AC 2009-485: GAMING AND INTERACTIVE VISUALIZATION FOR EDUCATION: A MULTIDISCIPLINARY AND MULTIUNIVERSITY COLLABORATIVE PROJECT

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Gaming and Interactive Visualization for Education - A Multi-Disciplinary and Multi-University Collaborative Project

1 Abstract

Most people are more perceptive to the geometric rather than the symbolic representation of information. In engineering disciplines, visualization combined with game characteristics can provide an essential mode to facilitate students' understanding of important and abstract concepts, and improve students' willingness to learn. In this project, game characteristics are introduced into course module design, but different from commercially available games in that the level of the contents and assessment tools in this project are meaningful to teachers, students, and parents.

This paper focuses on the design of the Gaming and Interactive Visualization for Education system. Specifically, some initial design results from the three universities for three different courses plus the development of evaluation system will be presented. The system is expected to (1) offer interactions with gaming scenarios that can excite emotions, (2) provide an engaging learning experience of understanding engineering concepts by allowing students to visualize and interact with 3-D objects in a game scenario, (3) employ situated learning by exposing students to the type of challenges they will face in industry, and (4) fit better with the learning styles of the majority of engineering students..

2 Introduction

Student enrollment and graduation rates in U.S. engineering schools have been decreasing over the recent years, with the exception of only top academic institutions [1-4]. This phenomenon is related with students' lack of willingness to learn abstract engineering concepts. In engineering disciplines, learning through a medium that combines course materials with interactive visualization can be a powerful tool for education. ***G**aming and **I**nteractive **V**isualization for **E**ducation (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, to improve the image of engineering, and to attract a greater number of high school students to the study of engineering.

Current high school or undergraduate engineering students grew up in an era where video and computer games became one of the major components of the entertainment industry. The game approach in education has the potential to capture student interest and improve learning and teaching methods [6-7]. Sanderson and Millard [6] applied a team-based game strategy in manufacturing education, where students/users assumed the roles of product designer, manufacturing engineer, marketing expert, and product manager. Hsieh [7] investigated a web-based 2D game environment for teaching line balancing concept. The game concept has proved to enhance student interest in learning the materials. But on the other hand, these game systems lack interaction between the users and the system. In this project, we use the technique of visualization to enhance and enrich the interaction aspect of the design.

An increasing number of educators are concentrating on utilizing visualization to explain scientific and engineering knowledge to a broad audience. Since the 1990s, visualization has been used in different science and engineering courses, such as CAD, FEM analysis [8], parallel system [9], longitudinal vibration [10], electronic related engineering class [11], transportation engineering applications [12], microwave amplifier design [13], and transmission line series compensation [14]. Researchers and industry have used virtual reality in geology, medicine, and automotive design, etc. for better understanding. But specific design of engineering courses, such as basic AME and EE courses, has yet to fully benefit from the application of game and visualization technology.

GIVE is different from the conventional blackboard, PowerPoint based lectures, and e-learning methods [15]. Because it is used for high school and undergraduate students, *GIVE* is also different from edutainment that is mainly for small children [16].

In terms of interaction between *GIVE* and its users, it has the following three unique characteristics. (1) *GIVE* uses a well-designed game scenario to enhance student's understanding and involvement. Some may worry that game based teaching cannot be as efficient as conventional methods, or that it may not be feasible to find out whether or not the level of complexity is proper for an individual student. However well-designed, highly interactive simulations 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 [17]. Students in games will spend literally many hours to learn obscure details and practice their learning "muscles", such as abstract concepts in certain courses [18-19]. It is noteworthy how close the skills required to play games are to the skills needed in a person's work place. A good game can help develop all such qualities in our students. (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.

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 project is in the stage of course module design and development. The team proceeds to develop detailed contents of the courses selected and much attention has been paid to form a serial of questions and answers for each course module. Such questions need to be designed and given to the students in a progressive manner, and answers should be flexible enough to reflect different thinking angles. Video clips are often used as hints in modules. Four different databases were identified and built preliminarily, which is flexible enough such that it can be easily used by all course modules. In addition to the development of the course modules, the assessment tools are under investigation as well, through which the *GIVE* system is expected to be evaluated in the coming fall semester of 2009.

This paper is organized as follows. First, we describe the overall structure of the project. Then, the game characteristics incorporated in the learning software are discussed. The status of three course modules which are currently under development is illustrated in details. Finally the assessment methodologies are designed followed by the section of conclusion.

3 Project Architecture

The following sections present an overview of the proposed *GIVE* system. The description presented here addresses three principle issues: the housing, display configurations, and software. The housing of the *GIVE* environment is an important consideration that will affect student interest. Currently, *GIVE* will be implemented in a regular classroom with projection systems and internet connections. The fundamental function of the display system is to show the class material graphics generated by computers in a regular classroom. The display configuration includes a flat screen, a projection system, and a computer. The commercial software to be used in designing course modules includes Flight Simulator, MATLAB/Simulink, Pro-E, Flash, and in-house software including the basic modules developed by the PIs.

4 Game Characteristic

While commercially successful games such as DMA Design® and incredible machine® find broad markets for certain sophisticated environments, they have had little influence on mainstream education [18]. In the *GIVE* system, the mathematic model will be much more accurate and the level of the materials presented in *GIVE* will be meaningful to teachers, students, parents, and employers. In this section, we will detail out how various game characteristics will be implemented in order to engage students in a gaming environment. For example, real time help will be provided with text hints for each question, and meaningful visual presentations (images or videos) are included to enhance student understanding.

Table 1 gives the game characteristics and how it will be applied to course modules. These typical game characteristics, shown in the left column, are often used by the game industry. The right hand column described how these characteristics are considered in the module development. In this table, "answering/reasoning structure" (denoted by "*") means: For each step, students need to choose correct answers to a sub-question, and also choose the reasoning for the answer within a specified time to avoid guessing. "Incremental question/answer structure" means the difficulty level of questions given to students after each video section will increase from easy to difficult. Also, in order to increase the feedback level and provide real-time help, hints will be given to the students who picked wrong answers. These hints can be either in the form of video or text depending on the nature of the problem.

Table 1 Game characteristics incorporated into the *GIVE* module

Game characteristics	**Effects on *GIVE* course module design (examples)**
Distant / asynchronous	Web based course modules
Progressively balanced goal	Incremental question/answer structure*
Equal chance to win	Same questions for each student
Feedback	Give score and hints (video and text) spontaneously*
Multiple-goal structure	
Clear goal	Understand the engineering concepts
Adaptive scoring	Answering/reasoning structure*
Time sensitive scoring	Scores are updated in real-time
Meaningful visual presentation	Problem specific videos and visualization
Emotional involvement	Emotions by the entities in the game
Avoiding guess	Answering/reasoning structure*
Real time helps	Give score and hints (video and text) spontaneously
Core mechanics Constitutive rules Operational rules Implicit rules	Depends on the specific course material
Background	Depends on the specific course material
Maximum tries	Limited to 3 tries
Challenges and rewards Small challenges Large challenges The final challenges Explicit challenges Implicit challenges	Scores in playing modules Grades in the course
Game settings Graphics, sound, story Time treated: relative time	Currently no sound Limited time for each question
Experiences	Incremental question/answer structure*

5 Course Module Development

Software development is the key and the most time-consuming task of the project. Here the information flow, database construction and three course module examples are discussed. The software development is expected to be completed by this summer, and then, the course implementation and evaluation will follow.

5.1 Information Flow

The game module will continuously evaluate the student's skill thus he/she will not become bored or frustrated [17]. In a good game model, goals are clear - you know why you are learning something and there are plenty of opportunities to apply what you learn. Therefore, every course module in *GIVE* will have two key components - game-based education material and a time-sensitive scoring system.

A flow chart representing implementation of the course modules in the *GIVE* system for undergraduate classes is shown in Fig. 1. For a 50-minute class, instructors will first demonstrate the game scenario to attract student attention, and then teach the theoretical content (i.e., concepts, equations, etc.) needed to accomplish game goals. Afterwards, students will solve the relevant problems with *GIVE* in the visualization environment. A typical module can consist of n steps with each step moving closer to the overall solution. For each step, students need to choose correct answers to a sub-question, and also choose the reasoning for the answer within a specified time.

The *GIVE* system will implement an adaptive progression system that generates a game-like bonus or penalty by letting students jump several steps forward (gain more points) or send students one step backward (lose points) depending on whether correct reasoning was given for the sub-questions (progressively goal). These reasonings show whether students have fully understood the theoretical contents. Students can repeat the game up to a limited number of times for each step. The web-based point scoring system will help the students and instructors to be aware of difficulties associated with specific concepts. If students are confused by certain concepts while solving problems, they can pick from a set of learning questions (offered by the module) for hints and get pre-programmed answers from *GIVE*.

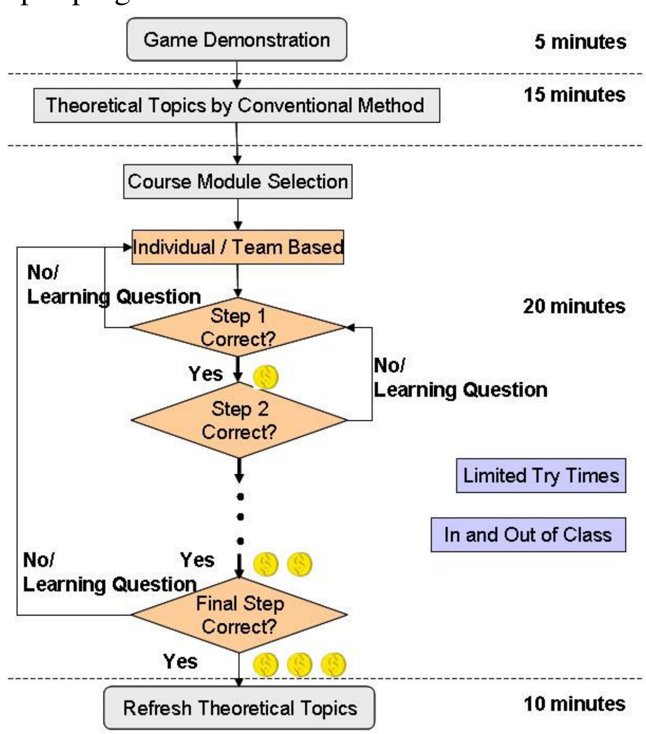


Figure 1: Game scenario of a *GIVE* based lecture

5.2 Database Construction

The key component of the software package design and development is the database. According to the game scenario of a typical *GIVE* module, four databases are required (as shown in Fig. 2): student performance database, question & answer database, movie database, and emotional involvement database. In Fig. 3, the information flow interface and databases are demonstrated.

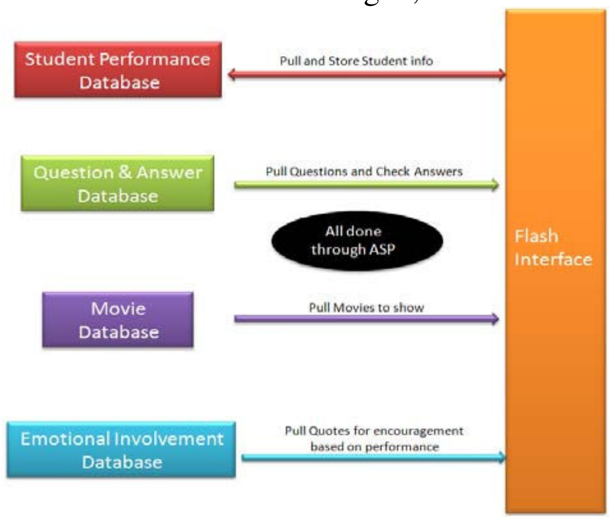


Figure 2: Four databases and their communication with the interface through ASP.

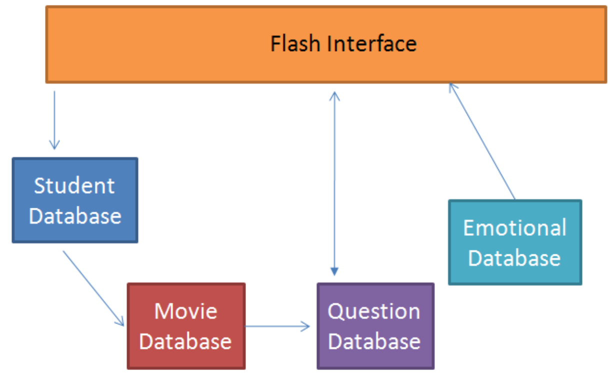


Figure 3: Information flow sequence between databases and the interface

The information included in the "student performance" database is: student ID, student Name, password, number of attempts for each module and section, and student score for each attempt. In the "question & answer" database, questions, correct answer, almost right answers, wrong answers, and completely wrong answers will provide the user different combinations of the question proposed and answer options they can select from. Movie id, location of the movie, length of the movie clip and its brief description are included in the "movie" database. Finally three different types of encouragement, a set of quotes for students who did the question well, poorly, and close are designed into the "emotional involvement" database. The logic flow of how these databases are accessed is shown in Fig. 4, in which the upper limit of the attempts time is explicitly considered.

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 details.

5.3 Module Example 1 – Flight Mechanics

From Fig. 5 to Fig. 7, some screen shoots have been taken for one of the section in the course model "flight mechanics". Students are required to log in using the teacher assigned ID and password (Fig. 5). After that s/he can select any module s/he likes to work on (Fig. 6), in this step, the program will tell the student how many time s/he has already tried. If the maximum trial time is met, the system will not allow her/him to continue on this particular module.

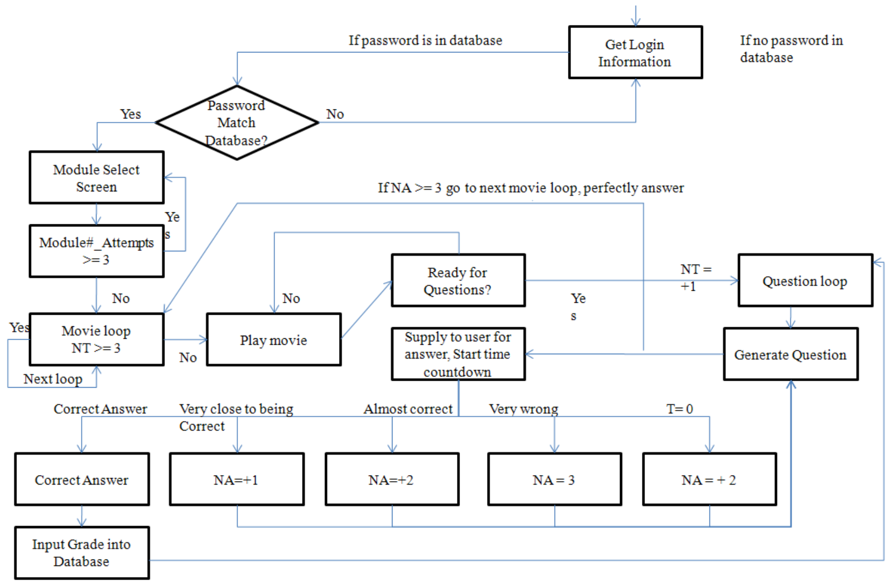


Figure 4: Programming logic for accessing the database.

Figure 5: GIVE model log in system

Figure 6: Module selection

Figure 7(a) gives the overall picture of the course module. In Fig. 7(b) a movie clip corresponding to the question is playing. In the movie clip, important aspects are highlighted in different color such as the ones shown in Fig. 7(b) where pilot input, control surface deflection, and cockpit view are demonstrated. In Fig. 7(c), the question and options for answers are shown. To avoid student from just remembering the answers, for the same question, different option choices are randomly generated such that the student will not see the exact choices for different trial. If the student chose a wrong or almost wrong answer, real time hint will be provided to the students and for particular cases, movie clip or slide will be shown to the student to help them better understand the technical content (see Fig. 7(d)). Important parts are highlighted as well in the hint. Emotional comments will be provided to students whenever they get the answer correct or wrong. Real time scoring system is demonstrated (Fig. 7(e)) to students as well, in which s/he will not only see her/his score, but also the average scores based on her/his peers' performance on the same question. Note that in order to avoid guessing of the answers, for each question section, up to nine questions have been prepared in sequential, so that students' answer can be further questioned. This adaptive scoring system will help the instructor to get a better idea whether or not the student really understand the technical materials instead of simply guessing. Also currently, the student has been given 60 seconds to choose her/his answer.

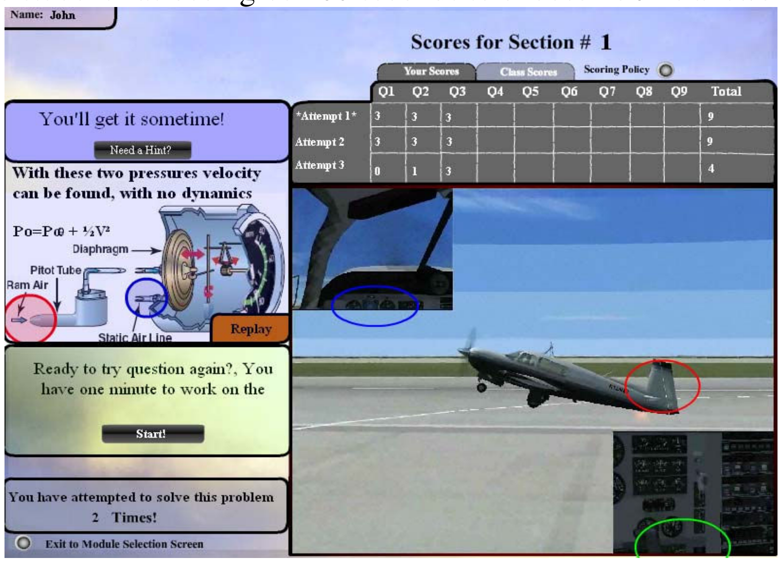


Figure 7 (a): Overall layout of the module

The following game characteristics have been considered during the module design: progressively balanced goal, distance/asynchronous, equal chance to win, feedback, multiple-goal structure, clear goal, adaptive scoring, time sensitive scoring, meaningful presentation, emotional involvement, avoid guessing, real time helps, rules for win, background, maximum tries, challenges and rewards, and experiences.


Figure 7 (b): Movie clip which can be run either before or after the question section

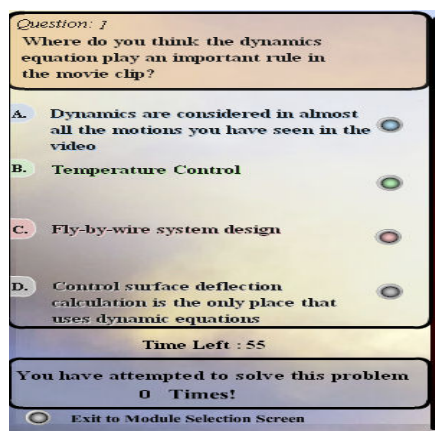


Figure7(c): Question section

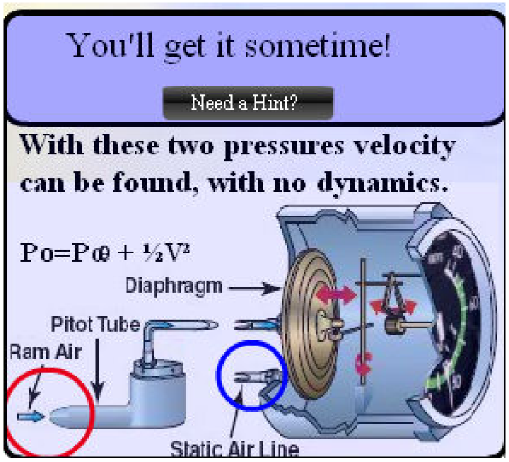
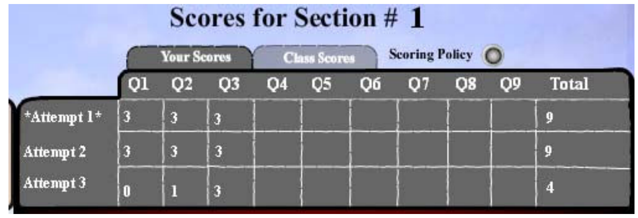


Figure 7(d): real time hint


Scores for Section # 1

Your Scores | Class Scores | Scoring Policy

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Total
Attempt 1	3	3	3							9
Attempt 2	3	3	3							9
Attempt 3	0	1	3							4

Figure 7(e): Real time score update system

5.4 Module Example 2 – Design and Manufacturing

Understanding "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 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 high tolerance will require less time and cost to manufacture. The goal is to motivate the player to use high tolerance limit in manufacturing components. On the other hand there are some components which will need 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 is being developed using the same framework as described in Section 5.3, only the course content are different. The 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 (Fig. 8) are shown to provide students with information related to different topics.

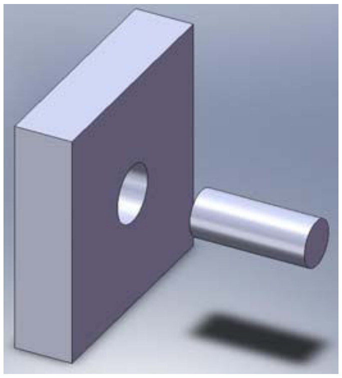


Figure 8 (a): Clearance fit: The internal member is always smaller than the external member so that the parts will slide together.

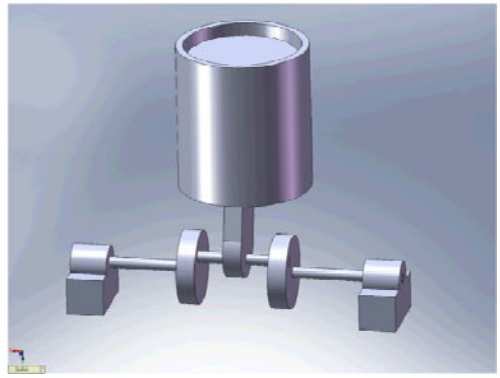


Figure 8 (b): Simulation showing clearances fits.

Each topic is divided into three sub-sections (i) fundamental information, (ii) test questions and (iii) results of questions. First students review fundamental information related to different topics. Text, graphics, and animations (Fig. 8) 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 question to be tested on their understanding of the concepts and materials. After the student answers a question, performance of the racecar related to the answer is shown to the student using videos of a race car game, 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 (Fig 9). The question 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. Figure 10 shows the crankshaft being dimensioned in different manners.

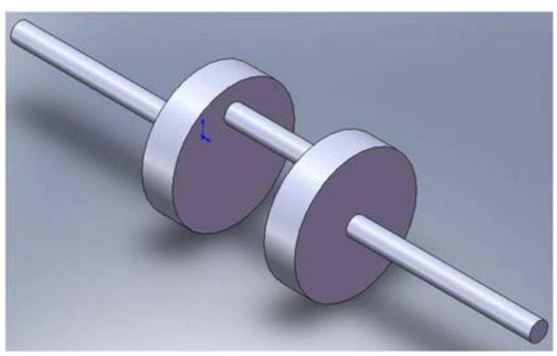
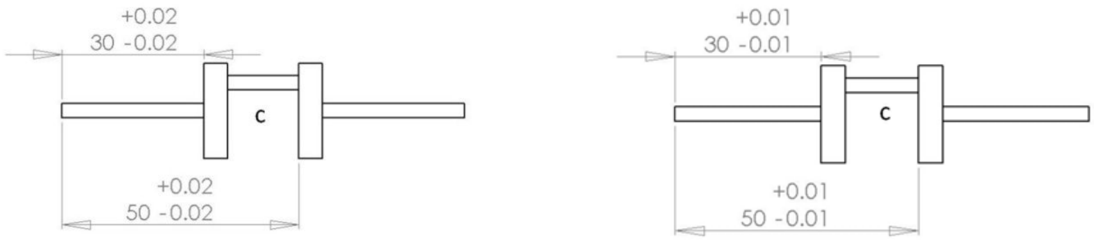


Figure 9: Crackshaft

Which dimensioning strategy will give better performance with cost of machining being low?

(a) (b)



(c) (d)

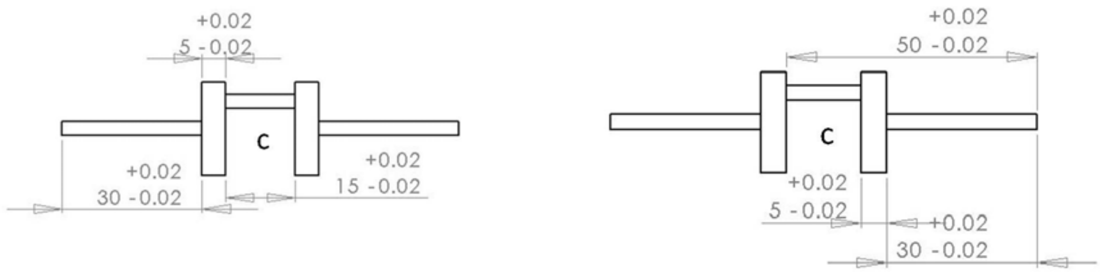


Figure 10: Tolerance stacking question

Depending on the answer chosen by the students a racecar video is shown that demonstrates how the performance might be affected. In order to easily convey the relationship between tolerance and performance, the crankshaft is related to speed of the vehicle – if the answer is correct then the racecar accelerates rapidly, if the tolerance is loose then the acceleration decreases. Several screen shots of the racecar video is shown in Figure 11.

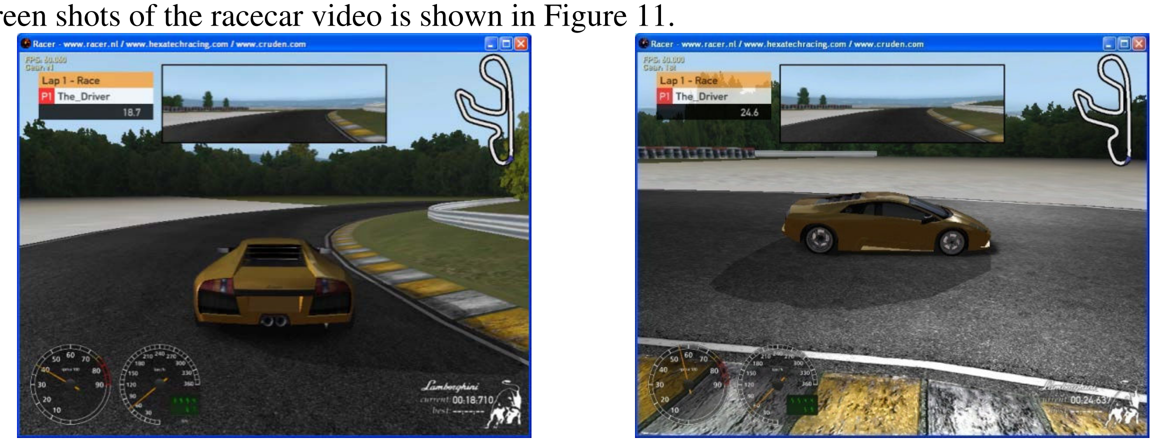


Figure 11: Screen Shots from Racecar video showing acceleration performance based on student answer to tolerance stacking for crankshaft

5.5 Module Example 3 – Introduction to Electrical Engineering

This course module is designed to assist freshman students in gaining an understanding of what the field of Electrical Engineering is about. Often times, freshman students start to study a major without having a clear and complete picture on what could be ahead in their future study and future career. After the module design is complete, it can be used in class to assist the instructor as an auxiliary teaching tool, and played by students after class.

The module covers the following topics: (1) what is electrical engineering and which are electrical system? (2) What are the different fields of electrical engineering? (3) What kinds of courses need to be learned? (4) What kind of assistant is available on campus to help learning? (5) How to have fun while studying EE? (6) What kind of careers do ECE majors commonly pursue? For each of the above topics, multiple specific questions are designed in a progressive manner, starting from easy/general questions and moving to more challenging/specific ones.

One unique feature of the module is that there is a common thread to connect the above different topics, that is, an autonomous helicopter. More specifically, students will learn how an autonomous helicopter is related to electrical engineering; what different fields and courses in electrical engineering are related to each component of the helicopter system; what kind of on campus activities and support are available to learn more about this system; and what are the potential workplaces related to the design of such systems.

To stimulate student interest and enhance learning outcome, visual presentations and animations are embedded into the learning process offered by this teaching module. An example is given below regarding the topic (1), i.e., what is related to electrical engineering. A video clip of 1 minute long is played about electric cars (a snap shot is displayed in Fig. 12), before the students answer the following question:

Electrical car is one type of promising future cars. After viewing the video clip on the right, identify which of the following is NOT studied by an electrical engineer: (a) Battery cells; (b) Windmills; (c) Biomass fuel; and (d) Solar cells.

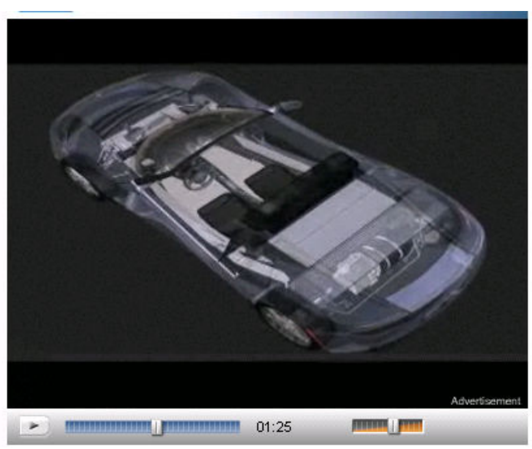


Figure 12: A snap shot of the electrical car video clip.

All the above answers (a)~(d) are mentioned in the provided video clip. To provide timely instructions, a hint or a comment is displayed after an answer is selected, regardless of being correct or wrong. For instance, after the answer (b) is chosen, the following text will be displayed.

Very close! A windmill is a mechanical machine powered by the energy of the wind. However, it contains electrical parts since a windmill is normally designed to convert wind energy to electrical energy.

Questions of various challenging levels are given to students. Low level challenge questions are associated with fewer and straightforward answers, such as yes/no. As the module progresses, high level challenge questions will be offered as well. The following is a sample question about the module topic (2), that is, different fields of electrical engineering. A movie clip is displayed first to show an autonomous flying helicopter, for which a snap shot is shown in Fig. 13. Then, the following question is asked:

Does an autonomous flying helicopter need to have the following components/capabilities? (a) Power system; (b) Communication system; (c) Control system; (d) Electronic circuits; (e) Computing unit; (f) Fossil fuel; and (g) the Internet connection.

No matter which answers students select, a text and image-based hint will be displayed to guide students to find the correct answers or to endorse the correct answers chosen by students.

Figure 13: A snap shot of the electrical car video clip.

6 Module Assessment Development

Along with the course module development and implementation, an evaluation system with formative and summative assessment techniques that are based on both subjective and objective data will be used to test the *GIVE* system's pedagogical effectiveness, student attitude change, and retention.

To understand whether the *GIVE* system can improve student learning and retention of course materials, the pedagogical effectiveness of *GIVE* will be assessed by measuring and analyzing the evidence of student learning outcomes. Performance of students on quizzes, tests, and projects will be compared between the course implemented with the *GIVE* system and the same course with conventional lecture format. The archival data of course performance with conventional teaching methods will serve as a baseline to prove the pedagogical effectiveness of the *GIVE* system. Based on the (a) to (k) ABET engineering criteria for each of the courses and the specific course objectives, specific student learning outcomes will be determined jointly by faculties who had taught these courses. Then, survey items, and open-ended questions in an assessment tool will be used to assess student learning. Individual interviews will be conducted with students taking the courses to get their opinions about using the *GIVE* system. Feedback from students will be used as a basis for improving the *GIVE* course modules.

To assess the impact of *GIVE* on student attitude towards engineering, student's attitudes towards engineering before and after taking the *GIVE* course modules will be measured through standardized surveys and interviews. A set of standardized survey items [20] which measure student general attitude towards engineering in 13 key areas will be administered to students taking the *GIVE* courses at the beginning and end of the course to characterize students' initial attitudes and attitude changes at the conclusion of the semester. The effect of the *GIVE* system on attitude change with students at different levels will be studied. Student attitudes measured with the survey will also be correlated with student retention data and academic performance data. Structured interviews with students will be used to get more insight on the reasons causing their attitude changes.

To ensure an engaging and satisfactory student learning experience, throughout the development of the *GIVE* system, usability evaluation methods will be applied to evaluate and improve the usability of *GIVE* system. During the early development stage of the *GIVE* system, heuristic evaluation methods will be used to evaluate game design aspects including game interface, game story, game mechanics, and game play with heuristics for game playability [21] and the learning system aspects with heuristics for effective learning [22]. When *GIVE* system takes shape, laboratory-based user testing sessions with think-aloud protocol will be conducted with students followed by satisfaction questionnaires and interviews. User comments, failures, and subjective feelings will be used to identify design characteristics leading to positive and negative user experiences.

Table 2. Sample Questions for *GIVE* System Assessment

Assess Student learning with GIVE	Assess Attitude change toward engineering with *GIVE*
• Please describe your experience of using *GIVE* • Please describe your first reactions to *GIVE* • Please describe your present opinions to *GIVE* • What would you tell another person about *GIVE* system for learning engineering concepts? • What kinds of successes have you experienced? • What kinds of problems have you experienced? • What improvements would you recommend? • What is your opinion of using the *GIVE* system to help teaching this course?	• Please describe your attitude towards engineering before using *GIVE* system. • Please describe your attitude towards engineering after using *GIVE* system. • Have your attitude towards engineering changed? If so, please describe.

7 Conclusion

It is envisioned that *GIVE* will provide an interactive gaming environment for learning which is drastically different from e-learning systems. While retaining the advantages of e-learning systems, such as distant and asynchronous education, the GIVE system enhances learning by incorporating game characteristics, such as a progressively balanced goal, feedback, multiple-goal structure, adaptive scoring, meaningful visual presentation, and emotional involvement.

In this paper, the detailed design of the course modules in which the interactive game characteristics are incorporated is illustrated. The components of the project include information flow, hardware/software tools, database, and three different engineering courses in three universities.

Acknowledgement

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