EVALUATING THE VISUALIZATION TOOL SIMREAL TO SUPPORT THE LEARNING OF MATHEMATICS: A CASE STUDY IN TEACHER EDUCATION

Said Hadjerrouit

University of Agder, Kristiansand (NORWAY)

Abstract

There is a huge interest in visualizations in mathematics education, but there is little empirical support for their use in educational settings. SimReal is a new visualization tool used to teach mathematics at the university level, but there is little evidence that the tool can play the same role in teacher education. The aim of this study is to evaluate the opportunities provided by SimReal to support the learning of mathematics in teacher education. The evaluation framework draws on five main criteria: Technical usability, pedagogical usability, mathematical content, assessment, and adapted education. A survey questionnaire with open-ended questions was used to collect data on students’ views of SimReal. Recommendations are suggested to improve the design and use of the tool to better suit the specificities of mathematics in teacher education.

Keywords: Adapted education, pedagogical usability, technical usability, SimReal, visualization.

1 INTRODUCTION

SimReal is a new visualization tool that is used to teach a wide range of mathematical topics at the university level, but the suitability of the tool has not yet been evaluated for use in teacher education. The specificities of teacher education require that SimReal is both technically and pedagogical usable. Moreover, SimReal should be mathematically correct, and help students gain knowledge that is otherwise difficult to acquire. Furthermore, formative assessment issues in terms of feedback should be considered to support the learning process. Hence, the adaptability of SimReal to a teacher education context is a complex issue that needs to be evaluated on the basis of criteria that are pertinent to mathematical learning in teacher education. The aim of this paper is to evaluate the usefulness of SimReal to support the learning of mathematics in a technology-based course in teacher education.

2 THE VISUALIZATION TOOL SIMREAL

SimReal is a new visualization tool for teaching and learning mathematics for a range number of mathematical subjects. It uses a graphic calculator, video lessons, video live streaming, video simulations, and interactive simulations (Figure 1). It provides about 5000 exercises and applications in various areas of mathematics at different levels [1].

The basic idea of SimReal is that visualizations are powerful mechanisms for learning mathematics and explaining difficult topics. According to Arcavi [2], visualization is the ability to use and reflect upon pictures, graphs, animations, images, and diagrams on paper or with digital tools with the purpose of communicating information, thinking about and advancing understandings. There is a huge interest in visualizations in mathematics education [3], [4].

However, there is little empirical support for the use of visualizations in educational settings [5]. Three studies from the literature focused on teaching mathematics in higher education [1], [6], [7]. The studies report on positive attitudes towards the use of SimReal and its usefulness in difficult and abstract mathematical areas. Students considered SimReal as a positive supplement to ordinary teaching. Another study addresses the use of SimReal in a secondary school [8]. It reports on positive students’ attitudes towards the use of the tool in classroom. Some students did not found visualizations very useful, and that integrating the tool into the curriculum was not simple. Lastly, there is a study on the first experimentation with SimReal in teacher education.
3 EVALUATION FRAMEWORK

This study draws on criteria from the research literature to evaluate SimReal in teacher education [9], [10]. The criteria can be divided in five main categories: Technical usability, pedagogical usability, assessment issues, mathematical content, and adapted education. Technical usability as defined by Nielsen [11] is a self-evident requirement for any digital tool. In many cases, however, the technicalities of a particular tool do not always result in pedagogical opportunities, which will only be visible when an explicit pedagogy guides the use of the tool in classroom [12].

Nokelainen [13] expanded the concept of usability to include pedagogical usability issues, such as learner autonomy, collaboration, variation, motivation, differentiation, and individualization. In addition, the assessment dimension in terms of feedback is crucial for evaluating the quality of digital tools in mathematics education. Another criterion is the mathematical content in terms of correctness of mathematical concepts, notations, and symbols, and congruence with paper-and-pencil techniques to facilitate mathematical reasoning [9]. Finally, the evaluation should consider the requirement of adapted education and enable teachers to concretize the mathematics subject curriculum in teacher education. Table 1 gives an overview of the evaluation criteria.

<table>
<thead>
<tr>
<th>Main category</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical usability</td>
<td>• Ease-of-use: SimReal should be easy to use, to start, and to exit.</td>
</tr>
<tr>
<td></td>
<td>• Accessibility: SimReal should be accessible anytime and place.</td>
</tr>
<tr>
<td></td>
<td>• Management facilities: SimReal should provide facilities to store answers given by students, modify readily available content, provide a user manual, etc.</td>
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</tbody>
</table>
**Pedagogical usability**

- **Motivation**: measures the extent to which SimReal is attractive to use, adapted to the students’ knowledge level, and tied to other activities.
- **Variation**: SimReal should present the content in several ways, and facilitate various activities with students. The tool should be used as an alternative to achieve variation in combination with other resources.
- **Learner autonomy**: SimReal should enable a high degree of learner autonomy. The knowledge provided by SimReal should be potentially powerful to enable students to become less dependent on the teacher.
- **Individualization**: SimReal should take into account different students’ knowledge levels. In addition, students should be able to work at their own pace and save their work and continue later.
- **Differentiation**: SimReal should provide multiple tasks with different levels of difficulty. The tool should also provide opportunities for the teacher to make individual adjustments and customize the tool.

**Mathematical content**

- **Quality of mathematical content**: The mathematical content of SimReal should be of high quality, mathematically sound and faithful to the underlying mathematical properties. It should display formulas correctly, and help students to gain knowledge that is otherwise difficult to acquire.
- **Congruence with paper-pencil techniques**: SimReal should enable students to apply their own paper-and-pencil technique reasoning steps and strategies, and facilitate mathematical activities.

**Formative and summative assessment**

- **Formative assessment**: SimReal should provide several assessment modes, appropriate feedback in the process of problem solving, and use of several question types that can be adapted to different students.
- **Summative assessment**: SimReal should provide teachers with quantitative data in terms of statistics, scores, and grading to evaluate students’ performances.

**Adapted education**

- This criterion measures the extent to which SimReal can be used in teacher education and provide opportunities to concretize the curriculum.

### 4 METHODS

This study involved 22 teacher students taking the course on digital tools in mathematics education in 2015. None of the students had any prior experience with SimReal. The work used a survey questionnaire with open-ended questions. Teaching activities included basic, elementary and advanced mathematics. Table 2 gives an overview of the activities over a period of three weeks.

<table>
<thead>
<tr>
<th>Teaching activity</th>
<th>Teaching aids</th>
<th>Topic</th>
<th>Date</th>
<th>Duration</th>
</tr>
</thead>
</table>
| Exercises in basic and elementary mathematics | • Written material
• SimReal                      | • Introduction to SimReal
• Basic mathematics: Games, dice, tower of Hanoi, and prison
• Elementary mathematics: Multiplication, algebra, Pythagoras, reflection | Week 34 | 3 hours  |
| Exercises in basic and elementary mathematics | • SimReal
• Online material               | • Basic mathematics: Games, dice, tower of Hanoi, and prison
• Elementary mathematics: Multiplication, algebra, Pythagoras, and reflection | Week 34 | 2 hours  |
| Exercise in advanced mathematics         | • SimReal
• Online material               | • Advanced mathematics: Measurement, trigonometry, conic section, parameter, differentiation, and Fourier | Week 35 | 3 hours  |
Exercises in advanced mathematics

- SimReal
- Online material

Advanced mathematics: Measurement, trigonometry, differentiation, and Fourier

<table>
<thead>
<tr>
<th>Exercises in advanced mathematics</th>
<th>SimReal</th>
<th>Advanced mathematics: Measurement, trigonometry, differentiation, and Fourier</th>
<th>Week</th>
<th>2 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation of SimReal</td>
<td>SimReal</td>
<td>Evaluation of SimReal using a survey questionnaire with open-ended questions</td>
<td>Week</td>
<td>1-2 hours</td>
</tr>
</tbody>
</table>

To measure the students’ responses, the survey questionnaire used a five-point Likert scale from 1 to 5, where 1 was coded as the highest and 5 as the lowest (1 = “Strongly Agree”; 2 = “Agree”; 3 = “Neither Agree or Disagree”; 4 = “Disagree”; 5 = “Strongly Disagree”). The average score (MEAN) and Standard Deviation were calculated, and the responses to open-ended questions were analyzed qualitatively. The survey included 70 items that were distributed as follows: Technical usability (12 items), pedagogical usability (22 items), mathematical content (14 items); assessment (12 items), and adapted education (10 items). The students were asked to comment each of the items in their own words, and 10 open-ended questions as well.

5 RESULTS

The students’ responses to the survey questionnaire are described for the five broad categories of the evaluation framework, and for supplementary issues that were addressed by open-ended questions. The results are also compared with those achieved in the first experiment with SimReal [14].

5.1 Technical Usability Issues

The results show that SimReal has not improved very much in terms of ease-of-use, user-friendliness, response time, storing of students’ work, and some management facilities as this comment reveals: “Although SimReal seems to have a vast range of mathematical potentiality, (…) it is rather hard to figure out how you can fiddle with them, for example, how to manipulate parameters (…). Moreover, in some dynamic visualizations there is only a limited space where you can see the movement that takes place”.

Otherwise, the students were globally satisfied with the technical usability of SimReal in terms of easy-to-start, accessibility, management facilities, readiness of mathematical content, video life streaming, and in lesser degree with the navigation.

5.2 Pedagogical Usability Issues

In terms of pedagogical usability, SimReal has improved in terms of various mathematical activities, multiple representations of mathematical content, and that SimReal can be used as a lecture and textbook supplement.

More specifically, most students agreed that SimReal is fully appropriate to use as an alternative to achieve variation in teaching mathematics as this comment clearly shows: “It is a great tool that can contribute to teaching and amplify the learning outcome and the comprehension of notions (for example in the case of graphs of functions and derivatives (…))”. Another student thinks that “this is the best part of SimReal. It offers a lot of opportunities to work with visualizations (…)”.

Likewise, most students think that the tool provides more autonomy to do mathematics, as this rather critical student’s statement shows: “SimReal provides little of mathematical background description of the visualizations. Even though formulas are provided in order to reach a generality, one would need teachers or textbooks. However, the possibility to meddle with the visualizations offers the opportunity to (…) develop the understanding of notions”.

In terms of motivation and satisfaction with the overall design, a representative student’s comment indicated that the “menu is not optically nicely designed, but how this effects the learning depends on the age/level of studies (…). E.g. that would rather be a problem for primary school children, but not for university students, who are more conscious and directed to the content of the course they learn”. Another comment pointed out that “visualizations are highly stimulating and pose a problem in a much exciting way that verbal description would do”.

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In contrast, most students think that SimReal does not provide sufficient individualization and differentiation, and choice of level of difficulty. However, the tool enables students to work at their own pace, which is a motivational factor in keeping them engaged in mathematics.

Furthermore, the tool does not easily allow students to customize the tool, as this rather critical comment reveals: “There exit different types of exercise that have diverse level of difficulty (…). But, when it comes to each category specifically there is not really a variety of scaled-difficulty exercises. For example, there are no equations that would need more technical, sophisticated algebraic manipulations, but only very simple ones”. Most students also still think that SimReal does not fully enable students to work independently from teacher assistance or fellow students. Textbooks are also needed when using SimReal in classroom.

Finally, the vast majority of the students did not find deliberate collaborative tools installed. Nevertheless, it is worth noting that “some visualizations stimulate communication in a sense that one might want to take ideas from another, for instance (…), how somebody else perceives the visual illustrations and work with them”.

5.3 Assessment Issues

The results achieved for assessment issues are mostly similar to those from the first experimentation [14]. Indeed, the vast majority of the students think that SimReal does not provide feedback or assessment modes. The following comment summarizes the limitations of SimReal in terms of formative assessment: “Feedback in each attempt must be (…) ameliorated. Where one fails to provide a correct answer, SimReal could “gauge” the nature of it and provide the proper feedback/help”.

5.4 Mathematical Issues

Most students agreed that SimReal has a high degree of mathematical content in terms of correctness and representation of mathematical properties and operations, e.g., formulas, functions, graphs, and geometrical figures: “SimReal presents the mathematics in a thorough and principally correct manner”, but as another student formulated, “it can be done more, for example to solve an equation of second grad, (…), or to do more logical games, (…), exercises from number theory”. Most students also believed that SimReal visualizations are easy to understand.

Likewise, the issue of whether SimReal provides practical tasks obtained an average result in term of design quality, and that the advanced tasks were not difficult to understand, as this rather critical comment shows. “Many tasks lack explanation or are not well-formulated, but once one understands what should be done, the exercises show a high degree of quality that promotes knowledge acquisition”.

Furthermore, SimReal is very useful and “absolutely essential” for most students, especially when it combines video lessons, live streaming of lessons, and exercises, because it “can help students to understand and see the connections between different mathematical themes”. This combination provides opportunity to help students gain knowledge that is otherwise difficult to acquire.

Finally, most students think that SimReal is not a better tool than GeoGebra, which has more advantages, such as better user interface and more differentiation. Furthermore, students think that it takes more time to learn a given mathematical topic using SimReal than a textbook. Likewise, less than the majority believed that SimReal is congruent with paper-pencil techniques when solving mathematical problems, and it does not help much to update and renew mathematical knowledge.

5.5 SimReal and Adapted Education

The majority of the students think that SimReal can be used in teacher education to teach mathematics at the secondary school level, and in lesser degree in middle schools, but not in primary schools. They also think that SimReal enables teachers to concretize the mathematical subject curriculum. However, when asked whether they will continue using SimReal to learn mathematics on their own, most students answered negatively.

5.6 SimReal and Flipped Classroom setting

When asked whether SimReal can give students new possibilities in teaching mathematics in a flipped classroom setting, most students expressed a real interest in this issue as this comment clearly...
reveals: “Flipped classroom will give more prepared students and better discussions in the classroom”. Nevertheless, many students focused mostly on out-of-class activities and use of videos rather than Flipped classroom as a new teaching approach.

5.7 Programming Visualizations and Use of Templates

The students were asked in what way programming mathematical visualizations by their own will help them in understanding mathematics if they can use different templates without any special tool (just write the code directly into a Web page) so the concentration can be on mathematics and not on difficult details in the programming process.

Most students agreed that templates can help to concentrate on the mathematical part, and “investigate empirically properties of math structures that lie behind the visual representations”, “help to explore mathematics realities in ways pen and paper can’t”, and “force to think through how the concepts really are”. Likewise, most students think that it is a great and interesting idea to plan to design such templates so that they will be able by their own to program mathematics using both elementary and advanced visualizations directly into their own Web pages without any special tool. They just need to write their own mathematical code. Clearly, most students like the idea of using templates, as this comment clearly highlights: “Would be a great idea to have easy access in such a thing”.

5.8 Specific Issues

Specific issues concern students’ engagement and motivation when working with visualizations, usefulness of demonstrations and explanations of mathematical concepts, level of patience when working with visualizations, and difficulty of navigation. Most students liked visualizations that trigger engagement, because the level of motivation and curiosity is increased. These in turn foster the learning of mathematics. Likewise, demonstrations are also needed because many students think that they learn more by visualizing and connecting various mathematical representations.

5.9 Suggestions for Improvements

The students were asked to provide suggestions to make SimReal more appropriate for use in teacher education. The most frequent suggestions were a better interface for different type of users, assessment and review modes, more help and feedback, possibility to design own videos and visualizations, differentiation, and individualization.

6 CONCLUSIONS

The number of participants (N=22) is not sufficient to adequately support the generalization of the results. However, it is possible to make some reasonable interpretations of the results and draw some recommendations for using SimReal in teacher education. Firstly, in terms of technical usability, the user interface must be simplified to make SimReal easy to use in teacher education. The navigation must be improved to make it more straightforward. Secondly, the use of SimReal in teacher education indicates that the tool shows potential for teaching mathematics that is suited to the students’ knowledge level, although not all criteria are equally met. Then, SimReal is technically well designed in terms of accessibility and management facilities. Furthermore, SimReal covers a wide range of mathematical content with varied levels of difficulty. Likewise, the content is mathematically correct and reflects the underlying properties of mathematics. Furthermore, SimReal seems to be pedagogically usable in terms of motivation, supplement to lectures and textbooks, variation in teaching, and multiple representation of mathematics. But still, work needs to be done to adjust the tool to the individual students. Moreover, SimReal does not provide assessment capabilities, and many students are still not ready to use the tool to learn mathematics for their own benefit. As a result, SimReal in its present form can be used to learn mathematics but not on a regular basis, unless the user interface is made more intuitive and easy to use. Likewise, there is a need for more didactical functionalities in terms of assessment, differentiation and individualization in order for SimReal to become an integral part of teacher education [15].
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REFERENCES


