GAMIFICATION OF DSP: ELECTRONIC VS PEN-AND-PAPER

Richard K. Martin[1], *Kirsten R. Basinet*[2], *Jacob Rosenblum*[2], *Alexander Schwartz*[1], *Andrew G. Klein*[2]

[1]The Air Force Institute of Technology (AFIT)
Dept. of Electrical & Comp. Engineering
Wright-Patt AFB, OH 45433
Email: richard.martin@afit.edu

[2]Western Washington University (WWU)
Engineering & Design Department
Bellingham, WA 98225
Email: andy.klein@wwu.edu

ABSTRACT

Gamification is the incorporation of gaming elements into non-game situations, such as education or training. We have developed a game that can be used to teach signals concepts, and have implemented it in both a pen-and-paper version and in an electronic version. This paper discusses the game and how it applies pedagogical concepts such as active learning and game-centric curriculum design. We discuss the merits and drawbacks of each type of implementation, student reactions, and how a similar game could be incorporated into other signals-based classes.

***Index Terms*—** Gamification, active learning, signal processing education

1. INTRODUCTION

Gamification is a popular contemporary branch of active learning, a teaching model which gives students a direct role in classroom learning [1, 2]. While traditional approaches to active learning include group problem solving [3], design projects [4, 5], and inquiry projects [6], gamification attempts to capture student interest and enjoyment by incorporating gaming elements into traditionally non-gaming activities [7–10]. Gamification is a term related to and often used analagously (as it is in this paper) with the concept of *game-based learning*, which is the use of complete self-contained games (not merely gaming elements, such as leaderboards or achievement badges) in the learning process [11–13].

Relation to prior work: Gamification has recently been popularized in academia and industry for its potential to engage users more effectively. Crucially, learning games can provide extrinsic motivation among students [14], as evidenced by a University of Texas study that found students voluntarily did three times as much work when it was presented as a game [15]. Additionally, Kolb has shown that over time students in the sciences become more analytical and less creative (and students in the arts are the opposite) [16, 17]. Games may be able to counter this phenomenon by forcing students to think about course concepts more creatively through game rules that require them to interpret, explain, and demonstrate learning targets in non-traditional ways [18]. Games can also engage more regions of the brain than traditional lectures by incorporating verbal interaction, visual interaction, and motor skills. Finally, games provide an alternative model for student progress. McGonigal notes that games provide a series of carefully constructed obstacles which allow players to learn by *rapidly failing and improving* – thus mastering the challenge at hand [19]. Gamification research has shown promising results across many higher education disciplines including civil engineering [20], engineering graphics [21, 22], geoscience [23], English [24], and business [25–27], and has also proven to effectively improve learning across many demographics, including most age groups [28–30]. Much of the research has yielded positive findings by comparing approaches that are supplemented to varying degrees by the use of game against traditional pedagogical approaches, such as lectures or even general group work. For a comprehensive survey of research on gamification in engineering education, see [31].

While a large variety of gamification implementation techniques have been proposed across the literature, many researchers suggest that collaboration and teamwork have a strong impact on success [11, 32–34], and instructors are encouraged to take findings from education experts into account when creating learning games [31]. In [14], Kapp discusses effective gamification practices, highlighting the ways in which the added challenge and context of a game encourages students to work hard of their own accord. Likewise, Kapp discusses the importance of good gamification design for educational purposes. He advocates that any learning game should employ the qualities of other good games yet still be suitable for conveying content – in short, it must be fun with meaning.

2. PROPOSED LEARNING GAME

Each small group is given an Elements of Smyle Gameboard, role cards, signal cards, element cards, frequency tokens, an erasable marker, a 10-sided die, and an instruction sheet which describes the gameplay and the recipes (scenarios) for the transceiver topologies. The group is also given a submission sheet, which they use to record their solutions to the recipes. The gameboard, designed to be laminated for dry-erase use, is shown in Fig. 1; example recipes are shown in Table 2.

The name "The Elements of Smyle" comes from the backstory provided in the instruction sheet: "The absent-minded Dr. Sam Smyle needs to create a bunch of radio signals, but Dr. Smyle mixed up the transceiver elements and frequencies for each recipe. Help Dr. Smyle sort out the order of the transceiver elements, and which frequencies are associated with each element. Between each element placed on the board, sketch the the signal at that point. Sketch the signal in time domain, in frequency domain, or both."

For each recipe, students are given the input and output signals, the elements to use in creating a transceiver topology, and available

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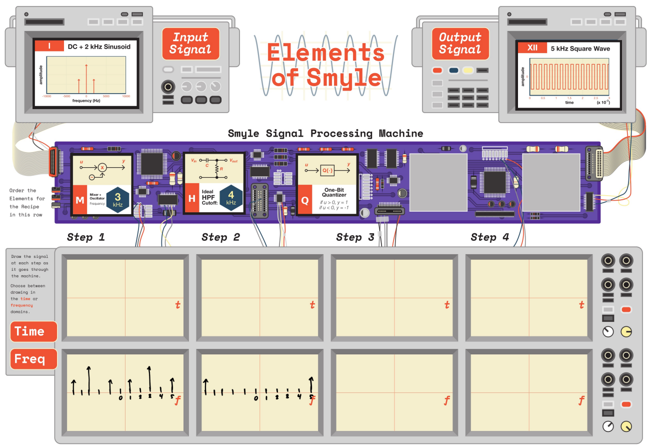

Fig. 1. Pen-and-paper board; materials are freely available at [35].

start	end	elements	freqs (kHz)
1kHz	DC+2kHz	M	pick any
DC	1kHz square	M, Q	pick any
10kHz square	1kHz	L, L, M, M	1, 5, 10, 20
DC+2kHz	5kHz square	H, M, Q	3, 4
1kHz	5kHz sampled at 20kHz	D, H, M, S	4, 4, 40
1kHz	1kHz sampled at 4kHz	A, D, E, S	9, 20

Table 1. Example recipes. The system elements are M: mixer (multiply by a cosine), Q: one-bit quantizer (signum function), L: low pass filter, H: high pass filter, D: downsample by 2, E: downsample by 5, S: sample, A: adder (second input is a cosine at specified frequency), X: squaring function.

frequency values. Signal types include: sinusoid, sampled sinusoid, square wave, and DC signal; most inputs and outputs consist of a single signal, but some are a sum of two such components. Each signal tile depicts either a time-domain or a frequency-domain representation of the specified signal. The system elements are: sampler (S), low-pass filter (L), high-pass filter (H), downsampler (D for down by 2 or E for down by 5), one-bit quantizer (Q), squaring function (X), mixer/oscillator (M), and add to a cosine (A). Frequency values are between 1kHz and 40 kHz, and each recipe either gives a set of specific choices or allows the players to pick any frequencies.

Each of 3-5 players chooses a card depicting their role. The "Engineer" arranges all of the elements in a correct order and places the frequency tokens, the "Artist" draws the signal created at each checkpoint between elements, and the other players are "Quality Checkers," making sure that the work of the Engineer and the Artist looks good. After each recipe, players switch roles, so that each person has an opportunity to do each role.

The game allows students to physically reorganize a signal processing system. This tactile creative process can appeal to hands-on learning styles, and encourages discussion among students. The gameboard, cards, die, and assigned roles make this activity a classic game style. Elements of gamification in this activity include clearly defined goals, collaboration as students work together to arrive at an answer, and different levels of difficulty. Competition can be added as an additional element of gamification by rewarding the group that completes the most recipes correctly for bonus points in the course.

3. ELECTRONIC IMPLEMENTATION

After the paper version of the game was tested in undergraduate classes at Western Washington University (WWU), an electronic, web browser based version was developed. Like in the paper version, the objective is to drag Digital Signal Processing (DSP) functions with frequencies to selection boxes that have an effect on the given input signal. Unlike the paper version, the graphs are automatically drawn, so the user can focus on design choices rather than signal modeling. If the user is correct in his/her DSP function and frequency selections, the program will alert the user that the choices made produced the correct output.

The electronic implementation is web browser based so that it can be played on many different platforms. Screenshots for a mobile platform (in this case, an Android phone) are shown in Fig. 2, and a screenshot of the desktop version is shown in Fig. 3. The browser version was implemented using JavaScript, Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), and a static website framework called Middleman. HTML and CSS work together by specifying classes and IDs for tags in HTML, and then the style for each page or type of page is defined in CSS files. JavaScript was used to perform all computations and to dynamically reconfigure plots, buttons, and windows. Middleman serves as the static website framework that essentially holds the site together. The game is responsive, meaning that it is formatted differently (and automatically) for mobile and desktop platforms, and the window sizes adjust to the screen resolution. As of now, there are 13 recipes and more can be added relatively easily with a little coding knowledge. Some of the gameplay features specific to the electronic version are as follows:

- In both the mobile and desktop versions, the user works incrementally through the system by choosing a function and a frequency (if needed) for each block in turn, starting with the first block. This unfortunately precludes working backwards from the end, though as some blocks (e.g. filters) remove information, it generally is not possible to work backwards.
- Either the time domain or frequency domain view of the signal at the output of each block can be viewed by clicking the appropriate buttons, and a zoom feature is available.
- Continuous-time signals are stored electronically as heavily over-sampled discrete-time signals. Continuous-time signals are shown as lines, and discrete-time signals are shown as plotted points. Additionally, each graph is labeled either "Continuous" or "Discrete".
- A modal (a separate viewing window) is available for each graph, wherein the graphs are enlarged for improved viewing.

The user follows the following process to complete a recipe:

- Choose a recipe.
- Select a frequency button.
- Click and drag a function to a system block tile in the middle; if the block has a frequency parameter, it will use the frequency selected in the prior step.
- Continue this process until all of the available system blocks have been used, at which point a success or failure point is reached. In the current implementation, every provided system block should be used, so if there are N blocks provided, the user will go through the process exactly N times.
- After completion, the user can either immediately go to the next level or first spend some time examining the signal graphs at each point in the system.

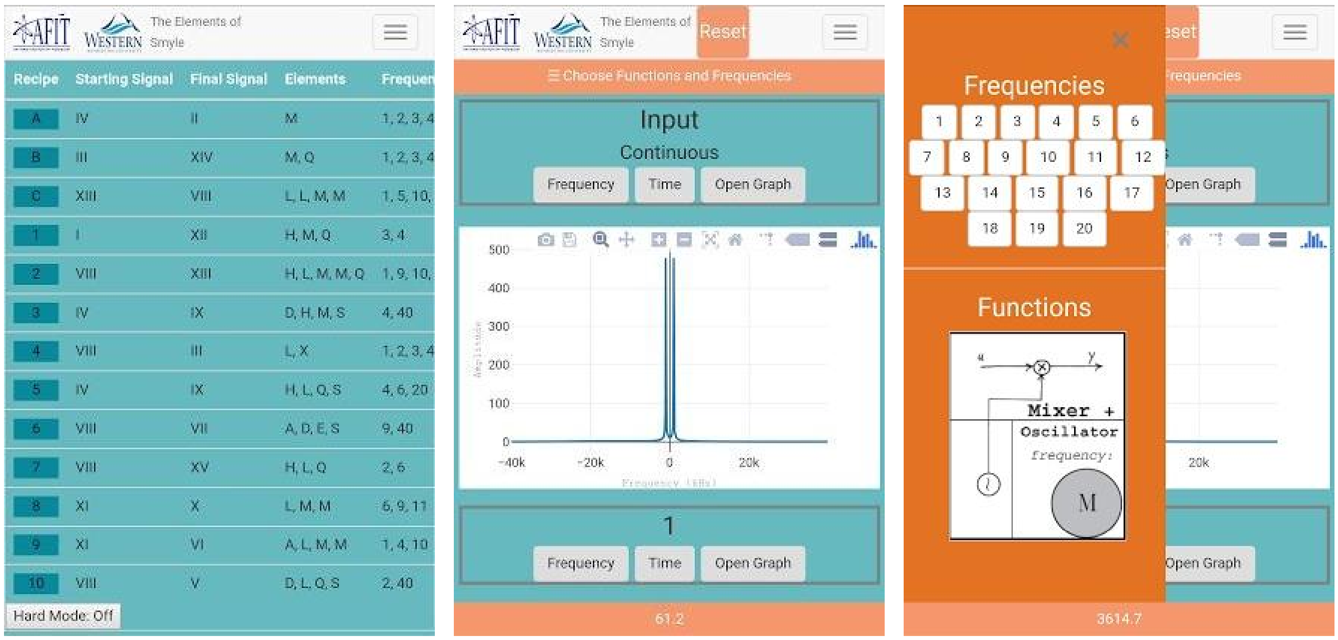

Fig. 2. Example gameplay screens (mobile version).

While most of the HTML is recycled for use between desktop and mobile views, the mobile version does not require the user to click and drag functions, but instead, the user need only select the frequency desired, followed by a function. The webpage will confirm the user's decision.

4. TRADEOFFS

In this section, we compare the pen-and-paper implementation to the electronic implementation. While the context is this specific game, most of the conclusions can be easily generalized to other games that could be implemented for other courses.

Advantages of the paper implementation: A paper implementation should be attempted before an electronic implementation, provided that a paper version makes sense for the game in question. This is because a paper version can be drafted and revised much more readily, so the basic gameplay can be adapted to match the student population's abilities. For example, in the context of the Smyle game, a weaker student population may have difficulty with some of the more advanced recipes, and the instructor can quickly beta test recipes of varying difficulties without the potential wasted effort of programming each recipe. Another advantage, which relates more to pedagogy, is that a paper implementation engages students more directly and via multiple learning modalities. By having the students draw the necessary plots, students engage in a kinesthetic learning modality rather than just a reflective learning modality. Finally, the paper implementation is necessarily a group activity. We have found that playing a group game in the classroom lead to rather boisterous interaction, and students leave the class feeling excited about the course material [18].

Disadvantages of paper implementation: A paper implementation leads to potential user error, since the accuracy of a student's sketches are evaluated strictly by other students. This can be mitigated by providing detailed solutions for each method. However, if there are multiple valid solutions, the instructor must predict and document them all, leading to a voluminous solutions handout for each recipe. Another issue is that the majority of literature on gamification focuses on electronic gamification, so it is not clear if the same benefits will apply to a paper implementation. For example, one benefit of gamification is that it allows students to rapidly try and fail, while learning from each failure [19]. In a paper version, each attempt requires laborious sketching, and a student may quickly get tired and frustrated after a few failed attempts.

Advantages of electronic implementation: Typically (but not exclusively), the literature uses "gamification" to refer to the use of video game elements [8–10, 15]. As such, applying methods from the literature to design games or interpret our results is much easier in the context of an electronic implementation. For example, an electronic version allows rapid trial and error as discussed in the previous paragraph; and it allows for some level of anonymity, which allows students to feel more comfortable in making potentially erroneous attempts at a problem [8]. The use of an auto-scoring mechanic in an electronic implementation reduces the grading burden and removes potential errors in peer evaluation of a solution's correctness. This also reduces the class time required to play a game, since no time is required for the grading (indeed, the entire game can be run at home, if desired). Finally, video game are fun, and that can improve student morale and bring a positive association to the coursework.

Disadvantages of electronic implementation: By far the largest barrier to an electronic implementation is the development time. If this is performed in a decentralized fashion, each instructor must somehow find labor hours to a programmer to create the gaming framework, and the instructor must work with the programmer to develop a correct representation of the technical content. In our case, the programming required approximately 240 man-hours by an undergraduate computer science major, plus perhaps 20 hours of instructor assistance with the content. This barrier can be greatly mitigated if development is managed centrally, either by the school or by a larger multi-institution grant. Alternatively, if an instructor happens to have the resources to create a game, then we encourage

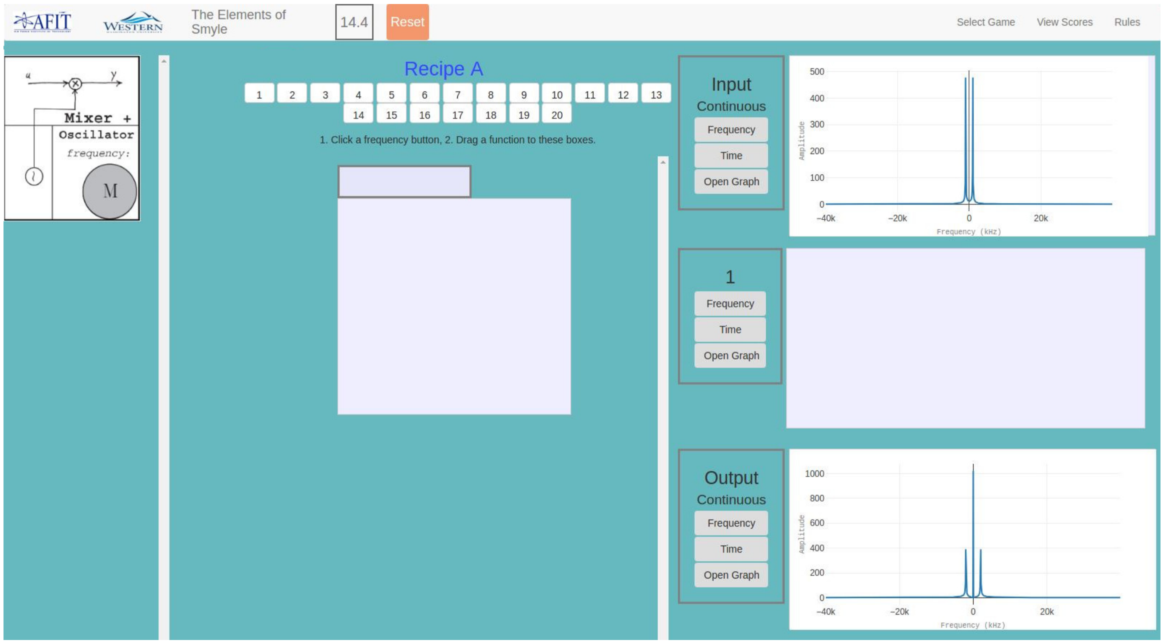

Fig. 3. Example gameplay screen (desktop version).

the sharing of the source code so that the game can be quickly implemented at other institutions. Another disadvantage is that it can be hard to update the game after the fact. If the initial programmer has moved on to another project, then it might be difficult to add a level or additional problem to the game unless the available workforce is skilled with the language in which the game has been implemented. Finally, an electronic version does not lead to the same level of boisterous energy as a hand-drawn group game.

5. STUDENT FEEDBACK

Though the electronic version of this exact game was not implemented in the graduate courses this year, we did focus on projects that performed all of the computation in Matlab and we assigned far fewer handwritten problems. This led to multiple students providing feedback that they feel like they don't know how to compute Fourier transforms or perform convolution by hand. A similar effect is anticipated as we offer the electronic version of the Smyle game this year, since it removes the explicit computational burden from the students and instead forces them to apply a more intuitive understanding of the signal elements so that they can predict the effects of each block. Despite the fact that the students seem to view this as negative feedback, this is desirable in a digital age in which effort should be focused on design rather than computation.

In the undergraduate course, students generally enjoyed the board game, and found that it was a useful and fun way to reinforce course concepts. The students were allowed to "check out" a loaned copy of the game for use outside class time, and a large fraction of the class pursued this option as a way to study for exams. Moreover, the end-of-quarter anonymous student surveys frequently mentioned the usefulness of the games overall, with several students wishing that there had been more games.

6. CONCLUSIONS

We have developed a board game that teaches signal processing basics in the context of developing a design flow to produce a desired output. A pen-and-paper version was implemented in undergraduate courses, and an electronic version was developed for deployment in the coming term. There are advantages and disadvantages to each type of implementation, and we have laid out these tradeoffs to encourage other instructors to implement tinkering-based games in their courses.

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