AC 2010-1623: GAMING AND INTERACTIVE VISUALIZATION FOR EDUCATION – YEAR 1 PROGRESS

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1 Abstract

In engineering disciplines, visualization can provide an essential mode to facilitate student understanding of important and abstract concepts. Learning through a medium that combines course materials with game characteristics can be a powerful tool for education. This approach is expected to improve student willingness to learn, which will in turn increase the interests of high school and undergraduate students towards engineering as a future career.

In this paper, three teaching modules based on the Gaming and Interactive Visualization for Education (GIVE) in three universities will be described in detail with enhanced game characteristics. Also, using the newly developed assessment tools, the evaluation data from the students who have experienced the GIVE system will be analyzed. More specifically, the three modules are designed and illustrated in this paper for the Flight Mechanics, Introduction to Electrical Engineering, and Design and Manufacturing.

The following game characteristics have been considered and implemented in the modules: progressively balanced goal, feedback, time sensitive scoring, adaptive scoring, meaningful visual presentation, emotional involvement, avoiding guess, constitutive rule, operational rule, background, challenges, and rewards.

Along with the course module development and implementation, the outcomes have been assessed using our evaluation system. The results have been analyzed and suggestions have been given for future work.

2 Introduction

Student enrollment and graduation rates in U.S. engineering schools have been decreasing over the recent years. Freshman retention rates are also decreasing due to students not being adequately prepared in high school to study engineering. More specifically these retention rates are decreasing because students find difficulty in fundamental engineering concepts. Retention problems are higher with engineering students and the root cause could be a mismatch in learning and teaching style [1]. The results from this mismatch are causing students to be bored, to be inattentive, to have poor test grades, and discouragement with their courses [1]. All of these factors are causing the students to change to different majors within the engineering school or to entirely drop out of the engineering school.

The previous study about student’s learning styles in engineering majors concluded that engineering students are active, sequential, visual and sensing learners (Felder & Spurlin, 2005). A student’s learning style influences learning effectiveness and outcomes in a technology-assisted learning setting [2]. Possible game genres for activists, who prefer working as a team, being a group leader, and brainstorming to solve the problem, are multiplayer, interactive, action, and role-playing games [3]. The game approach in education has the potential to capture student interest and improve learning and teaching methods [4]. Also the number of educators using
visualization to explain science and engineering concepts to students in different science and engineering courses is increasing. The advantages from using techniques of visualization are to improve interaction between users and game, and to enhance interaction aspects of the design.

The modules developed in this project, Gaming and Interactive Visualization for Education (GIVE), is a game-like learning tool which is composed of game characteristics (e.g., a progressively balanced goal, feedback, multiple-goal structure, and scoring), 2D/3D visualization, and state-of-the-art interaction technologies to help undergraduate students learn, and to improve the image of engineering.

GIVE is different from the conventional blackboard, PowerPoint based lectures, and e-learning methods [5]. Because it is used for high school and undergraduate students, GIVE is also different from edutainment that is mainly for small children [6].

The project has been under development since September 2008. As the initial step of the design, the overall architecture of each teaching module is established first including considerations of the software, hardware, course materials, and game characteristics. Currently the first version of the software has been developed, and some evaluation comments and lessons have been obtained.

This paper is organized as follows. First, we describe the developed GIVE based course modules. In this section the game characteristics incorporated in the learning software will be discussed also. Next, the software interfaces are shown for each of the course modules. After that the assessment methodologies are designed followed by the evaluation analysis. Conclusions and suggestions are drawn in the end.

3 GIVE Modules
3.1 GIVE Characteristic
In terms of interaction between the GIVE and its users, the developed GIVE has the following three unique characteristics [7, 8]. (1) GIVE uses a well-designed game scenario to enhance student’s understanding and involvement. A well-designed, highly interactive simulation can provide a wide range of experiences for abstract concepts, such as navigating difficult coordinate system, operating animated aircraft, and collaborating with colleagues to overcome obstacles [9]. Students in games will spend literally many hours to learn obscure details and practice their learning “muscles”, such as abstract concepts in certain courses [10-11]. (2) GIVE allows students to easily explore all the options, boundaries, and solution space for a given problem. (3) GIVE uses characteristics (e.g., realistic environment, user view points, etc.) of several commercial software tools (e.g., flight simulator, Pro-E, etc.) and combine them to illustrate engineering concepts (e.g., the airplane coordinate transform and component manufacturing).

In terms of scoring and educational settings, GIVE has the following three advantages. (1) GIVE enhances student’s understanding by considering both overall score and step-by-step reasoning. Reasoning behind the answers will be solicited from students and weighted by instructors in grading. This is to overcome one of the common pitfalls of game-based learning that students concentrate too much on completing, scoring, and winning, and become distracted from learning.
(2) *GIVE* uses an adaptive scoring system based on student efforts and progress. In addition, the scores and relative positioning of the performance compared to peers will be provided to students immediately for higher motivation. All these will encourage students to be actively engaged in attaining challenging yet achievable goals.

Other game characteristics such as distance/asynchronous, progressively balanced goal, equal chance to win, feedback, clear goal, adaptive scoring, time sensitive scoring, meaningful visual presentation, emotional involvement, avoiding guess, real-time helps, core mechanics, background, maximum tries, challenges and rewards are all considered. The detailed information of where these game characteristics are considered can be found in [7, 8].

According to the game scenario of a typical *GIVE* module, four databases are required: student performance database, question & answer database, movie database, and emotional involvement database. The detailed information of these databases can be found in [7, 8]. Based on the database structure and the information flow, the course modules development is focused on the meaningful questions, corresponding movie clips, images, answers, and various hints. In the next three sections, three course modules will be described in detail.

### 3.2 Course Module 1 – Flight Mechanics

In Fig. 1, after logging in, users will find the instructions on how to use the *GIVE* module, and the score policy. Also users will know which modules are included in the sections. In the scoring page (as shown in Fig. 2), users will have the access to his/her scores in different attempts, different sections, and the performance of their peers in the same class.

![Figure 1: Login system in the *GIVE* model](image-url)
Figure 2: Scoring systems used in the GIVE system

Figure 3 gives the overall picture of Section 1 in Module 1. User’s score is shown in real-time as comparing to its class average. Users are required to read the question first, watch the video which is related to that question, and finally select the answer. Also a timer is set so that the user will know how much time is left for him/her to answer the question and how many times he/she has tried.

Once the users selected the button “start question”, as demonstrated in Fig. 4, the randomly generated (to avoid guesses) choices are shown, and they will be given a limited time to select the one they think is correct. If a wrong answer is chosen by the user, a real-time hint (as shown
in Fig. 5) will be provided so that they can get a better understanding why the answer he/she selected is not correct.

![Module demonstration for Question 1 in Section 2.](image)

**Figure 4: Module demonstration for Question 1 in Section 2.**

![Real time hint](image)

**Figure 5: Real time hint**

### 3.3 Module Example 2 – Design and Manufacturing
Understanding the “Design for Manufacturing” concepts requires understanding the effects of materials, geometric tolerances, component shape, selection of tools, desired finish, and process parameters. In GIVE, students will be given a set of requirements to understand the effects of tolerance on design and manufacturing of a mechanical component. The GIVE course module has been developed for sophomore students and will be evaluated by students enrolled in Principles of Design (AME 4163) and Design and Manufacturing (AME/IE 2303) at University of Oklahoma, which focuses on basics of different manufacturing processes. The course module focuses on helping students to understand the basics of tolerancing and how it affects manufacturing and performance of components and products.
The module is centered around a racing car game, where the players not only have to race their car, but also have to fix their vehicles at during different levels of the game. Each player is given a fixed amount of resources. The game will be designed in such a way that, the performance will mostly depend on how the player fixes the vehicle. It will depend very little on the driving style of the player. After each level the player must fix some parts of the vehicle. There will also be time constraint. The product with a higher tolerance will require less time and cost to manufacture. The goal is to motivate the player to use the high tolerance limit in manufacturing components. On the other hand there are some components which will need the high precision. So, the player has to save the resource for those components. High precision components will increase the performance of the race car, but will be expensive to manufacture.

The course module focuses on providing an opportunity for students to internalize materials related to tolerancing, which includes tolerancing a component, types of fits, tolerance stacking, cost, product quality, etc. Text, graphics and animations (Figure 6) are shown to provide students with information related to different topics.

Each topic is divided into two sub-sections (i) fundamental information, and (ii) scenario. First students review fundamental information related to different topics. Text, graphics, and animations (Figure 6) are shown to provide students with information related to the topic being reviewed. Once the fundamental information has been reviewed, students can then click on related scenario to get better understanding of the concepts and materials. The scenarios are linked to games that the students can play. The performance of the race car is related to the information given in the scenario, along with text that details the effect of the selected answer on performance. As an example, for the topic related to tolerance stacking, a simplified crankshaft is used (Figure 7). The scenario relates the simplified crankshaft to the performance of the racecar - the crankshaft is attached to the piston through connecting rod and transforms the reciprocating motion to rotary motion. The two rotating masses balance the rotating force of the crankshaft. Hence, the distance between the rotating masses is very important for the stability of the engine. Consequently, the student needs to choose a tolerancing scheme for an Engineering drawing that reduces the stacking effect for the distance between the two masses. The scenarios show the crankshaft being dimensioned in different manner and an associated game that the student can play to judge the performance of the race car. In order to easily convey the relationship between tolerance and performance, the crankshaft is related to speed of the vehicle – if the scenario corresponds to tight tolerance then the race car accelerates rapidly, if the tolerance is loose then the acceleration decreases.
Currently there are two versions of the game exists with the same set of scenario: (1) online car racing and (2) car simulator. The first one (Figure 7) can be accessed by the student from anywhere, whereas the second one is located in the lab. The “car simulator” (Figure 8) has a realistic setup with steering, brakes and other controls.

3.4 Module Example 3 – Introduction to Electrical Engineering
The module provides basic concepts to freshmen in Electrical Engineering (EE) major on what is the major is about. Video clips are presented along with the questions/answers to explain students what are related to EE and what are the basic fields of EE. The portal page of the module is displayed in Figure 9, which can be accessed after students login with their user ID.

![Figure 9: Portal page of the GIVE module](image)

When designing the module questions, we tend to present and reflect different levels of knowledge, from being more intuitive to being involved with more critical thinking. Some examples of the videos and questions are described in below to illustrate this feature.

Figure 10 shows four snap shots of a video clip used in GIVE module. This video is designed to cascade a sequence of very short clips on various subjects, some are related to EE and others are not. After viewing the video, students are expected to determine which subjects are not related to EE. The subjects listed in the snap shots include kid toys, bicycles, washers, and the Internet. This module element encourages student thinking but is more intuitive and fundamental.

![Figure 10: A sequence of short video clips is used in the module to promote student thinking.](image)

Figure 11 shows another screenshot of the module. On the left side of the screen, a one-minute long video clip explains the various components and their functionalities of an autonomous helicopter developed by a student team. The multiple choice question is displayed on the right.
side of the screen; it requires students to identify which system components, such as communication devices and flight controller, are related to EE. Comparing to the previous example, this module question is at higher difficulty level, and requires students to exercise deeper critical thinking skills.

![Image of module layout](image-url)

**Figure 11:** A screen shot of the module which layouts the video, the question, and the scoring/timing information.

Another feature of this module is that enough hints are presented in the module for learning purpose. First of all, video clips are developed to illustrate the operations and functionalities of the subject under discussion. Then, for each video, audio scripts are written and added to the video to direct student thinking. Finally, after each question is answered by students, clues are displayed to encourage students to start another attempt. This feature is illustrated with the following example on control system modules.

The example asks students to identify a feedback control system from the following options: (1) a robotic arm grabbing a soda can; (2) a dog grabbing a sandwich and a soda can with his mouth; (3) a toilet being flushed and refilled; and (4) the pitch control authority of an SU-30 performing Pugachev’s Cobra. Each of the above four systems are illustrated in the video clip, which can be viewed by students prior to making a decision. Along with the video, the following script is developed, recorded and added to the video: “… this video shows a robotic arm picking up a soda can. The sensors attached to the hand of the device detect the distance that the arm must move to reach the can and sends that information to the controller. The controller makes the necessary input adjustments for the motor that drives the arm. This process is constantly being repeated until the arm reaches the can. This video shows a dog picking up a soda can. The dog’s eyes detect the distance the dog’s mouth is to the can and sends that information to his brain. His brain then sends the appropriate input signals to the dog’s muscles that drive him to the can …”
4 Module Assessment
4.1 Assessment Design
The GIVE system modules were evaluated on three university sites. Because the evaluation of Modules 1 and 3 are still on-going, here we only report the evaluation results of Module 2 related to tolerance concepts in design and manufacturing at the University of Oklahoma. Sixty six senior students who enrolled in the mechanical engineering courses AME4163 (Principle Design Class) participated in the evaluation. They were divided into three groups (1) a control group: traditional lecture format; (2) experimental group 1: traditional lecture combined with GIVE (Car simulator game); and (3) experimental group 2: traditional lecture combined with GIVE (Online flash car racing game). There are 22 participants in each group. All participants were taught about tolerance by traditional lecture format. Then the two experimental groups completed exercise questions by using GIVE (both the car simulator game and the online flash car racing game), and participants in the control group completed similar paper exercise questions. Afterwards, all participants took a quiz on paper in the classroom. Test results were analyzed using the one-way analysis of variance (ANOVA).

After the quiz, surveys were distributed to the participants in the two experimental groups to assess the effectiveness of GIVE. These participants were also contacted to schedule a face-to-face interview about their opinion of using the GIVE in education and their attitude changes toward Engineering. The interviews were held in private rooms. All interviews were audio recorded and documented with handwritten notes by the interviewer and each interview lasted from 15-20 minutes.

4.2 Pedagogical Effectiveness
The scores in the quiz were compared to assess the pedagogical effectiveness of the GIVE system. A nine-question quiz on tolerance concepts and calculation was administered in the classroom. According to the subject matter expert, questions 6 and 8 are rated as difficult and the rest of questions are rated as easy. The average scores in the two difficult questions are much lower than the average scores of the other questions.

The quiz scores among the three groups were compared with the one way ANOVA. The differences between different approaches are significance (p=0.056). The car simulator group achieved higher average quiz scores (M=7.27, SD=1.16) than both the online car racing group (M=6.23, SD=1.77) and the control groups (M=6.59, SD=1.30). When the scores of the difficult questions were analyzed, significant differences (p=0.002) were found among the three experimental condition. The Post-Hoc Tukey test reveals that the car simulator group (M=1.18, SD=0.66) achieved significantly higher scores than the control group (M=0.55, SD=0.51) and online car racing group (M=0.77, SD=0.53). The scores of the easy questions, on the other hand, were not significantly different (p=0.14) among the three groups.

4.3 Effectiveness of GIVE
After the participants completed the quiz, surveys were distributed to participants in the car simulator group and the online car racing group to assess learning satisfaction, learning effectiveness, effectiveness of design, and usability of games. Nine students (41%) of online car racing group and eight students (36%) of car simulator group took the survey.
In Table 1, the survey results about the effectiveness of *GIVE* were analyzed as a weighted average that was shown as a percentage of agreement. We measured user’s agreement with statements related to *GIVE* in four categories: learning satisfaction, learning effectiveness, effectiveness of design, and usability of games. In terms of learning satisfaction, users are 84% satisfied with the game in car simulator group and 70% satisfied in online car racing group. In terms of learning effectiveness, the game made it easier for users to understand the concepts of tolerance and design for both groups at about 70% and required less time to learn than it did in the lecture. In terms of effectiveness of design, both games still need more improvement in design, freedom to access, interface design, and interaction between users and game. And in terms of usability of games, users need more information and knowledge before playing the car simulator game.

Table 1. Summary of the effectiveness survey results of *GIVE*

<table>
<thead>
<tr>
<th>Evaluation parameters</th>
<th>Car Simulator (n=9)</th>
<th>Online Car (n=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weighted average</td>
<td>Percentage</td>
</tr>
<tr>
<td><strong>Learning Satisfaction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I like the idea of learning about tolerance and design by game</td>
<td>6.00</td>
<td>86%</td>
</tr>
<tr>
<td>Learning about tolerance by using game is enjoyable</td>
<td>6.00</td>
<td>86%</td>
</tr>
<tr>
<td>My learning experience in this course by using game is positive</td>
<td>6.00</td>
<td>86%</td>
</tr>
<tr>
<td>Overall, I am satisfied with the game</td>
<td>5.88</td>
<td>84%</td>
</tr>
<tr>
<td>As a whole, the game is effective for my learning</td>
<td>5.88</td>
<td>84%</td>
</tr>
<tr>
<td><strong>Learning Effectiveness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The game made it easy for me to understand the concepts of tolerance and design</td>
<td>5.00</td>
<td>71%</td>
</tr>
<tr>
<td>The game and the lecture work well together to teach me about tolerance and design</td>
<td>5.25</td>
<td>75%</td>
</tr>
<tr>
<td>The game offered an exciting and dynamic environment for me to learn</td>
<td>6.00</td>
<td>86%</td>
</tr>
<tr>
<td>Compared to traditional learning, game requires more time to learn</td>
<td>3.75</td>
<td>54%</td>
</tr>
<tr>
<td>Game provided enough interaction for me to learn</td>
<td>4.50</td>
<td>64%</td>
</tr>
<tr>
<td><strong>Effectiveness of design</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I like the design of game</td>
<td>5.88</td>
<td>84%</td>
</tr>
<tr>
<td>The game was easy to use</td>
<td>5.00</td>
<td>71%</td>
</tr>
<tr>
<td>The game gave me a freedom to access tasks at any time.</td>
<td>4.38</td>
<td>63%</td>
</tr>
<tr>
<td>The interface design of game motivated learning activities</td>
<td>4.63</td>
<td>66%</td>
</tr>
<tr>
<td>The presentation design of game motivated me to try different questions and achieve the goals</td>
<td>4.38</td>
<td>63%</td>
</tr>
<tr>
<td><strong>Usability of games</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Games provided immediate feedback for user actions.</td>
<td>5.38</td>
<td>77%</td>
</tr>
</tbody>
</table>
I can easily turn the game off and on, and be able to save games in different states. 4.38 63% 4.33 62%

Game gave context sensitive help me while playing so I do not get stuck or have to rely on a manual. 4.88 70% 5.11 73%

Upon initially turning the game on, I have enough information and/or knowledge to get start to play. 4.50 64% 5.56 79%

Game gets me involved quickly and easily with tutorials and/or progressive or adjustable difficulty questions. 4.63 66% 5.78 83%

### 4.4 Student’s feedback and comments

After participants completed all tasks and surveys, nine students of car simulator group and nine students of car simulator group were interviewed about their opinion of the *GIVE* system.

In the car simulator group, the feedback on *GIVE* in helping students learn about tolerance is positive and ranges from 75%-100% in most questions. The comments that users gave include the car was hard to drive and it was hard to control the direction. The improvement that the participants suggested included that they wanted more time to use *GIVE*, expand *GIVE* system to different topics, have more interaction between users and games, set up the tolerance settings by themselves, and have more explanation and communication about *GIVE* before implementing it to classroom. Fifty percent (50%) of participants felt their engineering attitude changed after using *GIVE*. They think learning engineering is more fun and interesting when the class used applied tools like *GIVE* to teach engineering concepts.

In the online car racing group, the feedback is positive on some questions. They liked the ideas of using games to teach some topics in this class but commented on the module design still needing a lot of improvement in term of design, interaction between game and users, and more explanation and communication before implementing *GIVE* to classroom. Seventy eight percent (78%) of participants did not have problems using the game. Eighty nine percent (89%) of participants felt online car racing game did not change their attitude toward engineering.

### 5 Conclusion and Future Work

This Study found that the use of *GIVE* in the class room can help students grasp difficult concepts and improve students’ performance and understanding. However, key factors in getting positive results from *GIVE* rely on the design of the game/interactive visualization as well as the learning styles of the students using it.

The quiz results from the easy questions showed that students in the two experimental groups and control group did not have a significant difference in their performance. However, teaching easy topics in class is not presenting any difficulties or problems to students, so they can learn these easy concepts from the lecture.

The more important thing that this study focused on was teaching the more difficult concepts to students. The quiz results from the difficult questions showed that the car simulator group and the control group have a significant difference in their performance, but there was no difference between the car simulator group and the online car racing group. Thus from analyzing the difficult questions only we can conclude that the students from those two experimental groups
have benefited from learning about tolerance with the assistance of games. To enhance students’ understanding of difficult concepts, mechanical engineering courses should present more games and interactive visualizations. The experience of immersing in the high-fidelity car simulation and feel the effect of different car tolerance in driving enhanced the students’ understanding of the tolerance design concepts. This is particularly shown in the student’s ability to solve more difficult questions which require a deeper level of understanding the course materials. The online simulator group, on the other hand, was found to bring no significant benefit in terms of student learning. Later evaluation of the system through survey and interview revealed a number of design issues associated with how the online system is rendered. Therefore, the intended benefit in the online GIVE system has not been fully reaped due to the current design issues, and implementation and evaluation methods. The team plans to redesign the online module according to student’s feedback and comments and conduct the implementation and evaluation more in a better way.

Also, the study showed that most students in these three groups were active, sensing, visual, and sequential learners, which agrees with previous study [1]. To motivate students who are learning engineering concepts, the mechanical engineering program should allow more time for students to perceive the information, present the information through the visual images, add more lab practices for students to process the information actively, and present the guideline of material in class that might help student to progress their understanding sequentially.

Acknowledgement

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Reference

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