Creating Serious STEM Games by combining a Game Platform and Mathematical Software

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***Abstract*—The perceived complexity of many engineering courses is partly due to difficulty visualizing or interacting with the underlying mathematics. Traditional game-authoring environments lack STEM-related support, making them ill-suited to build serious games to explore these concepts. To address this issue, we have integrated an external math tool into the Unity game-authoring environment, and tested it by creating a game to teach basic concepts of mobile communications to engineering students. Players of the game had to fine-tune parameters in a simulated spectrum analyzer. We describe how we integrated STEM support for the generic authoring platform that we used, and present results from a pilot test of our game. We believe that this approach is extensible to a wide range of STEM disciplines.**

***Index Terms*—Serious games, Engineering education, Serious game technology, Serious STEM games**

I. Introduction

Educational games have been proven to be a powerful tool, both to motivate students and also to enhance their learning [1]–[6], allowing high school or college students to comprehend, interconnect and explore the formulas commonly found in a STEM (Science, Technology, Engineering and Mathematics) curriculum. Nevertheless, quoting [4] "there are very few [sic] software that explain mathematical concepts, such as the use of the quadratic formula, at college level in a fun way". More specifically, in Electrical and Computer Engineering, it is necessary to use many different programs or applications, but, nevertheless, there are few if any software resources that teach the theoretical concepts that underlie the contents and formulas, or that allow them to be visualized to better understand their meaning. However, building serious games to explore these concepts is not as straightforward as it could be, because game-authoring tools typically lack support for engineering tools.

In this paper, we describe an approach to the problem of communicating engineering tools with serious games that attempt to teach STEM concepts. The next section presents the general problem and possible approaches, motivating our choice. Then, we describe a serious game which uses this approach, a small pilot carried out to evaluate its effectiveness, and show the results of this first experiment.

II. Communicating mathematics with serious games

Many engineering tools such as R, Matlab or Octave contain collections of field-specific modules, and act more as extensible frameworks than as monolithic products. This is not surprising, as this design increases their flexibility. However, the most straightforward approach, that of implementing selected parts of the tools in a game-authoring environment, would greatly compromise such flexibility: due to the implementation effort involved, the chosen subsets would necessarily be small. Another option is to communicate the game with a locally-running tool. This, however, limits the platforms on which games can run to those on which engineering tools can be installed, ruling out, for example, playing from browsers or low-capacity mobile devices; while also complicating game delivery and installation. A final approach, the one we have finally chosen, is to communicate the games via an HTTP server, which acts as a *bridge* and allows to query the engineering tools.

A. Displaying engineering elements

For the development of our STEM serious game, we decided to use the Unity game authoring platform as it is freely available and it allows building cross-platform games with good performance. Unity for education has increased in popularity in recent years to support virtual labs and to teach STEM-related-content [7]–[9]. However, by default it includes no support to represent, visualize or interact with basic engineering elements such as formulas, graphs or equations. We addressed this by implementing an HTTP bridge as described in the previous subsection and represented in Fig.1.

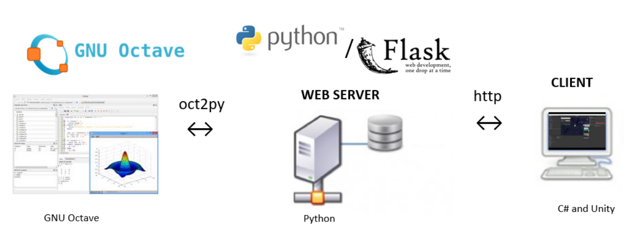

Figure 1. Engineering tools (left) communicate via an HTTP bridge (center) with a serious game client (right).

The use of the bridge, which consists of a Python Flask server that communicates GNU Octave with a Unity 3D component that can be integrated into target games, allows game developers to use the full power of Octave from within Unity, without needing to implement any math-related logic within Unity. Instead, developers can write the engineering parts in Octave, and use them from games with minimal hassle. We have also implemented a small graphing library that can display interactive plots within Unity, and have packaged it into the reusable game component part of the bridge. This allows serious game authors to easily build game content that relies on interactive plots of formulas.

III. Pilot experiment

In order to demonstrate the practicality of this HTTP bridge solution to create serious games for engineering students and also to help us both detect problems in the game design and roughly determine whether learning is occurring, we developed a serious game called "Frequency Selectivity" for students of the third year subject "Fundamentals of mobile communications and cellular networks" of the degree in Electrical and Computer Engineering, to teach this concept.

As reported in the literature [10], realistic resources in science learning are perceived by students as highly engaging, so we decided early on to implement a simulated real lab within the game, where players handle the dials of a virtual spectrum analyser to test their solution to the problem.

The experiment was carried out fully online, within a distance learning institution, as part of one of the three compulsory practical activities of the course. Due to the low number of students enrolled in the subject – seven participants–, we decided to carry out a pilot experiment, without a control group, although we are aware that a control group would be highly desirable once the game design has been tested.

We used both quantitative and qualitative methods to conduct the pilot experiment. On one hand, we relied on a set of surveys and questionnaires, to measure motivation and changes in knowledge after the game is played. On the other hand, we also collected interaction data while students played the game.

To determine whether the actions of students followed expectations and to locate and diagnose possible shortcomings in the game design, the game tracks user interactions and stores them for later upload, using the xAPI-SG format [11]. Collecting player interactions is a critical first step towards Game Learning Analytics, which allows teachers to understand how users play serious games and determine where and how learning occurs.

IV. Results and analysis

Comparing pre- and post-tests, most students increased their scores after playing the game, as shown in Fig.2. The only outlier is *s5*.

To better understand how students played the game, we built the visualization seen in Fig. 3, using ObservableHQ and D3.js. Each line of the figure depicts a play-through of a student, with time on the horizontal axis. Since players could choose when to play over a span of several days, time in the figure is displayed as relative to the start of each play-through. Actions in different game scenes are encoded with different icons, and actions that involved trying to solve a puzzle are depicted with larger versions of those icons. Large differences can be observed in how students chose to play the game. For example, *s1* spent the most time playing the game, although several pauses are visible in the figure. *s2* completed the tutorial but became trapped in the first of the three main game levels. *s3* played the game without visiting the tutorial and reached the last level, but became stuck and did not finish it. *s4* rushed through the tutorial, but became trapped in the first level of the game, similarly to *s2*. Finally, *s5* rushed through the game, playing less than a third of the time as *s1*, and avoiding the tutorial altogether.

V. Discussion

Since the play-throughs of students can be linked to their survey and questionnaire responses, they provide important insights into the learning process. Comparing Figs. 2 and 3 shows that *s1*, who completed the entire game, achieved the largest score increase between the pre- and post- tests. *s2* and *s4* both completed the tutorial and became stuck in the first scene, and slightly improved their scores (+0.9 and +1.0, respectively). Participants who played the game but skipped the tutorial had the worst ratios (+0.5 and -2.7). While six participants- one of the participants did not complete the proposed tasks- is a small sample for statistical purposes, the combination of analytics with pre-post questionnaires proves to be a powerful tool to analyze the effectiveness of a serious game. Based on this evidence, it appears that the tutorial was underused and that those students who did the tutorial had

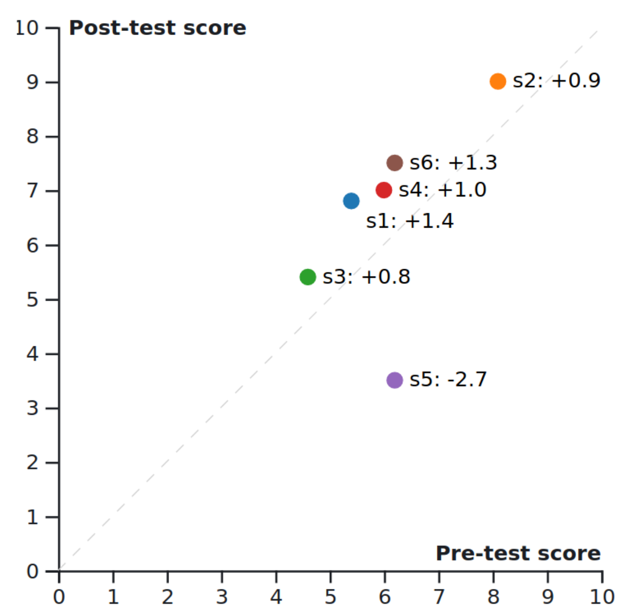

Figure 2. Comparison between pre-tests and post-tests results for each student. Total change (post-pre) has been included in the labels. All but one student (s5) improved their scores.

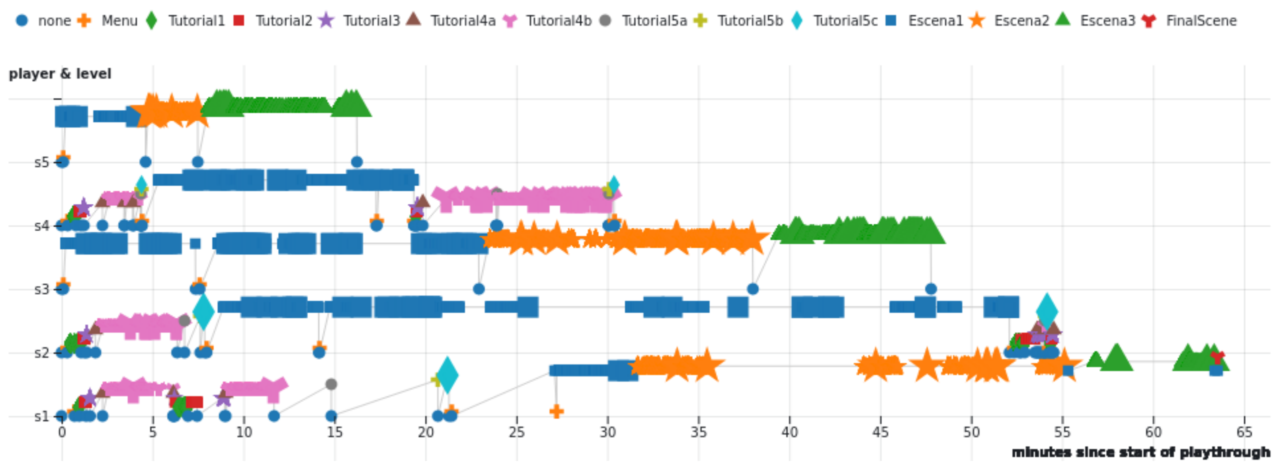

Figure 3. Progress of players *s5* (top) to *s1* (bottom) throughout the game. Larger symbols indicate attempts at solving an exercise. Different symbols and heights reflect distinct levels and sublevels. Hovering over any marker displays a tool-tip with the corresponding details.

a better performance in the game. We can also observe that the time students spend playing the game positively influences their learning.

Despite the low number of participants, our results reinforce evidence that serious games can be very motivating tools for learning abstract and complex concepts such as those related to this particular area of STEM knowledge; and that students enjoy playing them to learn in a more practical and interactive way, even though they constitute practical exercises that develop their competencies in the subject matter. The game pilot has therefore achieved a moderate success in the goal of transmitting the engineering concepts that were pursued in its design, has validated the approach of using an HTTP bridge to communicate a generic game environment and a scientific tool, and has allowed us to detect several possible game improvements for future versions.

VI. Conclusion and Future Work

The present pilot study shows promising results, with participants reporting higher motivation and generally increasing scores in knowledge of abstract engineering concepts.

We have proposed the use of an HTTP bridge to communicate game environments and engineering tools, and demonstrated its practicality by integrating it, as a reusable component, within a serious game for engineering students. The pilot design made for the game "Frequency Selectivity" has allowed us to verify that this solution is indeed practical for the creation of serious STEM games. The approach can be readily extrapolated to other theoretical concepts or subjects, and once a bridge and in-game component have been developed, requires minimal development effort.

Serious STEM games can be promising resources for learning STEM concepts and competencies, but they should continue investigating complex game designs that can address and delve into the intrinsic complexity of the subject of study in order to fulfil their potential.

As future work, we will be improving the implementation of our serious game based on the feedback and results of this first study, as well as designing additional games to explore supplementary areas of the target domain.

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