Practices, which deals with common practices used by computer scientists to implement solutions, such as iterating, testing, and debugging. The final category is Transversal Skills which looks at useful life skills that can enhance thinking like a computer scientist, for example, reflection, communication, and collaboration. Lehtimäki et al. [10] identify the eight CT concepts of decomposition, pattern recognition, representation, abstraction, algorithms, evaluation, logic, and generalisation.

The Bebras Computing Challenge [4] is an international contest that aims to promote computer science and CT among school pupils 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 [4]. These Bebras tasks allow teachers and pupils to work in a constructivist manner, building new knowledge and problem-solving skills based upon the foundations of previous learning through scaffolding.

Vygotsky introduced scaffolding as a teaching strategy where learners complete small, manageable steps in order to reach the goal [22]. While working with an instructor or peers, a learner can make links between concepts, and as they grow within their Zone of Proximal Development they become more confident, and practice new tasks, scaffolded by the social supports around them [8]. Dagiene & Dolgopolovas [5] highlight the interrelationship between CT and scaffolding and use Bebras tasks to scaffold learners learning CT skills. Bebras tasks are one established set of CT resources and have been used in developing a testing tool to measure CT attainment skills in pupils [12] and in developing resources for teachers [9]. Caeli [3] suggested that CT skills are rooted in non-digital (unplugged) human approaches to problem solving, which is something afforded by Bebras tasks.

Bebras 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' ages, and with solutions that should take on average three minutes per task [2]. During the November 2021 to April 2022 season, more than 3 million pupils from 59 countries took part in the challenge with the main aim being to get pupils all over the world excited about computing [1]. Unique among international computer science competitions is Bebras' approximately equal gender balance (e.g., Ireland national finals 2021: 41% female, 44% male, 15% unknown [7]).

The skills that make up CT are vital to a computer scientist, and learning these through formal computer science education in school is the most obvious option. However, where computer science is not an option in schools, it has been shown that CT has successfully been incorporated into subjects such as Mathematics and English [13, 19, 21, 24, 25].

In Ireland, the National Council for Curriculum and Assessment (government body advising the Minister for Education on curriculum and assessment) is in the process of revising the primary curriculum to include aspects of CT, following a consultation process with interested stakeholders which highlighted that CT would be best placed within Mathematics, Science, and Technology [18].

3 CT OBSTACLE COURSE

The main part of the unplugged resource is a sequence of 20 posters, each containing a Bebras-style CT task in the form of a multiple-choice question, ordered by increasing difficulty, with the first task appropriate for 8-year-olds, and the final task a challenge for 18-year-olds. In keeping with a well-rounded computer science education, this activity was designed to promote literacy, communication, and teamwork among pupils and enhances their logic, mathematics, and problem-solving skills. An opportunity for self-reflection is included at the end. Besides the sequence of posters, the resource comprises

1. A set of A4 answer sheets, one for each pupil or group.
2. A class answer sheet for the inter-task activity.
3. A combination lock box containing prizes for the final activity.

Differentiation. The number of posters available was dependent on pupil reading age. We have found that the most challenging aspect of these tasks is often one of literacy rather than CT. As examples, 10 posters were used for 8 year olds, 14 posters for 12 year olds, and all 20 posters for 16-18 year olds. Each group of two or three pupils could also work at its own pace. Each poster was labelled with one, two, or three diamonds according to its difficulty. We informed the class that each group could decide itself which available poster it would go to next – whether it would attempt the same level of difficulty, or an easier/harder one. The class was also told that each group should aim to solve 5 to 8 tasks, as the class working together as one big team would be able to solve them all in the given time (see Final Activity below).

Preparation. The posters were printed at size A0 or A1, mounted on A-frame boards or hung on walls in weatherproof plastic sleeves, in an indoor or outdoor space (see example in Figure 1). The class answer sheet was positioned in a central location. Class sizes ranged from 15 to 35 pupils. The whole event took 40-60 minutes. The facilitators of the CT Obstacle Course were the authors of this article, and pre-service teachers (from both primary and secondary levels) recruited from our university. The class was partitioned into self-selecting groups of two or three pupils, and each group was given a different colour felt pen. After an introduction to CT, the groups were asked to choose a different poster from each other as their first poster.

Inter-task activity. Pupils were encouraged to discuss the tasks within their group, and come to a consensus for their answer sheets. After each task, the pupils also wrote their answer on a common class answer sheet with their group colour. They were instructed to use a letter size proportional to how confident they were (see Figure 2). After updating the class answer sheet, each group threw a die to select an action to perform on their way to the next poster (e.g. bunny hops, skip, penguin walk). Facilitators circulated throughout the space proactively helping with literacy issues and encouraging intra-group and inter-group communication, e.g. encouraging them to explain to each other why they thought their solution was correct.

Figure 1: Photos of the setup.

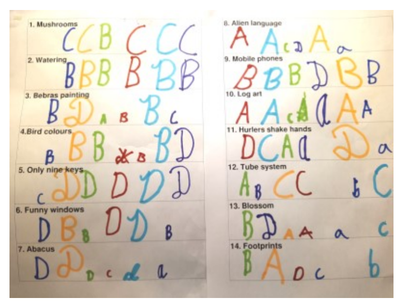

Figure 2: Class answer sheet showing, for each of 14 tasks, confident answers in large letters and less confident answers in smaller letters. The colours represent six different groups.

Final activity. Close to the end of the session, the class was brought together for a period of self-reflection to discuss different groups' approaches/strategies for selected tasks. The solutions were not revealed, however we offered tutorials for the most challenging tasks, as identified by the pupils or lack of consensus in the class answer sheet. For the final activity, the class as a whole, consulting the class answer sheet, had to use the answers for specific tasks to compose the combination for a lock box that contained prizes for the whole class.

Teachers. Class teachers had an observation role during the obstacle course, and had an opportunity to discuss CT and its importance with facilitators. Teachers were given an A4 printed booklet to use later in the classroom that contained the tasks, solutions, explanation of solutions, and links to CT. An example

CT Obstacle Course (posters, pupil answer sheet, and final task) is also available on our website pact.cs.nuim.ie.

4 RECRUITMENT AND DATA GATHERING

Schools were recruited through our website, teacher mailing lists, teacher conferences, and as a result of an article by the national broadcaster. Participating schools were a mix of city centre, suburban, and rural schools, including disadvantaged schools. Visits to schools took place during school hours, with typically 3-4 obstacle courses with different classes per visit. Typically, only one teacher in a school applied for the visit and was positively pre-disposed to the benefits of CT, and the other 2-3 teachers were new to CT. The online questionnaire, consisting of 11 optional questions, obtained university ethical approval in advance. The questionnaire was anonymous, but teachers could optionally give their school name.

We delivered the CT Obstacle Course to 146 primary school classes during 38 school visits between May 2021 and June 2022. In total, 3,445 pupils, 146 class teachers, and 49 other school staff participated. In the days following the school visit, the questionnaire was completed by 32 teachers (22% response rate) representing 15 different schools (39% coverage of schools visited), taking an average of 12 minutes each to complete it.

5 TEACHER FEEDBACK

In this study, the target group for our obstacle course materials were primary schools in Ireland, with pupil participants mostly from 3rd to 6th class (8-12 years of age), but a small number of participants were as young as 5 years of age (2 classes). Primary school teachers are qualified to teach all aspects of the curriculum, without specializing in any particular STEM subject. Most participating pupils and teachers had very little or no exposure to CT (or computer science) before the activity.

After running the obstacle course, we asked the teachers who observed the participating classes about their opinions on the CT Obstacle Course. The complete teacher feedback questionnaire is available on our website [26]. One of the first questions in the questionnaire was how well does this type of CT activity support the development of problem solving skills in pupils; 94% of the teachers (32 responses) indicated “extremely well”. (Other responses were 3% moderately well, 0% slightly, 0% not at all, and 3% skipped the question.)

5.1 Interest in CT

Figure 3 shows the teacher responses where teachers expressed a high level of interest in CT and a strong interest in including CT materials in their existing teaching. When asked if they thought it difficult to teach CT skills to pupils only 6% of teachers indicated that they would find it extremely difficult. As the teachers have no formal training in computer science, we interpret this interest in including CT materials in the curriculum and the teachers’ perceived approachability of the material as a positive reflection on our CT resources.

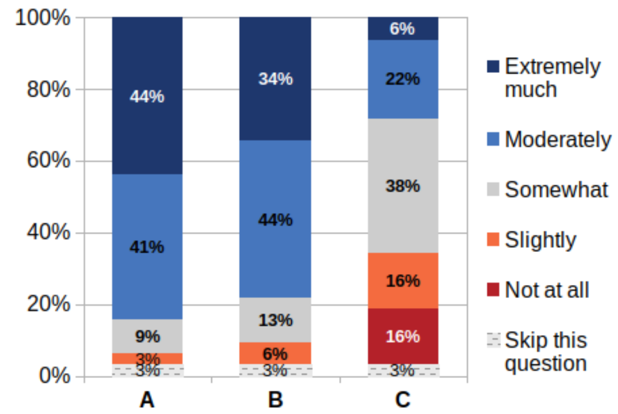

Figure 3: Interest in CT. A: How interested are you in computational thinking? B: How much do you think you will include computational thinking into your teaching? C: Do you think that it is difficult to teach computational thinking skills to pupils? (32 responses)

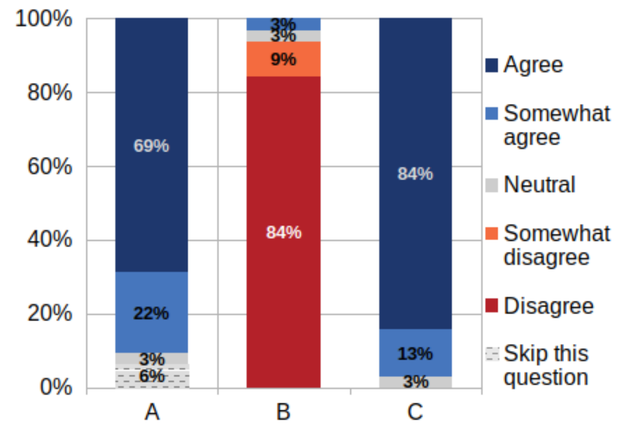

Figure 4: Evidence of positive effects. A: This school visit made me more interested in CT; B: I did not learn much during the CT school visit; C: The CT school visit was useful for my teaching. (32 responses)

In total, 91% of the teachers responded that the school visit, where we ran the obstacle course, made them more interested in CT and that they learned a lot during the school visit. Some of this learning came as a result of the teachers participating in the obstacle course activities themselves, some from observing the pupil interactions and learning as pupils participated in the activities, and some from the teacher guidance notes that we provided to teachers. These resources explain the concepts used in solving the tasks and their links to CT. Teachers also responded positively that the CT school visit was useful for their teaching. Teacher responses can be seen in Figure 4.

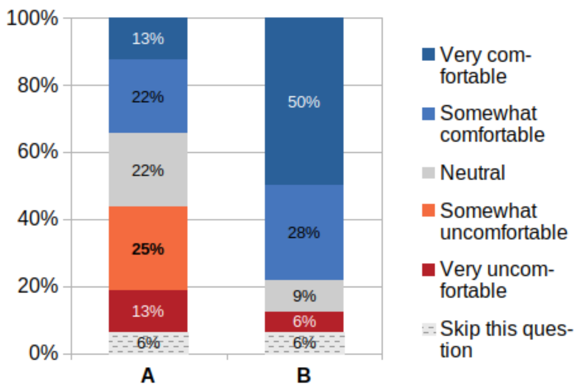

Figure 5: Comfort with teaching CT material. A: How comfortable were you teaching CT to this class before attending this activity? B: After this CT activity, how comfortable would you be teaching similar CT material to this class? (32 responses)

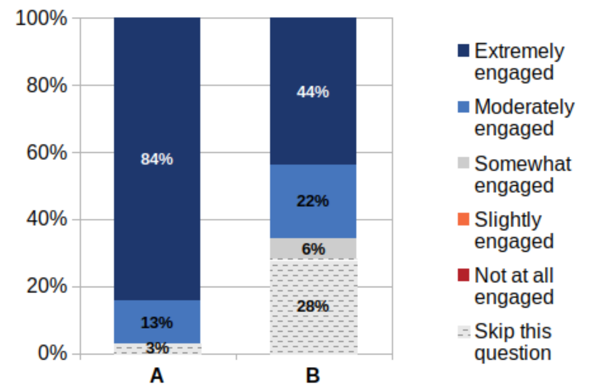

Figure 6: Engagement during the school visit and during a follow up activity run by teacher. A: How engaged were the pupils during the CT activity? B: How engaged were the pupils during a follow up CT activity run by you? (32 responses)

5.2 Comfort with teaching CT

Our motivating question for this research has been: How can we support teachers without formal computer science training to deliver CT materials in Ireland? Therefore, we were particularly interested to learn if teachers would be comfortable teaching CT to their class, and if observing our CT activities made teachers feel more comfortable when delivering the materials in the classroom. Figure 5 shows that more teachers felt comfortable teaching CT after attending our CT activity, increasing percentages who were somewhat comfortable and very comfortable from 34% before the activity to 78% after.

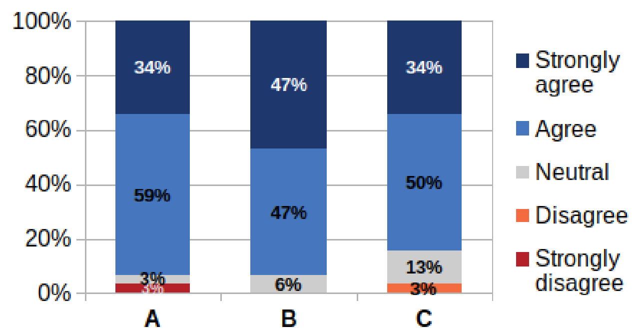

Figure 7: Differentiation – how well our CT resources suited a range of pupil abilities. A: This set of CT tasks worked well for the class as whole; B: All pupils were challenged tackling these tasks; C: This activity was encouraging for every ability in the class. (32 responses)

5.3 Engagement and differentiation

Figure 6 shows that in the teachers' opinions the majority of pupils (84%) were extremely engaged during our CT activity. Teachers were firstly interested in running follow-up activities to reinforce CT skills. Secondly, teachers were able to replicate CT activities using our CT resources without any formal CT training. Furthermore, pupil engagement in these follow-on activities ran by teachers was high, with over 60% of pupils moderately or extremely engaged in them. These findings are encouraging as they indicate re-usability of our resources for non-specialists in a way that maintains high engagement from pupils.

Figure 7 shows how successful our resources were in the classroom, and in particular how well our CT resources suited pupils with different abilities. Choosing the difficulty level of tasks is not straightforward. We aimed to include all class members, using group work to ensure that nobody was alienated, while challenging pupils so that they would be engaged and motivated to participate in the activity, hence developing their CT skills. Feedback illustrates that our CT resources worked for 84% of the classes, challenging and encouraging them regardless of ability.

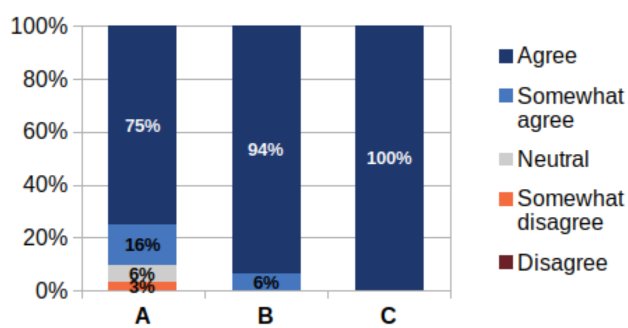

Figure 8: Teacher impact. A: The CT school visit gave me new ideas for my teaching; B: I plan to go through some CT tasks with my class in the future; C: I would like to participate in a similar activity again next year. (32 responses)

5.4 Impact

Figure 8 shows that our CT school visit provided 91% of teachers who attended our obstacle course activity with some new ideas that they can use in their teaching, with 100% of teachers planning to work through some CT tasks with their classes in the future.
All responding teachers were strongly interested in participating in a similar CT activity in the following year.

5.5 Freeform teacher feedback

The questionnaire sought freeform feedback with the question "*What did you find beneficial / What did you like about this CT activity?*" In our analysis of the teacher feedback, the following themes emerged: teamwork and engagement, differentiation, active learning approach and presentation of the resources.

Teamwork and engagement:
"Seeing groups working together to solve tasks, reading the question again when they weren't sure, suggesting different answers and working through the right and wrong. Excellent practice of these skills."
"I loved how all the pupils were engaged and how I could see the working together and communicating in order to solve the problem. They really had to listen to each other."
"I liked that all of the pupils were really engaged. They were thinking, discussing and active. It worked really well."
"It was very engaging for the children and everyone was challenged. Loved that it was completed in teams."
"The majority of the class were very engaged and enjoyed problem-solving themselves without much support from the teacher. Great to see this."
"The children really enjoyed the tasks and worked well in groups. I think some of them would be more apprehensive if they were working alone."
"Children worked independently which gave me more confidence in teaching it in class"

Differentiation:
"Easily differentiated."
"Whole class involvement in mixed ability groups"
"Gave me some problems that I know the children, whether they be strong or weaker, could all attempt."
"I enjoyed that the activities were "graded" so that everyone could find something accessible to get them started"
"It catered for all abilities. The help and instructions they have received before and during the tasks. All kids been active during the tasks."
"The ones who were very good at them really enjoyed them. The ones struggling didn't find it at all stressful. They still enjoyed them and once explained, some of the tasks were manageable so they had that same sense of satisfaction."

Active learning approach:
"The fact that it was active and outdoors. The team work element. The movement in between each activity and the way they all filled in the group sheet with letter sizes indicating their confidence in the answer. All great ideas to keep the activity lively and just completely different to the norm!"
"Hands on activity, active learning, many skills used to solve task"
"It was a great opportunity for discussions in how they were approaching problems and arriving at answers."
"They just saw it as fun."

Presentation of the resources:
"The presentation and resources were excellent."
"The easy and visual layout."
"Resources for both student and teacher, group work and teacher manuals."
"Very visual layout"

6 CONCLUSIONS AND FUTURE WORK

Feedback on the CT Obstacle Course suggests that unplugged activities based on Bebras tasks can serve as a starting point for introducing CT by primary school teachers in Ireland who do not have formal computer science training. Teachers reported differentiation was possible for different abilities. These activities give teachers confidence to seek further opportunities to bring CT into their primary school classrooms, including the many similar resources freely available on our website. According to their teachers, primary school pupils have found CT fun and engaging, and we conclude that for these pupils their first experience of computer science education was a positive one.
We exceeded our outreach target: Our aim was to visit at least 25 schools and 100 different classes and their teachers, introducing them to CT. In addition to the delivery of this resource to 146 different primary school classes in 38 primary schools, as reported in this paper, we have also piloted this CT Obstacle Course with nine different classes from five secondary schools. Further data is needed to determine the resource's suitability for these age groups, and in this regard we plan to visit more secondary schools. Further research is needed to assess the sustainability of the resources and applicability in different contexts, e.g. with special needs pupils.

The CT Obstacle Course is designed to be an initial exposure to CT for teachers and pupils. Teachers found the activity particularly beneficial because it was engaging, and supported active learning, teamwork, and differentiation. They also liked the presentation of the tasks. In order to provide a comprehensive introduction to CT to teachers, we are designing additional resources and training for teachers to supplement the CT Obstacle Course. A separate research project could associate explicit learning goals with these materials and assess pupils over the duration of their delivery.

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