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Developing Digital Technologies for University Mathematics by Applying Participatory Design Methods

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***Abstract*— This paper presents our research efforts to develop digital technologies for undergraduate university mathematics. We employ participatory design methods in order to involve teachers and students in the design of such technologies. The results of the first round of our design are included in this paper along with future research directions.**

***Keywords*— Mathematics, Teaching and Learning, Technology-Enhanced Learning, Participatory Design, GeoGebra**

I. Introduction

The importance of mathematics education is widely acknowledged. Its (inter)disciplinary, practical, and cultural value has been highlighted since the first schools made their appearance. Moreover, the social and political dimension of mathematics education has been extensively studied [1].

Despite its importance, performance of many undergraduate university students in mathematics education is poor ([2], [3]). Poor performance in mathematics has been recognized as one of the main causes of dropout at university level [4]. Difficulties in the exposition and development of mathematical ideas create difficulties in performing well in core subjects and thus developing a sense of general failure in undergraduates. Moreover, performing poor in mathematics lowers self-esteem and increases the anxiety level of students, making them more prone to drop out of university [5].

In the last decades, the rapid development in ICT has provided new possibilities for education to integrate digital technologies into schooling and thus enhance teaching and learning. Such technologies have been widely used to face challenges in mathematics education both in primary and secondary schools, and in a lesser extent in universities [6].

However, the use of such technologies has not met yet the initial expectations on reforming teaching and learning [7]. The efforts described in this paper are related to our ongoing research that explores the challenges of integrating digital technologies to support mathematics teaching and learning at university level. We are particularly interested in undergraduate university studies where mathematics is not a core subject, but it is fundamental for coping with core subjects (e.g. engineering, media technology, medical studies). Students in such studies lack not only background in mathematics but also motivation to study this subject, since the relation between mathematics and their study is often not evident [8]. We believe that the introduction of digital technologies in mathematics education for these students can contribute to increase motivation, since it offers new possibilities for mathematics representation and for connecting mathematics with the other subjects of their studies.

The paper is organized as follows: section two presents our methodological approach, namely participatory design, which aims at involving teachers and students in this research effort. Afterwards, we introduce a set of design implications for digital tools in mathematics education that was compiled during our collaboration with teachers and students. The paper ends with a discussion and an outline of our future work.

II. Participatory design

Participatory design – also called cooperative design – is the inclusion of all stakeholders within a development team, such that they actively help in setting design goals and planning prototypes [9]. It is an approach that attempts to ensure that the product designed meets the stakeholders' needs.

In the field of technology-enhanced learning, participatory design has been used in order to enable teachers and/or students to participate effectively in the design of digital educational tools [10]. It is expected that active participation of the target group will result in tools that will correspond to their needs and interests, and thus be engaging and better accepted [11].

Since we are focusing on students who lack motivation, we decided to adopt a participatory design method. By involving students in the design, we aim at developing tools that students will find interesting and attractive, and consequently at increasing their motivation to study. Furthermore, we want to investigate how teachers and students can contribute to this design collaboration. We are guided by beliefs that both groups should participate effectively in the design of educational applications, and that their expertise in education (each group is considered to be an expert in different aspects of education) could be especially critical. Each participant should be seen as an equal element contributing to the design, but at the same time none of them should have the full responsibility for the participatory design decisions.

As a first step in our design, we decided to investigate how the “Mathematics for Multimedia Applications” course is taught for Media Technology students and how digital technologies could contribute in improving teaching and learning for this course. This course is given during the second (spring) semester and introduces mathematics needed for media technology applications by covering basic elements of Calculus, Trigonometry, Geometry, and Algebra.

The course is conducted in the form of lectures, which are followed by exercise sessions in groups. The lectures are given by a professor, who follows a transmission teaching model and uses slides projected on the wall for communicating the content of the curriculum. After these lectures, the students have to work in groups in hand-in assignments. The teaching assistants support the students during this process but only when the students ask for it. In order to complete successfully the course, the students have to pass an individual written examination. To be eligible to take the exam, students must hand in half of the assignments.

Our participatory design involves two professors, two teaching assistants, and seven students in Media Technology. One professor comes from the Mathematics department, and teaches the introductory mathematics course, called “Mathematics for Multimedia Applications” at Media Technology. The other professor teaches technical courses at the Media Technology department that require mathematical knowledge. The teaching assistants come from the same department and they support the students during their exercise time. Both of them were previously students at Media Technology. All the students are in their second semester and currently attending the “Mathematics for Multimedia Applications” course.

Our hypothesis was that incorporating all participants in one design team would create barriers in expressing criticism for established practices or for other participants’ performance. Therefore we approached each group separately and established different ways of collaborating with each group. The framework for collaboration with our three groups (professors, students, and teaching assistants) is presented in the following sections.

A. Collaboration with Professors

In order to establish a common ground, and to avoid obstacles imposed by the culture and professional jargon of software design in our interaction with professors, we created a cooperative relationship between the professors and a software engineer, which spanned the fall semester of 2012. The software engineer worked with them in five sessions to design an intervention based on digital technologies for the “Mathematics for Multimedia Applications” course.

During this phase, we gave full control to the professors to decide what kind of digital technologies should be introduced in the course, and which parts of the curriculum would be suitable for working with such technologies. Our goal was twofold. Firstly, we wanted to identify how they conceptualize the introduction of digital technologies in this course and what they consider to be important. Secondly, we aimed at gaining professors’ acceptance and use of our intervention, by developing applications that they value and are familiar with.

After this initial phase, we would have a prototype to share with students and teaching assistants that they could comment on. As it is aforementioned, in participatory design no one should have full control of design decisions, and therefore the design team was aware that this would be an initial attempt that would undergo evaluation and redesign by the other groups and the researchers.

B. Collaboration with Students

At the beginning of the semester we asked for volunteer student groups to cooperate in our design. One group composed of seven students, three females and four males, responded to our request. The collaboration with this group of students took part in thirteen focus group discussions that followed their exercise time [12]. We chose focus group discussions rather than interviews because focus group discussion produces data and insights that would be less accessible without interaction found in a group setting. Listening to others’ verbalized experiences stimulates memories, ideas, and experiences in participants, which could not be achieved through a one-on-one interview.

During these sessions one of our research team moderated the focus group discussion on students’ experience with the specific course assignments. The moderator was asking questions to encourage students to participate, probing when necessary, but mainly was listening and taking notes. The students were very eager to reflect on the lecture and assignments they just had, and were also critical on the developed applications. Moreover, they proposed ways to improve teaching of the specific part of the curriculum.

C. Collaboration with Teaching Assistants

Although teaching assistants play a subsidiary role in the “Mathematics for Multimedia Applications” course, we believe that their contribution to our design is valuable. By having the opportunity of supporting the students while they are working on their assignments, they get insight into which parts of the curriculum are challenging for students. Moreover, the current assistants have been also students in Media Technology and therefore have an overall perception of both teaching and learning of mathematics in this study.

Our collaboration with the teaching assistants was established in the form of group interviews during the semester. During these interviews we aimed at getting feedback on how students worked in their assignments and whether and how they used the developed applets. Based on this feedback, we crosschecked the data we were gathering during the focus group discussions with students. Moreover, we sought proposals on improving our intervention based on their experience and observations.

D. Observation of teaching and learning

In order to get insight in the process of teaching and learning in its natural setting, we have conducted overt, direct observations of seven lectures and of seven exercise sessions (for the group that we are collaborating with). During these observations we gathered data on individual behaviours of students and teachers (the professor and teaching assistants) and interactions between them. Moreover, we were able to evaluate the introduction of the developed applets in the course. These findings will be incorporated in the future steps of our design and are presented in the next section.

III. RESULTS

The preliminary results reported in this paper concern the initial phase of our participatory design, where an intervention conceptualized by teachers was performed in an introductory mathematics course, and then feedback from students and teaching assistants was gathered, together with suggestions for alternative interventions. The aim of this phase was to investigate what parts of the curriculum our groups consider to be important or challenging and how they conceptualize the introduction of digital technologies in mathematics. Table 1 summarizes the findings regarding which parts of the curriculum are considered challenging by our groups, informed also by our own observations of students working on their assignments.

TABLE I
CHALLENGES IN THE CURRICULUM REPORTED BY TEACHERS AND STUDENTS

Topics	Challenges
Basic arithmetic	Negative numbers, absolute value, factors and multiples, adding/multiplying fractions
Algebra	Difference between a variable and a parameter, notation of a function, summation operator (∑), properties of systems of linear equations
Trigonometry	Definition of sine and cosine in the unit circle, trigonometric functions and their diagrams related to the unit circle, difference between radians and degrees
Calculus	Definition of derivative, meaning of derivative, applying the chain rule in differentiation, finding the anti-derivative of a function,
Geometry	Vectors: addition, dot product
In various topics	Proof of theorems

Our findings from collaborating with the different groups seem to suggest that professors, teaching assistants and students do not always share same perceptions about how the mathematics curriculum should be taught and which parts of it are challenging. While professors focus on visualizing mathematical concepts (e.g. trigonometric functions, definition of derivative, addition of vectors), students and teaching assistants stress the importance of focusing on basic mathematics first and also presenting applications of mathematics in Media Technology. The overall results can be summarized in the following:

- An important finding is that allowing professors to choose the tools for developing applications facilitated communication between them and the software engineer, since they chose software that they had used before and were comfortable with. Moreover, it enabled them to act as designers and actively participate in the development of the applications, by making adjustments and corrections.
- Geogebra was the tool chosen by professors, because it joins geometry, algebra, tables, graphing, statistics and calculus in one easy-to-use package, and it is free and open source software [13]. Moreover, the fact that graphics, algebra and tables are connected and fully dynamic was considered of great importance by the professors.
- At the beginning of our sessions both professors agreed that teaching and learning for the “Mathematics for Multimedia Applications” would be enhanced by incorporating interactive learning material (applets) in teaching in order to visualize core mathematical concepts. This material was not connected directly with course assignments, a fact that resulted in students not using it during their exercise time.
- Our observations confirm the perception that collaboration in design of educational material is beneficial both for teachers’ professional learning and students’ learning [14].
- Teachers and students have in some cases different perceptions of challenging concepts in mathematics and envisage the role of digital technologies in different ways. Students mentioned topics (such as the summation operator and the anti-derivative of a function) that teachers consider trivial. Furthermore, they stressed the importance of connecting mathematics with its application in the specific study. They proposed the development of illustrations of media technology projects, where mathematics was applied, in addition to the interactive illustrations. Moreover, they proposed to develop course assignments based on the interactive applets, while keeping a part of the current assignments (solved by-hand). They consider by-hand solution important to the learning process.

IV. CONCLUSIONS

In this paper we have illustrated how our initial participatory design efforts resulted in a set of interactive learning activities that were used in teaching a mathematics course in Media Technology students. These activities provide visualization of mathematics concepts that teachers considered important and challenging for students. By conducting focus groups with students following this course, we were able to get feedback on challenging subjects in the course and on improving the learning activities. We also conducted observations of lectures and exercise time of the course, in order to gain insight on problematic areas and adapt our research on dealing with them.

One issue that needs to be considered is the different perceptions of teachers and students about how digital technologies can be introduced to mathematics education and what the challenging topics are. Our participatory design enables us to consult both groups and design interventions that are based on both perceptions. Moreover, an important issue that became evident while observing students in exercise time is that the level of difficulty and interactivity of the developed educational material should be adjusted to students' cognitive ability. If the learning tasks evolve fast and are complicated compared to students' abilities, then they would not have any added value. On the other hand, if learning activities evolve slow or are trivial, students would easily lose interest. Finally, connecting mathematics to its applications is very crucial if one wishes to improve student engagement and performance.

The next stage is to use the aforementioned findings to better inform the design of a four-session workshop in mathematics. This workshop will serve as an introduction to the fifth semester courses "Computer Graphics Rendering" and "Computer Graphics Programming" in Media Technology. We will collaborate with the teachers involved in these courses in order to define the relevant topics, and to develop supporting educational material for the workshop. Our aim is to prepare students for these courses that require mathematical knowledge. In order to evaluate the effect of the workshop will implement pre- and post-testing. Furthermore, we will further explore the possibilities for creating tools to support collaboration and enhance performance in mathematics learning environments.

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