Pre-service teachers using programming to design learning objects: A case study

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In this paper we are interested in understanding how pre-service teachers use programming to design digital learning situations (learning objects). We discuss a case study of a pre-service teacher creating a learning object to teach a mathematics concept. Using a development-process model and the instrumental approach, with its concept of scheme, we analyze the pre-service teacher's engagement with the activity of creating the learning object and identify two schemes that she developed and mobilized for articulating the learning trajectory and articulating it in programming language. The analysis of schemes highlights the need for understanding operational knowledge in the context of pre-service teachers' experiences of using programming to design learning objects.

Keywords: Instrumental approach, programming, pre-service teachers, learning objects.

Introduction

Integrating computer programming into education is increasingly becoming a necessity in all levels and fields, from preschool to life-long learning (Schina et al., 2021). In the decades since Seymour Papert published his seminal work *Mindstorms* in 1980, the increasing research has emphasized the importance of programming in supporting students' understanding of mathematical concepts (Wilensky, 1995). Accordingly, teacher education and instructional programs are creating new learning paths and integrating programming. In particular, the Department of Mathematics and Statistics at Brock University has integrated programming into mathematics education for mathematics majors and future mathematics teachers through a sequence of Mathematics Integrated with Computers and Applications (MICA) courses (MICA I, II, III –for math and science majors / III* –for pre-service teachers). The MICA program is the context of the study reported in this paper. The learning objectives of MICA courses are to develop mathematics concepts in conjunction with programming skills and to encourage mathematical creativity. In the progression of the sequence of these courses, students engage in 14 programming-based mathematics investigation projects (4 in MICA I, 5 in MICA II, and 5 in MICA III or III*). Unlike other projects where instructors specify the topics, in each MICA course final project, students choose a topic of their interests and the type of project. Pre-service teachers may choose to create a "learning object (LO)" (Muller et al., 2009), i.e., a step-by-step guided learning interactive object of a school mathematics concept, and to work individually or in pairs in its design, which may be relevant to their future profession. Research highlights the importance of developing pre-service teachers' understanding of computational thinking in the context of the subject matter, such as mathematics (Yadav et al., 2014). However, there is limited research on pre-service teacher' learning experiences (Aslan & Zhu, 2016). This paper focuses on MICA pre-service teachers' learning experiences of creating LOs. Specifically, the paper discusses a case study aimed at exploring a pre-service teacher's engagement, and her development and mobilization of schemes through the activity of creating a learning object.

Theoretical Framework

We frame the pre-service teachers' engagement with the activity of designing an LO using a development-process (dp) model (Figure 1), proposed by Buteau and Muller (2010), that represents the student engagement in the activity, involving multiples steps that arise in a dynamic and non-linear way.

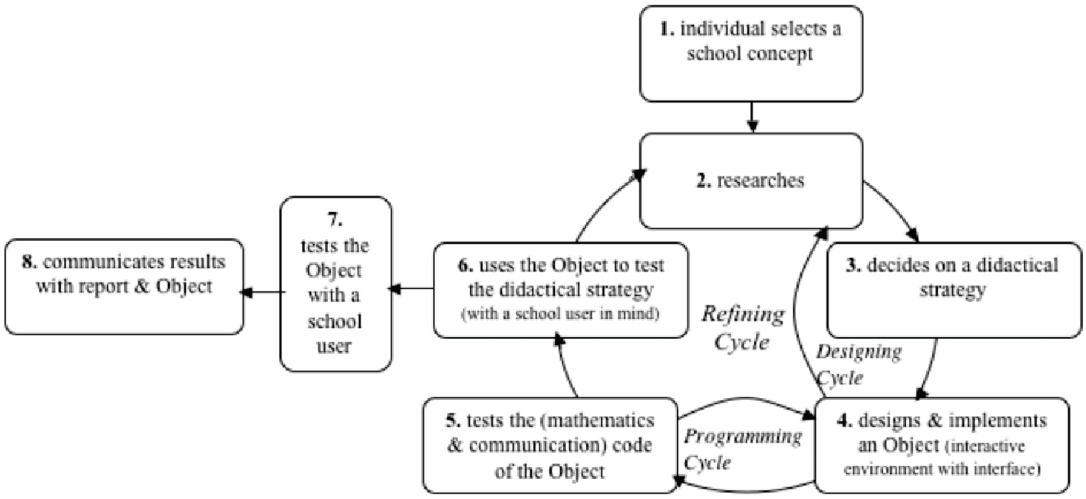

Figure 1: Development process model of an LO of a mathematical concept (Buteau & Muller, 2010)

Our understanding of pre-service teachers' development and mobilization of schemes is framed by an instrument-mediated activity approach –the instrumental approach– which was developed in the field of ergonomics to account for the active role that a user of an artefact plays, and the development of competence during his/her activity (Rabardel & Beguin, 2005). The instrumental approach has been further articulated and used in mathematics education research to conceptualize teaching and learning situations involving artefacts (Guin et al., 2005). In contrast with the dyadic subject-object interaction, the approach highlights the triad interactions among the subject, the instrument and the object towards which instrumented action is directed.

Critical to our study is the theory of instrumental genesis, which articulates a distinction between an artefact as a material or semiotic construct and an instrument as a psychological construct that emerges from the subject's activity with the artefact for a given goal. Put differently, "…during the activity and in situation… the user constitutes the artifact (whether physical or symbolic) as an instrument" (Rabardel & Beguin, 2005, p. 4) through an instrumental genesis process. The instrument is composed by a part of the artefact and a scheme of its use. A scheme (instrumented action scheme) is a stable organization of the subject's activity for a given goal, which is developed and mobilized by the user in action. It constitutes a whole or a set of mutually dependent components: i) one or several *goals* of the activity; ii) *rules-of-action* (RoA), to generate action, information seeking and control according to the features of the situation; iii) *operational invariants*: concepts-in-action (CiA), which are concepts considered as relevant and theorems-in-action (TiA), which are propositions considered as true and governing the RoAs; and iv) possibilities of *inferences* (Vergnaud, 2009).

Methodology

This paper is part of a 5-year ongoing research study, that seeks to examine how post-secondary mathematics students learn to use programming as a computational thinking instrument for mathematics inquiry. The naturalistic (non-interventional) study utilizes a mixed methodology and an iterative design approach. Data collected include each participant's programming-project assignments (e.g., the LO; and its associated report), and semi structured interviews with each of the participants after completing each of the project assignments. The design of the interview guiding questions was informed by the students' dp-model (Figure 1). In addition, data collected included post-laboratory session reflections and a questionnaire. After each of the 10 weekly 2-hour MICA lab sessions, participants recorded their reflections on their learning during the lab session (guiding questions were provided). All participants filled an online questionnaire before and after their MICA course. In this paper, we discuss the case study of a MICA II student, Kassie (pseudonym). Kassie was among eight MICA II participants recruited in year 2 of our larger study. Kassie was selected because she was particularly reflective and elaborative in her interview and lab reflections. Data for the case study include Kassie's final project –an LO and report, a semi-structured interview about her final project, and post-laboratory reflections related to her final project. The interviews were recorded as audio files and then transcribed into word documents. To describe Kassie's engagement with the activity, we analysed Kassie's final project interview, her report and the LO by trying to observe her activity in the steps of the dp-model. To analyse Kasie's schemes, first Kassie's interview and lab reflection data were coded individually by two coders, followed by a thematic analysis (Cresswell, 2014) done jointly by two coders. 16 subthemes were grouped in five main themes, two of which corresponded to strategies and perceptions. In addition to those themes, other themes specific to LOs were identified. Using codes under themes for the strategies (associated to rules-of-action) and the perceptions (associated to operational invariants) and informed by the steps in the dp-model, we then analysed the scheme according to its components (*RoAs* and operation invariants).

Findings

We present the results of the case study. First, we describe Kassie's engagement with the activity of creating the LO. Second, we present two examples of Kassie's schemes that were identified through analysis.

Kassie's engagement with the activity

As indicated below in Figure 1, the development process of an LO begins with the student selecting a school concept to teach (step 1). Kassie and her assignment partner started by looking for potential high school mathematics topics on the internet. They decided on the derivatives topic after discussing three possible topics between each other and their professor. They stated on their LO report that the focus was on first derivatives, specifically focusing on velocity. After deciding on the topic, they referred mostly to their personal notes from high school, the internet and library resources to find out when and how the derivatives are taught in the Ontario school curriculum and what the prerequisite mathematical knowledge for the topic would be (step 2). They chose grade 11 and 12 for their LO and assumed that the students would have sufficient background knowledge on derivatives and velocity because they would have just learned or would be in the process of learning about derivatives.

In deciding on didactical strategy (step 3), Kassie and her partner decided to focus on the derivatives as a concept and planned to show the relationship between the derivatives and the graphs. They aimed at enhancing the students' understanding of derivatives, give prompts and fun refreshers to help them understand one of the applications of derivatives–velocity.

After deciding on their didactical strategy, they began to design and implement (through code in the vb.net programming language) an interactive LO with a self- contained interface (step 4). Kassie stated that they gradually built on the LO as they were developing it. For this activity, Kassie and her partner created a random equations generator, derivatives and graphs and led the user to match the graphs to derivatives. They designed their LO in a way as to lead the user to find the derivative, then find the graph, then find the velocity. Kassie and her partner tested the interface in terms of its functioning, communication and/or navigation in several different cases, to ensure the accuracy of their coding (step 5). Kassie indicated that she and her partner had to debug the programming when they randomly generated the questions. She also stated that, after they tested the LO, they improved the look of the picture and textboxes for the user.

Kassie and her partner revisited their didactical strategy by having three university students who are not in a math program to use the LO and complete a survey to control if any change or improvisation was needed in the activities (step 7). Kassie stated that the feedback they received from the university students affirmed that their LO was adequate for high school grade 11 and 12 students, and that it portrayed the information in an entertaining and interactive way. Subsequently, they submitted the LO and their corresponding LO report, which included the didactical purpose and strategies, the target audience and the mathematical background of the target audience, a summary of the school pupil's experience, and a discussion (step 8).

Kassie's examples of schemes

Table 1: Scheme of Articulating the learning trajectory

Goal	Rules of Action	Operational Invariants (TiA or CiA)
Articulating the learning trajectory / development of the topic	I identify the way students learn the best I identify a concept development I identify an interesting context to capture interest (Friends) I identify the possible applications between the selected topic with other topics (not only in mathematics)	When learners can relate the topic that they are learning with something from their lives, they are more interested. (Theorem in action) High school students need interesting situations/contexts to learn math (Theorem in action). A good context or situation to learn is one that relates mathematics to other area (e.g., physics) (Theorem in action) Relation between math concepts and other contexts (Concept in action) Math concepts can be applied to other areas (e.g., physics)

Table 1 summarizes components of Kassie's scheme of articulating the learning trajectory (step 3 of the dp-model). During the interview, Kassie was asked to articulate on what kind of a didactical strategy she used for the LO user to learn, and she noted:

> Well, we wanted them to learn the most basic way possible, but in a way that they could relate to, not something that's like just straight math. So, we put like a storyline and tried to enhance that so they would be interested in actually doing it. (LO, 15)

We interpreted this description by Kassie as indicating a rule of action such as "I identify the way students learn the best" and a theorem in action such as "When learners can relate the topic that they are learning with something from their lives, they are more interested". We interpreted Kassie's reflection on how the students learn the best as she is aiming to establish connections between real life situations. Kassie assumed that a story that LO users can relate to, is likely to draw the targeted age group's interest to the mathematics activity. Kassie was asked if her focus was more on the algebra and calculations, or more on the concept of what a derivative is. She stated:

> I think I focused more on the concept of what a derivative is, because we were looking at velocity and how fast something moves. So, we did a Friends (tv series) theme, and we gave them three options for Ross (a character in Friends) to get to work, and what was the fastest way for him? So, we said that they had a background in derivatives, we just wanted them to understand the concept of velocity and what that means and how you see if something has a faster velocity than something else. (LO, 14)

We interpreted Kassie's answer as indicating many RoAs such as "I identify a concept development", "I identify an interesting context to capture interest", and "I identify the possible applications between the selected topic with other topics that are not necessarily in mathematics". Kassie's emphasis on the derivatives as a concept, indicated that she intended to design the LO to develop the user's understanding of the concept with its relationship to other concepts such as velocity. In her explanation, Kassie identified a learning objective (comprehension of the derivative concept); and its relations to other areas (velocity in physics); and how the mathematics problem could be presented to the learner in a relatable and entertaining context to capture interest (the Friends theme and going to work). On her LO report, she expressed her thoughts on how learners are more interested when they can relate the topic with something from their lives, stating:

> By having our program F.R.I.E.N.D.S. themed, it not only engages the students in what is being taught to them, but it also gives them ideas and leeway into being creative with other concepts of math in order to better their own understanding. The students will gain a better understanding of velocity by comparing the velocities of three different modes of transportation, and actually conducting their derivatives in order to find the fastest velocity. This not only enhances their understanding of derivatives, but also allows them to explore a real-life situation in regard to velocity. (LO Report)

We interpret her explanation as she regards a good context or situation to learn is to be one that relates mathematics to another area such as physics.

Table 2 summarizes the components of scheme of articulating the learning trajectory in programming language. The scheme relates to the planning stage of step 4 of the dp-model.

Table 2: Scheme of articulating the learning trajectory in programming language

Goal	Rules of Action	Operational Invariants (TiAs and CiAs)
Articulating the parts of the learning trajectory in programming language	I identify the parts of the learning trajectory to be coded I code the parts separately step by step (e.g., equations, graphs) I use the story/context of the to code the parts I use my previous programming knowledge from previous assignments to code the parts	Learning trajectory shows how the user will develop understanding of the concepts to be learned The parts of learning trajectory must align with the story/context of the learning Programmed math must help the user to visualize the mathematics

When Kassie was asked how she incorporated the graphs with the concept of velocity and derivatives in her design, she expressed that she envisioned the user to first understand what a graph is and how it looks, then understand what a derivative graph is and how it looks and finally understand the relationship of velocity with the graphs and the concept of derivatives through finding the actual velocity. Kassie noted: “We wanted them to know what the graph looked like, know what the derivative graph looked like, and know like, what the actual velocity was.” (LO, 15)

We interpret the above as Kassie developing a RoA “I identify the parts of the learning trajectory to be coded” supported by the TiA, “Learning trajectory shows how the user will develop understanding of the concepts to be learned.” To design and execute these steps in the LO, Kassie and her partner started to design and work with the original graphs, then with the derivative graphs and finally find the velocity to imitate the user’s steps. Kassie noted: “So, I think we started with the original graphs, and then we started with the derivative graphs and then we went to find the velocity.” (LO, 15)

We interpreted this explanation as Kassie developed a RoA, “I code the parts of the learning trajectory separately step by step (e.g., equations, graphs)”. Kassie further elaborated on how she and her partner embedded a storyline –in this case, a character from a TV series trying to go to work– as they coded step by step the parts of the LO:

> We built on the learning object, because we explained the story where “he needs to get to work, let's try and find him the fastest way”. So, then they had the graphs, the original graphs, and then they had to match them to what they thought it was, and then they took the derivatives, or they practiced derivatives, just like random equations, then they took the derivative graphs and matched it to the derivatives that they took and then they found the velocity. So, it was kind of "here's your first part, then find the derivative, then find the graph, then find the velocity. " (LO, 16).

We interpret this explanation as Kassie developing a RoA, “I use the story/context of the learning task to code the parts” and the TiA, “The parts of learning trajectory must align with the story/context of the learning object."

When Kassie was asked why they wanted to include the graphs and the function with its derivative in their LO, she elaborated:

> I feel like it's really important because they make sure you know it in high school but also for our own understanding, I thought that "you want to know what that looks like", you want to know that the derivative of a parabola is like a straight line. I feel that is really important to know, so that they can visualize it while they're actually learning, the concept of it. (LO, 26)

We interpret the above explanation as Kassie developing a TiA such as “programmed math must help the user to visualize the mathematics”. Kassie was asked if she referred to her previous programming knowledge that had been covered previously in the course and she stated:

> Yes, definitely. Because there was certain things that I didn't remember how to do that, but I know we did it in previous assignments, so it was easy to go back and be like "this is how you do it, okay let's do it like that". (LO, 18)

We interpreted Kassie’s answer as indicating a RoA she developed during her design process of the LO as “I use my programming knowledge from previous assignments to code the parts”.

Discussion and Concluding Remarks

In this paper we presented a case study of a pre-service teacher experience of using programming to design a learning object. Using the dp-model and concept of scheme we described a case of a pre-service teacher engagement, development and mobilization of two schemes for the activity. The concept of scheme is crucial in understanding Vergnaud’s (2009) distinction between operational form of knowledge (action in the physical and social world) and the predicative form of knowledge (linguistic and symbolic expressions of the knowledge). While both kinds of knowledge are important in understanding pre-service teachers’ activity, mathematics education research tends to focus more on predicative knowledge (Vergnaud, 2009). Our analysis of engagement and two schemes developed by the pre-service teacher highlights the need to understand operational knowledge in the context of pre-service teachers’ learning experiences of using programming to design learning objects. As integrating computer programming into mathematics education is increasingly becoming a necessity, more research is needed to understand this kind of knowledge and its implication to mathematics teacher education. In our previous work on exploratory objects for pure or applied mathematics investigations, we have argued that the schemes that students develop and mobilize are associated to steps in the related dp-model (e.g., Gueudet et al., 2020). Likewise, our case study on learning objects indicates that the schemes that pre-service teachers develop and mobilize are associated with the dp-model for LOs. The two pre-service teachers’ schemes identified in the case study are associated with Step 3 and 4 of the dp-model (Figure 1).

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