Blending Mobile Technologies and Traditional Resources in Mathematical Learning Activities

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Abstract: Designing curriculum-based learning activities involves identifying and implementing affordances that provide opportunities for students to engage in actions directed at achieving specific learning objectives. These affordances may be mediated by information and communication technologies (ICT) or traditional resources, peers or teachers, or other contextual features of the learning environment. The learning objectives guide the designer's choice of affordances, whose deployment on specific artifacts is based on assessing the available artifacts' mediating capabilities. Such a design approach puts high demands on the designer's technological, pedagogical and content knowledge. In this paper, we discuss how we have addressed these demands by adopting a flexible co-design approach that invites the creative blending of mobile technologies and augmented reality with traditional resources, for the purpose of designing innovative mathematical learning activities with high relevance for teachers' practice and the mathematics curriculum.

Keywords: Co-design, design research, mobile technologies, augmented reality

1. Introduction

ICT offer unique opportunities for students to engage in mathematical explorations that naturally require self-regulatory processes such as forethought, planning, and activation; monitoring; control; reaction and reflection [1]. The learning of mathematics is a topic of interest within many research communities, which address mathematics learning from different perspectives and for different purposes. For example, learning mathematics with technologies is an issue that concerns researchers in technology enhanced learning (TEL) as well as researchers in mathematics education. While TEL research puts focus on developing innovative and often prototypical educational technologies, research in mathematics education addresses innovative use of mature, stable and teacher-friendly technologies for the learning of mathematics. The natural homogeneity of accumulated knowledge and restrictions regarding accepted forms and content of research communication within each community limits the educational impact of their research products. While research in mathematics education often does not fully exploit the use of (potentially) available ICT solutions for supporting innovative practices in the classroom, TEL research tends to fall short of addressing current trends in school curriculum development.

Our research team has addressed these issues by initiating and sustaining collaboration between researchers with expertise respectively in mathematics education and TEL. These researchers pursue curriculum-based collaborative design research directed at developing and testing educational activities for the learning of mathematics

[2]. The core of this team consists of two senior researchers who arrange teams from a pool of colleagues and doctoral students as well as school teachers in several different projects. The roles of the team members vary depending on their individual expertise and the character of the specific project, and so does the role of the participating teachers. In our very first joint project, the teachers' interests and desired learning objectives were prioritized and the technological solutions were directed at fulfilling their wishes [3]. In more recent projects, described later in this paper, the participating teachers have mainly served as reactors to the researchers' proposals. According to the researchers' judgment, the intended educational affordances of the technologies used in these projects had to be implemented before they could be efficiently communicated and discussed with the teachers.

Decisions about how to arrange the research team and the research process are always constrained by external factors such as available personnel, available funding, deadlines and other factors that frame and restrict the research effort. When these issues are handled, we achieve unique opportunities for enhancing the educational impact of our research efforts by drawing on the expertise of team members from different research traditions. The researchers' individual pieces of knowledge are integrated and cultivated in the collaborative research process. By initiating and sustaining collaboration between researchers in TEL and mathematics education, and drawing on the participating teachers' experience-based knowledge in the research process, we can seriously engage in the design of curriculum-based mathematical learning activities with innovative technologies.

In the next two sections, we briefly describe the methodological and theoretical foundations for our research efforts, following some recommendations provided by Sollervall and Milrad [2]. In section 4, we describe and elaborate on some of our recent research efforts that highlight the blending of mobile technologies and traditional resources as specific outcomes of collaborative design efforts. In the final section 5, we identify some key characteristics for enhancing the processes and products of educational design research.

2. Addressing educational innovation through collaborative design research

Design research may be considered as a reaction against the dominating educational research tradition of 'outcome evaluation' [4, 5]. By considering not only provision of opportunities for learning but also how learners should be stimulated to perceive these opportunities, design research explicitly addresses the issue of educational improvement [2, 4]. Addressing subject-specific learning objectives and their embedding in a learning activity requires the researcher(s) to make use of content knowledge and pedagogical knowledge, together with the pedagogical content knowledge (PCK, [6]) that concerns content issues in relation to teaching and students. Addressing the use of technologies in education, Mishra and Koehler [7] propose an additional dimension of technological knowledge and analogously describe TPCK (also known as TPACK) as a combined knowledge of content, pedagogy and technology in relation to teaching and students. Both these frameworks – PCK and TPACK – attempt to understand and describe the kinds of knowledge needed by individual teachers for effective pedagogical practice. In our design efforts, we extend these notions to team level and organize our design research efforts in the spirit of 'professional learning communities' (PLC, [8]). In contrast to PLC, which usually addresses the organization of homogeneous teams of teachers with similar educational backgrounds, we organize inhomogeneous research teams where the team members have different domains of expertise. We rely on a distributed knowledge approach where the knowledge needed is distributed among the members of the research team and emerge and develop as combined knowledge in the collaborative research process. This 'Collaborative TPCK' is needed to address the inherent complexity in considering a wide variety of digital technologies and traditional resources as potential mediators of the desired affordances that we identify in the research process. Instead of working as individual researchers and being committed to specific technologies, we compare and choose to deploy the affordances on tools that the team decides best suits our purposes as capable and efficient mediators.

3. Strategies for facilitating collaborative educational design research

Inspired by the notion of co-design [9] our strategy is to organize research teams where the team members have different domains of expertise and contribute with complementary knowledge needed for innovative design. Our research teams consist of researchers in mathematics education and in media technology, software developers and in-service school teachers who contribute in different ways to the knowledge base that guides collaborative decisions and scaffolds creative solutions in the design process. It cannot be expected that each individual team member should be acquainted with all aspects of the knowledge base. To facilitate effective communication within the research team we follow the tradition of scenario-based design (SBD, [10]) as a methodology based on narratives that enable rapid communication among different stakeholders [9]. These narratives concern sequences of students' possible interactions with the learning environment during a preliminary learning activity which is proposed but not yet implemented, and support our collaborative design process by facilitating communication about hypothetical learning trajectories within a preliminary activity without having to engage deeply in domain-specific considerations.

Although SBD narratives involve interactions with specific technologies, traditional resources, peers and teachers, a key issue in our efforts is to identify and reconsider the affordances mediated by the specific artifacts. An affordance may be defined as an opportunity for action, or a quality that the environment offers an actor [11]. For example, a ruler offers an opportunity for measuring distances. As designers, we can afford measuring by making a ruler available in a learning environment. A key issue in our design efforts is appropriating artifacts to an activity, specifically deciding which artifacts should be made available in the learning environment and deciding how this environment should stimulate the students to perceive the opportunities for action that are mediated by these artifacts [2].

The use of affordances in TEL design answers the need for creating design solutions that involve a suitable matching between (a) affordances that can be deployed on specific technological resources and (b) affordance requirements of the activity with respect to educational goals [12]. These latter educational affordances can either be pre-defined or, as in our case, emerging in a collaborative design process where a wide selection of technological affordances are discussed and negotiated between the stakeholders in the design team. When the desired affordances have been identified, their deployment in the learning environment is considered in terms of pedagogical affordances and the appropriation of mediating artifacts. The pedagogical affordances include providing instructions and hands-on trials to support students' processes of instrumental genesis, where they learn to unfold the educational affordances by interacting with the available artifacts [13]. Our strategy is to address the many interdependent issues in this complex design process through collaborative negotiations and team decisions.

4. Observed critical aspects in collaborative educational design research efforts

We proceed to account for aspects that have played crucial roles in the design of a number of specific mathematical learning activities we have carried out [2, 3, 14, 15]. The first and second cases concern outdoor investigations facilitated by mobile technologies, while third case concerns a classroom investigation with augmented reality. We describe how the designs are guided by mathematical learning objectives and address issues of importance for mathematics teachers and the mathematics curriculum.

Case 1: Mobile technologies for enacting geometry in an outdoor setting

The current learning activity [16], comprised of a combination of three different tasks, draws on the use of GPS technology available in a mobile device, allowing the user to measure distances between her own and other devices. In the first task, the students (13-14 years old) worked in pairs. They were asked to use one mobile device to coordinate themselves outdoors with respect to two given distances measured against two fixed reference points, which were marked on a field by a triangle and a square (Fig. 1 & 2).

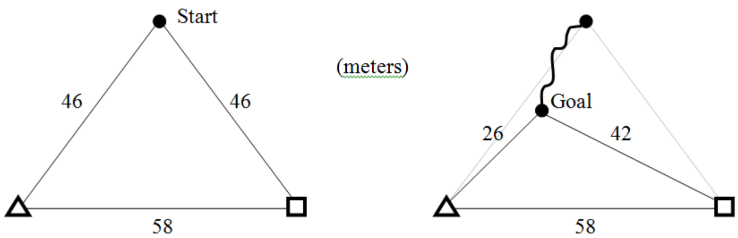

Figure 1: Visual representation of Task 1

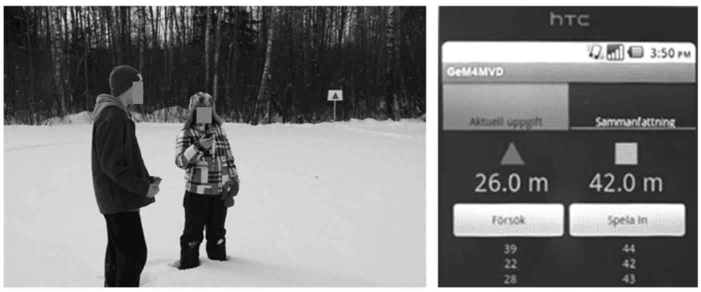

Figure 2: Picture from the outdoor activity and display of the mobile device

The students were given 10 different subtasks, providing a variation of given distances. The tasks were presented in numerical form only, for example as “26 42” (Fig. 2, right pane), although it would have been technically possible to provide the figures in Fig. 1 on the mobile display. However, this affordance for visualization of the tasks was excluded since it would have negatively interfered with the learning objectives, namely, to make use of their orientation ability instead of their visualization ability, based on 1) orientation and visualization abilities are two cognitively different dimensions of spatial ability, and 2) the visualization approach dominates geometry teaching in (Swedish) schools and students are seldom (or never) given the opportunity to engage in learning geometry by orientation [16].

The second and third tasks (Fig. 3) were designed with increasing complexity and new demands on the students. While the first task involved cooperation between (two) students, the second task required groups of three students to collaborate to manage the geometrical constructions by having one student at a time coordinating distances to the others by making use of individual mobile devices. When three groups of students had completed Task 2 from different starting points, they engaged in Task 3 that involved a jigsaw construction (Fig. 3, right pane). Task 2 and Task 3 mixed aspects of orientation and visualization, as not only the numerical values but also maps (and instructions) were provided on a sheet of paper.

Figure 3: Illustration of Task 2 (left pane) and Task 3 (right pane)

Critical collaborative decisions during the design process, such as excluding affordances for visualization, show the necessity of sufficient guidance by theories of relevance for the curriculum. While the technical staff was eager to deploy additional affordances on the mobile device, the team agreed to exclude some of these affordances in order to strengthen students' opportunities to achieve the specific learning objectives.

Case 2: Mobile technologies facilitating communication and transitions

Technological advancements in mobile computing and wireless communication offer learning opportunities extended across time and across contexts [17, 18]. Inspired by these opportunities, we designed a learning activity aiming at stimulating mathematical communication and reasoning about mathematical strategies [19]. Addressing the issue of instrumental genesis, the activity involved a preparatory session in the classroom where the implemented mobile technologies were tried out. The students, who were 12-13 years old, worked in groups of three and tested how to record messages, taking pictures, and answering multiple-choice questions. The introduction was followed by an outdoor activity focused on solving tasks and documenting strategies. The last part of the activity involved a follow-up session with the sharing of experiences of each of the groups and whole class discussions of their mathematical strategies.

The title of the activity was "Guess the height of the building!" The tasks and instructions were presented on a sheet of paper which was given to the students and read by the teacher in the classroom who also provided with a map with marked locations of three buildings. The session started with an introduction of the task and the technology. The students were informed that a mobile phone containing an application for data collection should be used to answer questions, take pictures, and record sound. They were informed that when they get back to class they would present their results. To aid their class presentation, they were prompted to "take two pictures of each house", "agree on an answer" and "record why you chose that specific answer". All the data collected in the field was geo-tagged, so it could be visualized via a digital map back in the classroom. The questions were about the buildings' heights, with provided multiple choice alternatives 8, 10, 12, 14, 16, 18, 20, 22, 24 (meters). The students were instructed (on the paper) to walk to the buildings, figure out their heights and answer with the mobile (Fig. 4). One aspect, which is particularly important to consider for innovative or "unusual" activities, is the presentation of the task and the instructions given to the students. In our case, it was necessary to describe the whole task to the students, including descriptions of the final activities in the classroom, so that they could identify a purpose for taking pictures and recording messages during the outdoor activity. Furthermore, because of the didactical complexity of the task and the technical complexity for the students, we favored short and distinct descriptions of essential instructions which fit on a single sheet of paper, in accordance with experiences from previous projects [3, 15]. These descriptions were complemented through activity prompts outdoors reminding the students of what they are supposed to do and providing a scaffolding structure for their otherwise self-regulated activities. The current prompts require the students to take pictures, give answers, and produce recorded messages of strategies and thus serve as a scaffold for the outdoor activity.

Figure 4: One building, the mobile application, students outdoors and presenting

Outcomes from the activity indicate that the mobile applications and the relaxed outdoor context enhanced the students' reasoning and the didactical quality of the voice recorded strategies [19]. This conclusion is supported by several observed instances where the students cleverly structure their recordings with a high degree of mathematical content and refer to the immediate physical setting for supporting their reasoning.

Case 3: Augmented reality offering unique opportunities for mathematical reasoning

Augmented reality (AR) is a technology that allows for mixing real-world images with computer-generated images. It also allows for making use of real objects in the virtual setting, thereby providing opportunity for students to interact physically with the virtual objects [15, 20]. Implementing AR in a classroom requires just an ordinary computer with webcam and a projector that supports computer generated images being shown together with projected real objects on an ordinary whiteboard. What needs to be added is software supporting the AR technology, and preparation of software-supported images [14, 15].

When students enter the classroom to engage in our activity, they see a photograph of their home city from a bird's-eye view. The photograph is laid down horizontally on a table and marked "Scale 1:800". A movable small paper tag with a printed barcode is placed on the table. The AR software supports showing a prepared image on top of the tag. We prepared images of several buildings including the Turning Torso (Fig. 5, right pane) and the Eiffel Tower (in Paris, France). The students were asked to test a tag by exposing it to the webcam. When the building shows up on the board (Fig. 5, middle pane) they are asked to figure out its height. Hence, minimal efforts are spent on the instrumental genesis and the students can readily engage in solving the tasks without having to know in detail how the technology works.

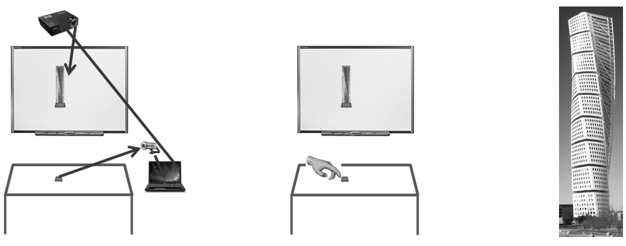

Figure 5: The technical set-up, the physical set-up, and the Turning Torso

Using well-known buildings and a photograph with familiar landmarks was assumed to be beneficial for the participants' ability to evaluate whether their reasoning or a proposed solution seemed plausible [14]. From a didactical point of view, the activity involves three distinct referential contexts (Fig. 6: table, whiteboard, reality) that are intended to stimulate the learners' reasoning and support their decision-making. The activity invites interaction not only with the provided tags but with any object that the students choose to project on the whiteboard. For example, placing a ruler upright on the table can afford measuring heights on the whiteboard.

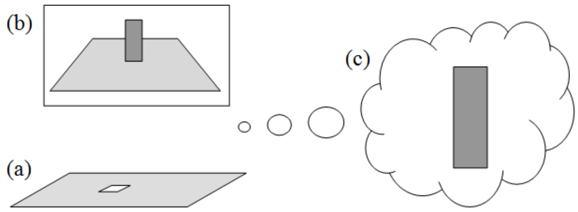

Figure 6. (a) the table context, (b) the whiteboard context, (c) the reality context

In this activity, the AR technology provided unique opportunities for mathematical reasoning and problem solving in that solving the task requires involving *at least two* of the three contexts since the size of the building shown (only) on the whiteboard has to be negotiated either with the scale on the table or with objects in reality [15]. The demand for coordinating multiple contexts sufficed, as intended, to stimulate learners engaging in collaborative discussions about mathematical strategies for solving the tasks.

5. Suggestions for future efforts in educational design research

The three activities presented in this paper have been successfully implemented and tested in schools in southern Sweden. The acceptance of our activities among mathematics teachers is due to the priority placed on curriculum-based learning objectives instead of specific technologies. Simply put, we address issues that the teachers agree are important for their students' learning of mathematics, and customize technologies that minimize the efforts spent on instrumental genesis so that students can focus on the mathematical learning objectives. We have identified some key characteristics that have contributed to enhance the quality of our design efforts and that we suggest be used in educational design research:

- Prioritizing curriculum-based learning objectives targeting improvement of current teaching practices.
- Organizing research teams where the team members have complementary domains of expertise, particularly regarding content, technology, and pedagogy.
- The TPCK needed for creative design emerges in the collaborative work process.
- Flexible involvement of teachers in the co-design process.
- Readiness to engage in new projects based on spontaneously arising opportunities offered for example by new technologies and school projects.
- Considering technologies in relation to other categories of artifacts such as traditional resources, teachers, peers, and contextual features of the environment.

The above characteristics allow us to engage in creative collaborative design processes that produce innovative curriculum-based learning activities. While we reuse and gradually develop the research methodology, the didactical foundation for each activity varies depending on its content and character. Although we could possibly speed up the design processes by reusing technological solutions and didactical foundations, we believe that such an approach would negatively affect the variety of possible learning outcomes. We conclude that designing innovative curriculum-based learning activities that may result in having high educational impact necessarily requires extensive efforts from all the collaborating researchers and teachers. Regarding sustainability of the research teams, it is in our opinion necessary and sufficient to maintain a core of researchers representing the necessary domains of expertise and allocating additional team members as needed.

On a final note, we are concerned not only about the lack of interaction between the mathematics education and TEL research communities, but also about the lack of maturation and evolution of educational technology innovations introduced successfully at a classroom level. We strongly agree with the claim from [21] stating that "innovations should be weaved into the daily activities of all actors in the learning ecology". The elaboration of the cases presented in this paper is intended to contribute towards developing models that will allow us to conceptualize the complexity of learning ecologies in order to understand better how to support the improvement of current educational practices.

6. References

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