Process of Creating and Evaluating Workbooks as a Resource for the Structured Teaching of Computational Thinking at Primary School

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Abstract. We report on a process of creating and evaluating a set of computational thinking (CT) workbooks for use in primary school. This resource was requested by our teacher feedback group for the structured teaching of CT. Our workbooks extend tasks from the Bebras international computational thinking initiative. The process of creating the three workbook set for different age groups has evolved to use co-creation with teachers. As an initial step, we created a pilot workbook with ten lessons for 3rd through 6th class students (approx. 8 to 12 year olds) from which to gain teacher feedback. A subset of the teachers from our community of practice (12 participants) volunteered to complete a pilot questionnaire about what age/class we should focus on, quality of the content, and whether the workbook was useful for teachers and interesting for pupils. The pilot workbook/questionnaire informed our work on the three workbook set and the main feedback questionnaire. This paper details our full process and what we have learned from our experiences of creating and evaluating new CT resources for primary schools.

Keywords: Computational thinking · Teaching resources · Unplugged · Primary school · K-12 education · Bebras.

1 Introduction

In 2020, computer science (CS) was introduced as a Leaving Certificate (formal end of high school state exam) subject in Ireland. Additionally, a short course in computer programming which requires 100 hours of student engagement, has been available since 2017 for the Junior Cycle (12 to 15 year olds). However, despite these subjects in secondary school there is no formal CS curriculum in primary schools. The organisation responsible for curriculum decisions is the National Council for Curriculum and Assessment (NCCA). It recognises the need for computational thinking (CT) [27] and programming to be taught at primary school level, and although not recommending CS as a full primary level subject, it does recommend [17] that mathematics and science are the most appropriate locations for introducing CS into the classroom. In the most recent Mathematics primary level curriculum, four processes of how children learn, called elements, were identified. One element relates to *Applying and problem-solving*, which has a reference to students developing and sharing their CT skills [18]. This is in line with many other countries where CS and in particular CT are embedded in primary schools [2].

There is no formal CS/CT training for primary teachers, and no CT lessons in primary school textbooks. However, primary teachers appreciate the value in teaching CT as an approach to problem solving, either in the context of mathematics or science, or during teacher discretionary time. Many teachers believe that it is only a matter of time before CT appears formally on the curriculum, and they want to get a started early.

Workbooks: Our workbooks, co-created with teachers, extend tasks from the Bebras international computational thinking initiative [6]. Our project involves the creation of a set of three CT workbooks for different ages. Each lesson in the workbook consists of a Bebras-style task, and a "second page", which is an additional activity that allows students to practice the particular CT skills illustrated with that Bebras task. Each lesson includes comprehensive teacher notes comprising a lesson plan, sample solutions, differentiation suggestions, extension activities, curriculum links, and links to CT.

In advance of creating the three workbook set, to understand our audience, we created a single pilot CT workbook with ten lessons for a broad range from third to sixth class (approximately 8 to 12 year olds) to get initial teacher feedback. We collected teacher feedback about what age/class we should focus on, the quality of the content, was the workbook useful for teachers, and was it interesting for pupils. We also collected detailed feedback on each of the ten lessons.

Evaluation: CS and CT are not on the primary school curriculum in Ireland. Therefore, in order to elicit opinions from teachers with as much knowledge as possible about CT, we invited to take part in our study teachers who had previously used CT resources that we had created. A total of 264 teachers from our community of practice answered our call to participate in the study, and all received printed copies of the pilot workbook for their classrooms. A subset of the teachers (12 participants) volunteered to complete a pilot questionnaire for the purposes of determining the suitability of specific tasks for different age groups, and in order for us to gain experience for the final questionnaire that asks the main body of teachers to evaluate the workbook.

This pilot questionnaire revealed some interesting results, such as that there is no universally agreed task that is definitely too easy for any age. Results also suggest strongest interest from 1st through 6th class for such workbooks. As a result of feedback, we have adopted a principle of not titling the workbook with specific ages/levels, due to the wide range of ages where the workbook can used. The results of the pilot questionnaire informed our work to finalise of the main feedback questionnaire, for example to include free form questions to better capture the range of responses to how well our workbook answers/fulfils the needs/expectations of the teachers.

In this paper, we report on the process of creating the three workbook set, the results of the feedback (pilot questionnaire) from the pilot workbook, the results of the feedback from the associated teacher notes, and what we have learned from our experiences of creating and evaluating new CT resources.

2 Related work

Workbooks are a key feature in education at primary school level in Ireland. The central aim of a workbook is to help to create a natural period of thinking for the students in solving theoretical tasks through reinforcement, practice, and consolidation. Utami et al. [25] found that the use of a workbook gives beneficial impact on students' learning since it can be a source of learning in addition to the teacher's explanation. These workbooks allow students to understand material with simple context and various methods of practice [20]. Preliminary evaluations of a higher education workbook to teach core concepts of computer programming suggest that it has fostered an interest in practical hands-on activities and collaborative work among students [22].

In previous work [12], we documented the co-creation of the teacher notes (lesson plans). This involved third-level CS academics co-creating resources with in-service and pre-service teachers during workshops. These teachers tend to have no prior CS or CT knowledge and thus are newly exposed of the material. One perceived benefit of pre-service teachers being involved in the curriculum co-creation process is that they can begin to think and practice differently and a shift in their metacognitive understanding of learning is often experienced [5,15].

Co-creating motivates learners by increasing their sense of ownership and engagement in the teaching and learning process [5]. Co-creation and partnership share many common values, including shared respect, shared decision-making, negotiation, valuing all perspectives, and shared responsibility [4]. Co-creation allows learners to develop knowledge and skills through their engagement with new concepts and through their experiences with staff and their peers [24]. The co-creation method, rooted in the principles of constructivism [3], which has links to Piaget's theory of intellectual development [19], empowers students to gain knowledge through interactions with an expert who evaluates the differences between the learner's existing knowledge and their capacity for learning [26].

Saito-Stehberger et al. [21] suggest that a strong foundation in CT is required in early education to allow students to develop an instinctive CT perspective of the world. They note that CT instruction is needed in primary school but it is hampered by the shortage of teachers qualified in, and interested in CT. In their work, when modifying a CT curriculum for novice teachers and language learners, the use of students' workbooks was seen as critical.

Cognitive load theory [9] acknowledges that meaningful learning occurs when cognitive processing does not exceed the learner's available cognitive capacity. Saito-Stehberger [21] attempted to reduce the cognitive load on learners, when

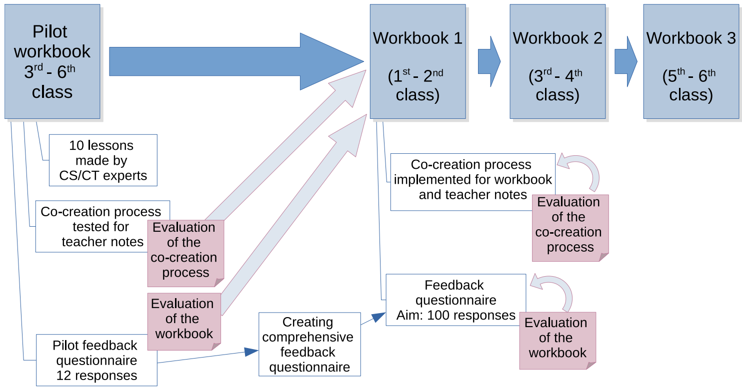

Fig. 1. An overview of the whole process of a pilot workbook followed by a three workbook set. The detail of the process for each workbook 1 through 3 is shown in Fig. 2.

developing their workbook by making changes around reducing ambiguity and wordiness, ensuring simpler sentence structure and eliminating unnecessary detail. They also ensured consistent activity sequences and headings were present throughout, allowing for familiarity to be developed by the learners. The starting point for our workbooks, namely Bebras tasks, ensure that the cognitive load is minimal for the child to understand the task, due to the well-established iterative process involved in creating these tasks [8]. Furthermore, the consistent usage in the workbook of a Bebras task followed by a second page of related activities allows children to quickly become familiar with the structure.

CS activities such as the Computer Science Unplugged project [1] have seen widespread interest from educators worldwide. Besides outreach, such activities are present in the primary school curriculum of many countries and are recommended in the ACM K-12 curriculum. Many are hands-on activities, but many are also suitable for direct inclusion in workbooks. Shimabuku at al. [23] produced a workbook that teaches programming concepts such as a control structure, a data structure, and an algorithm, using unplugged activities similar to Bebras tasks. They found that primary school pupils could understand such programming concepts using these activities. Learning by doing using workbooks allows students to learn in a more informal and supplementary fashion, and this learning by doing paradigm has been shown to be effective in numerous studies related to CT, including ones by Margaria [16] and Gossen et al. [10].

3 Process of creating and evaluating CT workbooks

Our process of workbook creation and evaluation is shown in Fig. 1. It shows the production and evaluation of a pilot workbook and a three workbook set. The pilot workbook was produced by our research team without direct teacher involvement (available in electronic form from https://pact.cs.nuim.ie/workbooks). Se-

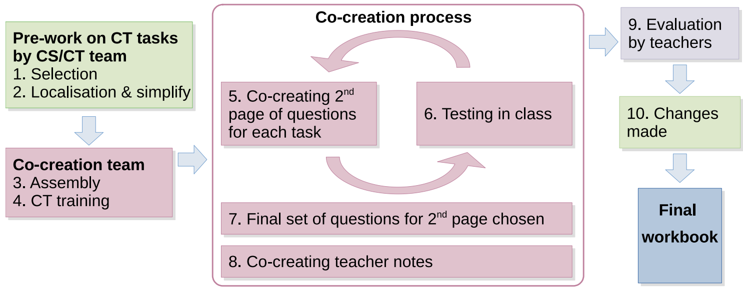

Fig. 2. The detail of the identical process used for each workbook in the three workbook set, where the numbering corresponds to the numbered explanations in Sect. 3.

lecting tasks used in the workbook was based on our experience using particular Bebras tasks during teacher training workshops [12], CT school visits [13], and feedback from teachers about seasonal CT resources provided online [14]. For selecting tasks to cover a variety of CT concepts (see Table 1 in the appendix), we used the set of CT concepts defined for our secondary school resource [11].

Co-creation of our resources was first introduced [12] for the pilot workbook's teacher notes (also available from https://pact.cs.nuim.ie/workbooks). Through involving experts from multiple domains we increased productivity, and have evolved our process to use it for each subsequent workbook and teacher notes. The pilot workbook was evaluated by 12 teachers via questionnaires investigating how they used the resources (results in Sect. 4). This evaluation informs our development of the three workbook set, and the choice of questions for our final questionnaire.

The creation and evaluation process for each of the three workbooks in the set is identical (see Fig. 2) and comprises the following steps:

1. A CS/CT expert pre-selected a superset of tasks based on
   - covering a range of CT topics/concepts,
   - indirect recommendations from the international Bebras community of teachers, education experts, and CS experts from the list of tasks selected for the Bebras challenge in multiple countries,
   - reasonable possibilities for an engaging second page in the workbook,
   - possibility of variants at different levels of difficulty (to fit tasks at different ends, or for the second page in the workbook), and
   - possibilities for a wide variety of extension activities in the teacher notes.
2. The narrative, language, and graphics used in tasks have been carefully prepared by the Bebras community to be easily localisable and translatable. However, we simplify the language and introduce local features (story, graphics, names of characters) to make it more engaging for local schoolchildren.
3. A diverse cohort of co-creators (primary and secondary pre-service teachers) is assembled, representative of the target groups for the workbook.

4. These teachers are trained in the topics/concepts of CT so they can distinguish CT from problem solving techniques such as lateral thinking, pure arithmetic, and common sense (and other non-mathematical approaches). The CT concepts covered in the training are documented in [11].
5. The development cycle for the superset of tasks and their second pages begins with off-line work individually or in pairs, for a group meeting of education domain experts and computer science subject experts each week.
6. Since co-creators have regular contact with classes during term time, they are encouraged to try out unpolished versions of tasks and give immediate feedback that is incorporated into the development cycle. In addition, we deliver workbook tasks in the course of our regular programme of free CT school visits throughout the country [13].
7. A subset of the tasks is chosen, based on how engaging they are for children, and ensuring a range of CT topics/concepts are covered. Then tasks are ordered, based on difficulty.
8. A comprehensive set of teacher notes is developed by the same co-creation team. Teacher notes include: lesson plan, sample solutions, extension activities, an explanation of links to CT topics/concepts (similar to the examples in [7]), and links to the primary mathematics and science curriculum.
9. A draft of the workbook with the teacher notes is given to a set of in-service teachers (with and without CT experience) for their feedback.
10. The results from a feedback questionnaire are analysed and documented for the next workbook. Recommended changes are made to the workbook.

4 Evaluating workbooks

In this section, we present a summary of the responses we obtained from surveying teachers in relation to their use of workbooks. The motivations for the survey were to uncover how the workbooks were being employed, importance and suitability of these type of CT lessons for range of classes, quality of the workbook, was the workbook useful and interesting, and the teacher preferences for the different lessons. Our aim was to get responses to at least to cover classes from 3rd through 6th (ages from 8 to 12 years). Twelve teachers responded. They had used the workbooks with total of 17 classes. The distribution of classes was from 2nd class of primary school to 1st year of secondary school (ages from 7 to 13 years). This distribution covered our target well. The majority of teachers had used the workbook with 6th class (for full distribution see Fig. 8 in Appendix).

Importance of computational thinking workbook by age (Fig. 3) The results for this question show that there was a very clear trend of increasing importance as students get older. This supports our plan to produce our three workbooks aimed from 1st class to 6th class. The results indicate significant interest among teachers, even at 1st and 2nd class. Perceived importance at a very early stage (infant classes) is not quite as marked, which is understandable. Nonetheless, the majority of respondents thought this type of workbook was important or

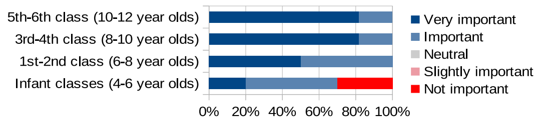

Fig. 3. How important is it to offer this type of computational thinking workbook to particular primary school classes, in your opinion?

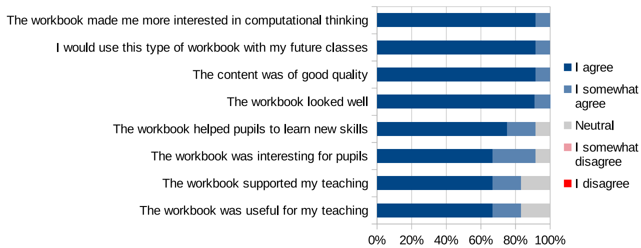

Fig. 4. We seek your opinions about the computational thinking workbook. Do you agree or disagree with the following statements?

very important - despite the challenges at that level (reading ability, teamwork/communication skills). This motivates us to create more tailored materials for these younger classes.

Quality/relevance of workbook (Fig. 4) This series of statements assessed the perceived quality of the workbook, its capacity to generate more interest in CT, whether it taught new skills, and how useful it was. Broadly speaking, the results were positive with over 90 percent of teachers agreeing that the workbook made them more interested in CT and that they would use similar resources in the future. Given that CT material is not yet on the curriculum, the responses to statements such as *The workbook supported my teaching* support the argument that CT is useful across many subject areas.

The difference between the responses to the first four statements and second four statements is interesting. In the main, the first four statements enquire about the teachers' opinions of the workbooks as academic resources, while the second four relate to the workbooks as teaching aids. While the difference is marginal, it appears there might be scope to improve the workbooks as a teaching resource.

Computational thinking lesson suitability for different classes (Fig. 5) This survey question was included to help us address the age appropriateness of individual lessons within the workbook. The results showed that some tasks were perceived as being appropriate for a wide range of ages (e.g. Pearl Bracelet, Passwords), while others were perceived as being suitable for a narrower range of ages (e.g. Footprints, Car Transportation). Again, it's worth noting that all tasks considered as suitable for younger age groups, seem to also be considered

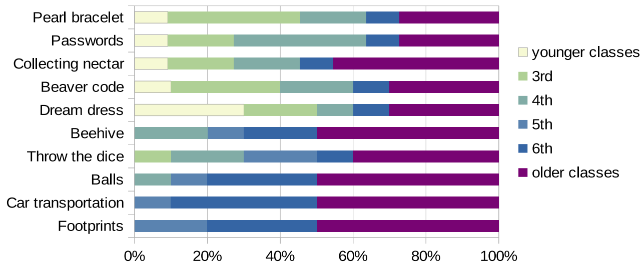

Fig. 5. Which class would each computational thinking lesson be most suitable for, in your opinion? (Each teacher selected for one class per lesson.)

as suitable for older students. For other tasks, we suspect that there is a minimum threshold age for students to understand the question posed in a lesson, after which it is useful for all levels. We plan to uncover this in future work with more refined feedback. In the meantime, this has implications for how we label the workbook and the associated guidance we provide teachers.

How workbooks were employed Teachers reported using the workbooks in different ways. In response to the open ended question *How did you fit these CT activities into your teaching?* teachers reported using the workbook...

- During maths (seven teachers): "problem solving in maths" (×3), "an introduction to maths lessons", "unlimited maths possibilities", "mental arithmetic", and "Maths Week activity",
- Outside maths (four teachers): "reading comprehension activity", "STEM Club", "orienteering activities", "with the Active School notices",
- Between subjects (six teachers): "morning activity" (×3), "transition activities between lessons", "Busy Break", and "homework", and,
- As rewards (three teachers): "fun Friday activity", "reward for good behaviour", and "early finisher activity".

This shows that although CT is not in the primary school curriculum, its inherent multidisciplinary nature and link with mathematics (possibly combined with the versatility of the Bebras task concept), meant that teachers were motivated, and succeeded, to find ways to fit it into their teaching.

5 Feedback on teacher notes

We sought feedback on the accompanying teacher notes from the teachers who used our workbooks. These teacher notes were co-created by computer science and educational experts, and provided common lesson guidelines, focusing on the pupils' thought processes when interacting with tasks in the workbook: articulating the different ways they have solved a given workbook task and reflecting on their approaches. The notes provide a guide to how a teacher might run the 30 –

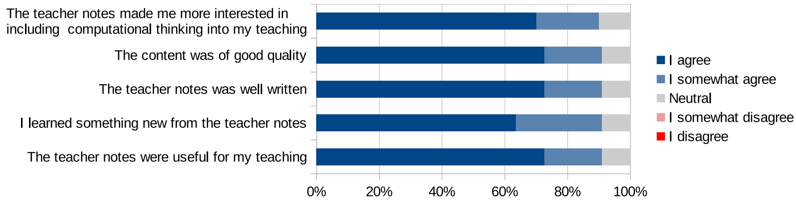

Fig. 6. We seek your opinions of the teacher notes for the CT workbook. Do you agree or disagree with the following statements?

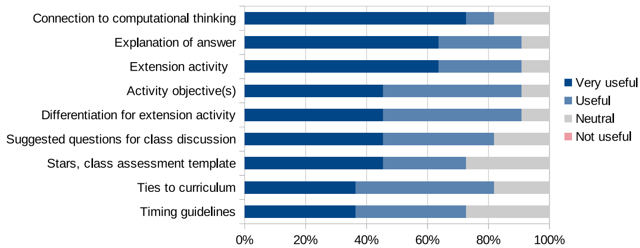

Fig. 7. How useful did you find the following sections of the teacher notes?

40 minute lessons (e.g. pupils working in pairs with the teacher as a facilitator) with associated recommended timings: on introducing the tasks; on the time spent solving the tasks (pair-work encouraged); on additional extension tasks (pair-work encouraged); on teacher-led class discussion where selected pairs can explain how they solved the task to the whole class; on comparison of answers and strategies and on guided questioning to lead a class discussion.

The 12 teachers that provided feedback on the workbooks also answered a questionnaire on the teacher notes. We discuss the responses below.

Opinions on CT workbook teacher notes (Fig. 6): In this figure, we show the teacher opinions of the accompanying teacher notes for the CT workbook. We see that at least 70 percent of teachers agreed that the teacher notes made them more interested in including computational thinking in their teaching, that the content was well written and of good quality, and that the teacher notes were useful for their teaching. Over 60 percent of teachers indicated that they learned something new from the teacher notes.

Teacher notes utility (Fig. 7): This figure shows the responses regarding the utility of each section of the teacher notes. All sections were deemed useful or very useful by over 70 percent of the teachers, with the section describing the connection of the task to computational thinking, the explanation of the answer, and the suggested extension activity reported as very useful in over 60 percent of responses. The weaker positive aspects were timing guidelines and ties to curriculum. Timing guidelines may need further refinement, given the wide range of ages the workbook is being used at. The issue of ties to the curriculum is a natural one, given the current status of CT in the national curriculum.

Extension activities (for details see Fig. 9 in Appendix): In this question, teachers reported on the extension activities that they did, or that they plan to do later. Responses indicate that teachers engaged with the extension activities in all tasks, with at least half engaging immediately with extension activities for four lessons and over 70 percent of teachers planning to engage with all ten lessons. This concurs with the extension activities being reported as being very useful in Fig. 7. Overall, from the responses, we conclude that the teacher notes (especially the answer explanations and extension activities) provided significant added value.

6 Conclusions and future work

Over the last four years, we have been refining a process which we feel would be useful to the wider community for generating and evaluating CT resources, such as workbooks. There are a number of central aspects to the process such as the key role that co-creation with teachers plays in the success of these resources, and the need to incorporate feedback into the process. Certainly, some aspects may be unique to our situation, such as the lack of CT in the primary school curriculum. Involving teachers in the co-creation process was invaluable, but not at every stage; we found that in the initial problem selection phase, working exclusively with CT experts was more valuable to get a good cross-sectional representation of CT tasks, as is documented in the appendix in Table 1.

Feedback and evaluation, as would be expected, are critical parts of our process. Some valuable nuggets of information have been uncovered. For example, it seems that no tasks are considered by teachers to be unsuitable for older age groups of students (i.e. no tasks are too simple). This has implications in terms of how we title and promote the set of workbooks. There is also quite a variation in which tasks are preferred by teachers, with some tasks eliciting a strong preference either positively or negatively, and others not. This deserves further exploration in the next iteration of the feedback questionnaire.

Our workbooks were used with 17 classes from 2$^{\text{nd}}$ class of primary school to 1$^{\text{st}}$ year of secondary school. It was interesting to see that teachers' opinions on the workbook (e.g. Fig. 4 and Fig. 6) were very similar despite the wide range of classes the workbook was used with.

Our co-creative process to developing suitable CT classroom and supporting materials has been successful. Buy-in from teachers is a natural result of the process and is evidenced by their wide range of uses for the materials in the classroom. Maintaining a feedback channel from teachers as they employ these materials in the classroom is a valuable component, allowing us to evolve our existing material and generate new material that teachers will find useful and have a sense of ownership over. This combination of co-creating materials and the establishment of long-term feedback channels alongside is an approach we have found extremely effective, and would recommend to practitioners with similar goals to ours.

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A Appendix

The selection of tasks in our workbook hits a broad range of CT concepts, as shown in Table 1. The age distribution of the classes that used the workbook in this study is shown in Fig. 8. The reported usage of extension activities by teachers for different lessons is shown in Fig. 9. Finally, a sample lesson from the workbook, and associated pages for the lesson from the teacher notes, is shown in Fig. 10.

Table 1. Representation of CT concepts in the tasks used in the workbook.

Task	Decom-position	Pattern recogni-tion	Repre-senta-tion	Abstrac-tion	Algo-rithms	Eval-uation	Logic	Gener-alisation
Pearl bracelet	x	x				x		
Passwords	x	x	x					
Collecting nectar	x				x	x		
Beaver code	x	x	x					
Dream dress	x			x	x		x	
Beehive	x	x				x	x	
Throw the dice	x				x		x	
Balls	x				x			x
Car transportation	x	x	x		x			
Footprints	x	x			x			

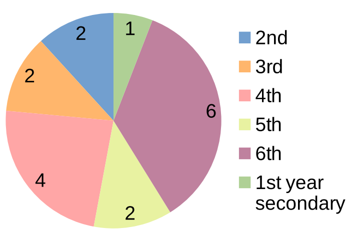

Fig. 8. What classes were the workbooks used with? The numbers in each segment specify how many classes of that age group used the workbook.

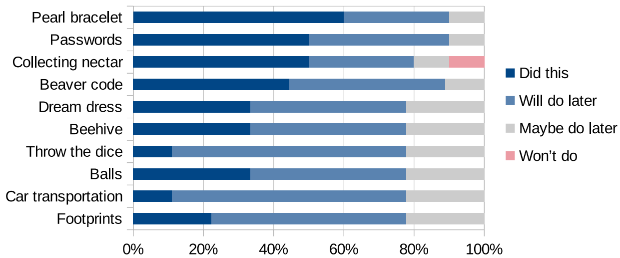

Fig. 9. Which extension activities did you do, or do you plan to do later?

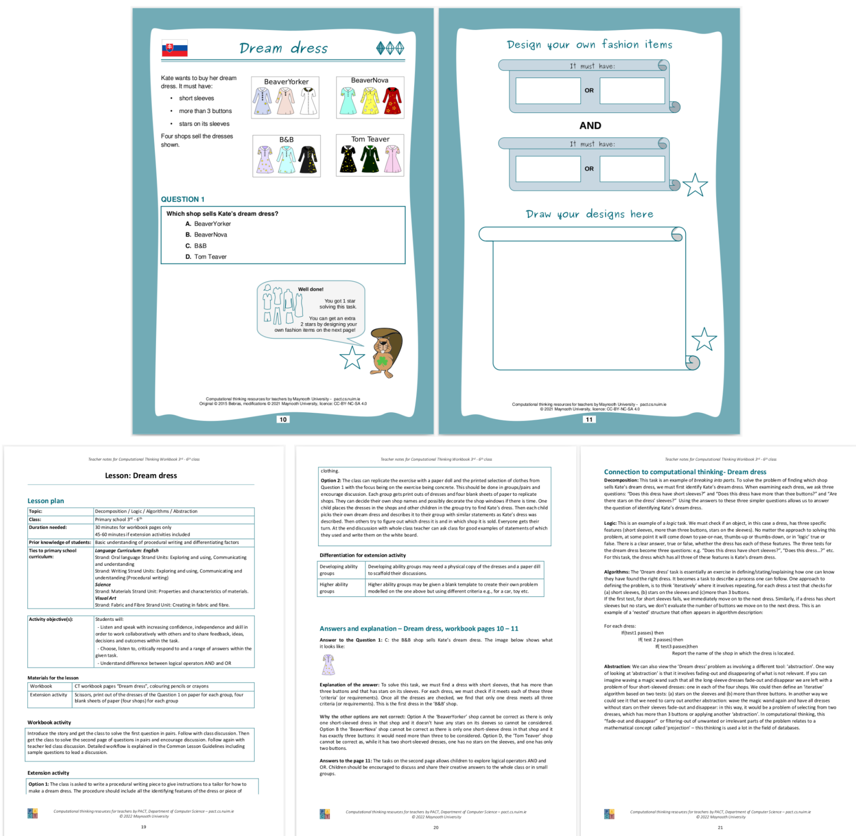

Fig. 10. Sample lesson "Dream Dress" with the associated teacher notes.