Video Based, Game Integrated Concept Tutors – Effectiveness in Freshman Courses

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Many students who take Introduction to Engineering classes are freshmen and need help in learning engineering concepts. In this paper, we discuss the development, implementation, and evaluation of a video- and game-based instructional tool called a concept tutor. These concept tutors focus on one concept at a time, and they can be used as supplemental material to a lecture. These tutors provide additional help to students in explaining the concepts taught in class and reinforcing their learning. The purpose of concept tutors is to increase the undergraduate students' enthusiasm for and attention to the concepts taught using this instructional methodology. The concept tutors engage the students in a learning process meant to improve retention rate.

The concept tutor consists of three phases. The first phase is definition and real-world applications of the concept. The second phase includes a step-by-step presentation of the concept in a general format that explains the concept through a targeted problem. In this phase, the concept tutor is split into topic videos. The third phase consists of assessments to measure the students' understanding of the material presented. After viewing each video, the students are required to answer a set of questions that test the concepts they learned. Students are allowed to choose the format of the test. They can choose either a regular multiple-choice assessment or a game-based assessment.

Quantitative and qualitative results show that students find such materials useful; furthermore, the students preferred this method to complement a lecture. We report the development methodology of the tutor and evaluation results in this paper.

Keywords: Pedagogy (Didactics) of Higher Education, Knowledge Gain, Engineering Education Research, Course Construction, Computer Aided Learning

1. Introduction:

Universities have continued to improve in the use of technology in teaching-learning methodologies. Tools like videoconferences, chats and blogs, podcasting [1], webcasting and webinars [1], video streaming [2], and networked educational videos [3-5] have rapidly appeared. Research [3, 6] has shown that videos are a helpful tool to engage students with different learning styles beyond the textbook and traditional lecture. They can also increase the students' enthusiasm about the concepts presented and thereby increase information retention [6]. The focus of these methodologies is to engage students in intellectual work that facilitates the assimilation of knowledge in a disciplined manner that will have value beyond school.

Research by Holtzblatt et al. has shown that videos can be used as a beneficial tool to increase student engagement and enthusiasm [6] in the learning process. This increased engagement has a direct impact in increasing information retention, which will have value beyond school [7]. Media-based presentations are beneficial not only for reproduction of factual information but also for information processing [4]. Providing students with this kind of material gives them the opportunity to adapt the presentation to their own cognitive needs and skills.

A 2011 study concluded that online videos are the most widely used multimedia resources in class and outside class [8], used not only by students but also by 80% of faculty. During classes, students must face the problem of rapidly organizing the information presented at a rate that they cannot change. While reading the textbook allows them to tune their information gathering to their cognitive needs [4], video material can enhance the process by adding audio to the visual. Another study [10] found that 70% of students who used videos before or after a classroom lecture said that the videos were helpful in understanding the class material. Sharing educational videos in existing educational platforms is highly valuable because of the registered increase in students' interest and motivation [2]. In addition, tutoring is a highly effective way to increase students' learning. In a 1984 article, Benjamin Bloom found that average students under tutoring perform two standard deviation better than those students that learn under conventional methods[9].

Two separate groups of college students at Auburn University conducted surveys regarding the need for a specialized online tutoring. The survey results show that a majority of the students who used search engines to seek help for homework benefitted from tutoring that targeted specific class material. Students listed YouTube, DVDs, Khan Academy, tutoring study guides from bookstores, and chegg.com as some of the materials that helped them outside class. While 74% said this form of supplemental material helped improve their overall learning experience, the students disliked the fact that this material did not have step-by-step instructions. However, they liked being able to watch the video as many times as needed and said that the videos allowed for multiple ways of learning the same thing. Furthermore, 83% said they felt that a voice-animated lecture, followed by practice problems, would be helpful with learning school material. The survey participants also suggested that supplemental material should include "voice over, games," "easy-to-understand practice material," "ease of use and access to variety of material," or "professor's own form of supplemental material." The responses from the surveys show that because in-class information requires fast organization and processing of information, students search for supplemental materials to satisfy their learning styles.

One such supplemental material is Khan Academy, an instructional website on a variety of subjects that has 7-minute to 14-minute videos with a voice over by Mr. Salman Khan, founder of Khan Academy, presenting a concept or how to solve a problem. The images in the video are hand-scribed formulas, diagrams, and key words that appear on the screen aligned with the audio explanation [5]. However, Khan Academy videos do not go very deep into the subject discussed and are mostly explained through examples [11]. The videos do not target a specific audience; therefore, for many students, the content is either too advanced or too simple and fails to achieve any consistent content objectives.

This paper outlines the development, implementation and evaluation of an application that aims to extend student comprehension of more in-depth material presented in class. Two concept tutors were built to introduce Simulink in MATLAB (by MathWorks) to students as a graphical programming tool for controlling a LEGO Mindstorms NXT Robot [12]. These concept tutors were developed to allow a self-paced review of Simulink GUI and programming logic concepts.

2. Development of Online Tutor:

The application described in this paper comes as a tutor with step-by-step instructions with practice problems after each step. It also has an option of choosing a game-based environment while answering the questions. The tutor-like material is learner-centered in that the learners go through the material at their own pace, are actively engaged by adapting the presentation to their needs [4], and are quizzed on material after each step. Having the possibility to pause and rewind, review a video, take notes, and answer review questions gives each viewer the ability to customize his learning [5, 11]. The users are not forced to rapidly organize information because it is presented at a rate that they can control [4], thus distributing their attention and cognitive resources across the whole process of mastering a concept according to their metacognitive strategies [13]. The tutor is designed so that the viewer gains a thorough understanding of theoretical concepts supplemented with numerical examples.

The concept tutor discussed in this paper was created for two assignments in the Introduction to Engineering course. In the first assignment the students had to program a NXT Mindstorms Robot using Simulink in MATLAB (by MathWorks) [12] to go in a square. Out of 117 students, approximately 93% of the students had no prior experience using Simulink. Two separate tutors were developed to help students with their assignments. This product has been created in collaboration with Toolwire Inc. Figure 1 shows the tutor-user flow experience on which each concept tutor is based.

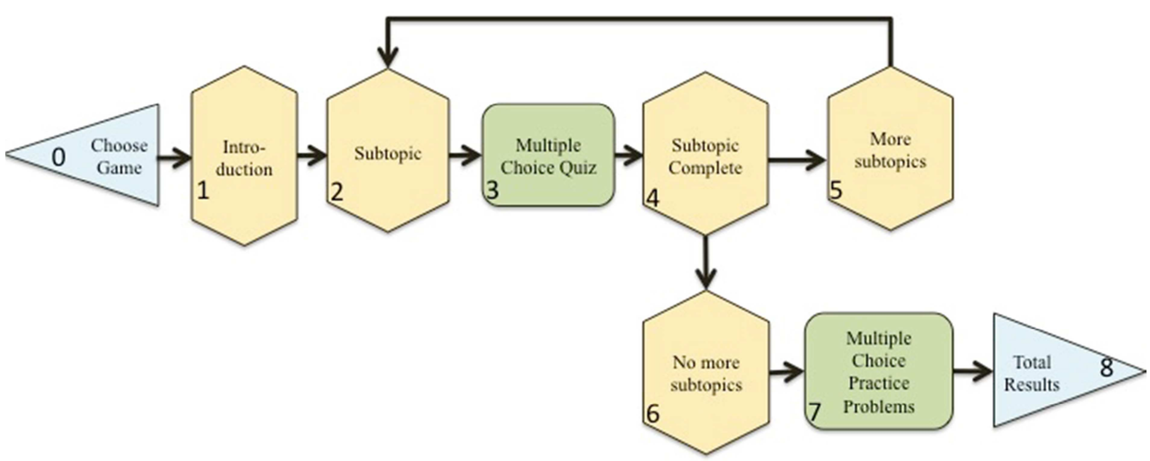

Figure 1: Tutor-User Flow Experience

Figure 1 explains the phases of the tutor. Before the user starts the learning process, the viewer has to choose the type of game (Figure 1, block 0) he wants to play while self-assessing his learning.

There are three options. The first option is a no-game option where students answer multiple-choice questions after each subtopic (Figure 1, blocks 3 and 7) without playing a game. The second option is a medium difficulty game. In this case, the learner will gain points by connecting correct answers on a grid. There are no points deducted if the answer is incorrect. The third option for playing a game involves moving toward the correct answer while avoiding enemies. After the game option is selected, the tutor starts with an introduction (Figure 1, block 1) to the topic to be discussed, followed by subtopics of the concept. This section includes objectives of the tutor, a short description of the concept, and real-world applications of the concept.

The objective of the tutor is to help students maintain clear purpose and focus throughout as well as having a compelling application of the concept. Block 2 in Figure 1 represents each step; the overall concept is divided into subtopics. Each subtopic consists of a video describing the step (Figure 2) followed by a small number of self-assessment questions from the same step. Figure 2 shows the screenshot of a video which explains how to drag and drop blocks (subtopic) from a library to a new file in Simulink).

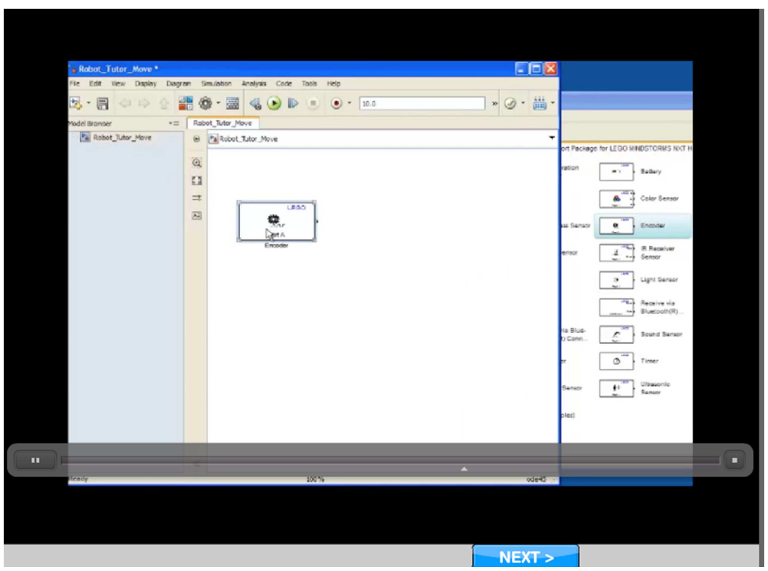

Figure 2: Screenshot of a tutor video in the application

Each concept can include multiple subtopics depending on the number of steps needed to complete the definition or methods employed. After each step, the viewer has to answer a series of questions about the step for in-depth retention and self-assessment (Figure 3). After the last subtopic is completed, users must answer a set of 10 to 15 questions based on the entire material. The aim of this sequential process is to maintain a progressive learning [11] approach that can be adapted to all learning styles.

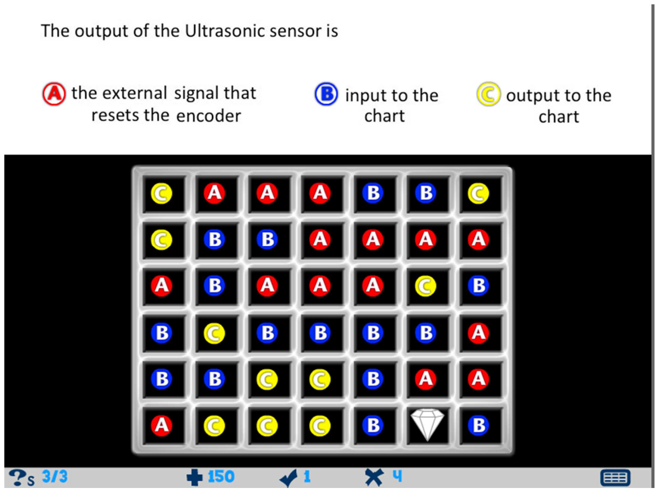

Figure 3: Screenshot of a self-assessment question

3. Implementation:

Two concept tutors were created and tested in an Introduction to Engineering course with freshmen at Auburn University. The objective of the study was to evaluate the capability of instructional video- and game-based teaching methodology to reinforce learning of engineering concepts. There were two learning modules used in each assignment. The first module was called the Simulink Learning Module 1 (SLM 1). In this module, the students were exposed to a lecture on Simulink. The second module was called the Simulink Learning Module 2 (SLM 2). In this module, the students were exposed to the same lecture on Simulink and to the tutor applications. In the lecture, the instructor used a PowerPoint presentation to teach the use of Simulink in programming a NXT Robot. In terms of training, students watched an instructor go through a practice test (Figure 1, block 3 alone) to demonstrate the way the three game options work. The purpose of the practice test was to familiarize the testers with the environment and to explain the game interface. After the practice was finished, each student was directed to a computer and was given access to the activity. At this point the students were free to manipulate the application at their own pace. After completing the exercise, the students were asked to take a survey that included open-ended questions about how well the video enhanced the tutor. In this way, each concept tutor was created with the students to meet their expectations.

The targeted student groups for this experiment were 117 freshmen engineering students at Auburn University. An experimental and control section were used to obtain students' perception of the information they gained and retained while performing these learning modules. There were three experimental and three control sections. The students were randomly assigned to a section. The instructional material covered in the control and experimental sections is explained below.

The control section used Simulink Learning Module 1 (SLM 1), which consists of a lecture on Simulink. The control section had 57 students in SLM 1.

The experimental section used Simulink Learning Module 2 (SLM 2), which included the lecture on Simulink and video- and game-based concept tutors on Simulink. The experimental section had 60 students in SLM 2.

4. Evaluation:

The video- and game-based concept tutors affected the higher-order cognitive skills (HOCS), concentration, and student enjoyment. We also found an effect of gender. Personal factors and characteristics have an effect on students' attitudes toward learning and learning outcomes [14-16]. By studying the attitude toward learning models used by Biggs and Moore [15] and Nemanich et al., [17], Sankar et al. developed the 4P model [18]. The following model has also been used to test the effectiveness of serious game [19]. According to this model, students' attitudes toward learning (process factors) are affected by presage conditions and learning modules (pedagogy factor). The process factors in turn affect the learning outcomes (product factors). Hence, the students' learning outcomes in Simulink concept depend on presage and process factors. Figure 4 shows the 4P model with learning modules being the moderating variable.

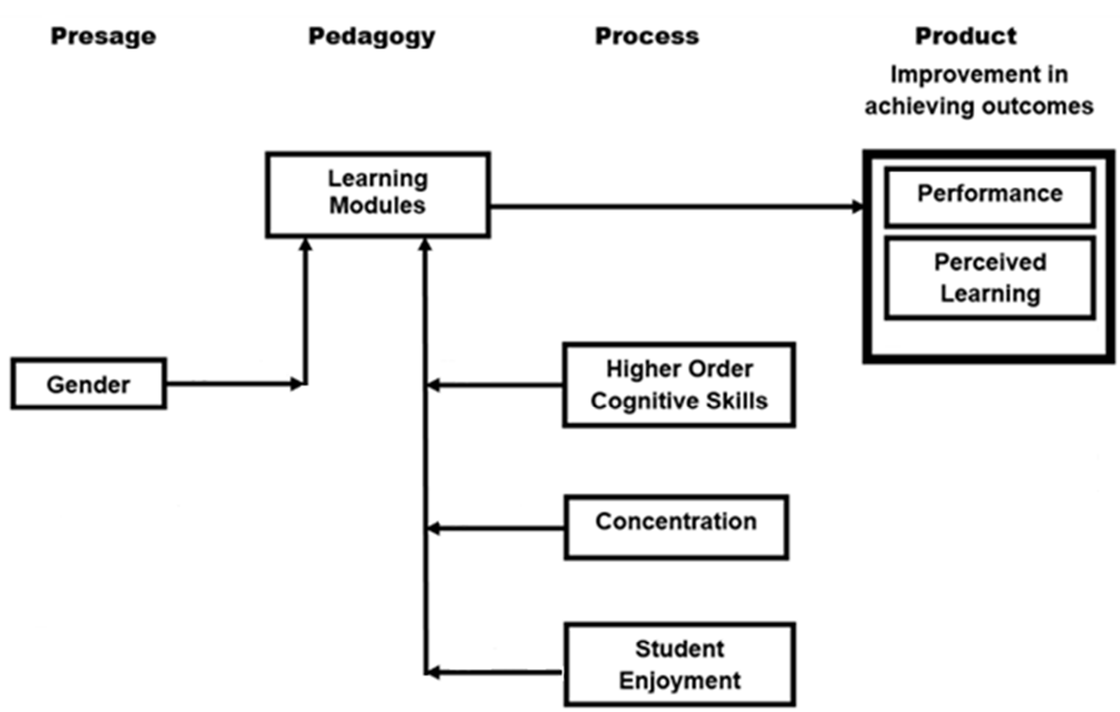

Figure 4. 4P model with learning modules as the moderating variable

4.1 Presage

Presage factors are those that occur before the start of learning process and still affect the learning outcomes. The presage factors affect the process factors as well by interacting with the learning module. Gender is counted as a presage factor. This factor is an independent variable in this model.

4.2 Pedagogy

As mentioned before, the control section used Simulink Learning Module 1 (SLM 1). The experimental section used Simulink Learning Module 2 (SLM 2).

4.3 Process

Process is defined as the learning modules or the instructional tools given to the students, which might or might not give rise to desired learning outcomes [20]. The students' learning experience is incorporated in Process. [17]

4.3.1 Higher Order Cognitive Skills (HOCS)

Skills such as analysis, evaluation, and synthesis are considered higher-order cognitive skills in Bloom's Taxonomy [21]. The ABET [22] 3(e) criterion states that students need to be able to identify, formulate, and solve engineering problems at the end of their education. The questions measuring higher-order cognitive skills were taken from Hingorani et al. [23]. These questions are shown in Table 1.

4.3.2 Concentration (CONC)

Concentration is thinking about and analyzing the same task over a period of time without losing attention. In order to secure the students' concentration, only a targeted scope of information should be allowed into awareness [24]. The tutor with the game is designed to minimize the distraction of the students. The questions measuring concentration were taken from Koufaris [25]. These questions are shown in Table 1.

4.3.3 Student Enjoyment (SE)

This term refers to the pleasure that students experience while going over the learning modules. Typically it refers to the students' desire to utilize the instructional tools. The questions measuring student enjoyment were taken from Nemanich at al. [17]. These questions are shown in Table 1.

4.4 Product

Product factors are those that students have gained by participating in the learning modules. They are the outcome of the instructional tools. Three product factors are identified and explained below.

4.4.1 Performance

There are two measures of performance:

- The students were given two assignments on programming a LEGO NXT robot using Simulink. The score is the average of these two assignments. This score will be referred to as Robot Lab Assignment Score (RLAS) in the rest of this paper.
- The students were given two quizzes after the learning modules. The performance score is the average of the two quizzes. This score will be referred to as Robot Lab Quiz Score (RLQS) in the rest of this paper.

4.4.2 Perceived Subject Matter Learning (PSML)

Perceived subject matter learning is defined as the awareness and the approach toward the subject matter. Perceived subject matter learning may be affected by different learning modules. The questions measuring perceived subject matter learning were taken from Alavi et al. [26]. These questions are shown in Table 1.

Table 1. Perceived and demonstrated measures of process and product variables

Constructs/ Items	**Measures**
Process Variables *1. Higher order cognitive skills*	***Perceived*** *measures of higher order cognitive skills used by Hingorani et al., [23]* • *The instructional materials in the Simulink learning module helped me identify engineering tools that will assist me in decision-making.* • *In this Simulink learning module I learned how to inter-relate important topics and ideas using the instructional materials.* • *In this Simulink learning module I learned how to identify various alternatives/solutions to a problem using the instructional materials.* • *The instructional materials in this Simulink learning module improved my problem-solving skills.* • *I learned how to sort relevant from irrelevant facts using the instructional materials in this Simulink learning module.*
2. Concentration	***Perceived*** *measures of concentration used by Koufaris [25]* • *I was absorbed intensely in the Simulink learning module.* • *My attention was focused on the Simulink learning module.* • *I concentrated fully on the Simulink learning module.* • *I was deeply engrossed in the Simulink learning module.*
3. Student Enjoyment	***Perceived*** *measures of student enjoyment used by Nemanich et al [17]* • *The learning module has been enjoyable.* • *This was one of my favorite learning modules.* • *I had fun working on this learning module.* • *I enjoyed many aspects of this learning module.*

Product Variables *1.Performance*	***Demonstrated*** *measures of performance* • *Robot Lab 1 & 2 Scores* • *Robot Quiz Score*
2. Perceived Subject Matter Learning	***Perceived*** *measures of perceived subject matter learning used by Alavi et al.[26]* • *I became more interested in the concept of Simulink.* • *I gained a good understanding of the concept of Simulink.* • *I developed the ability to communicate clearly about the concept of Simulink.* • *I was stimulated to do additional work in the area of Simulink.* • *I found the Simulink learning module to be a good learning experience.*

5. Evaluation Results:

5.1 Quantitative

The students were asked to complete a survey that included questions relating to the students' prior knowledge in computer programming. Based on this survey result, the scores of students with prior knowledge of programming were eliminated from the sample to remove the possible bias in the analysis. The reduced sample size was 91.

The students were asked to rate the extent of their agreement with the evaluation constructs on a 5-point Likert scale. In order to test the relationships in Figure 4, we relied on independent *t*-tests (e.g., mean comparisons). The data in the following tables represent the results of the mean comparisons for several variables of interest across the control and experimental groups. *P*-values that were significant at the .05 level or smaller are highlighted (bold and italics) and reported. Further explanation is given for each of the significant results.

5.1.1 Simulink Tutor Evaluation

Several significant findings are revealed in Table 2. All student scores on perception measures (higher order cognitive skills, concentration, student enjoyment and perceived subject matter learning) and objective measures (robot quiz and lab assignments scores) were significantly different between the control and the experimental groups in that the experimental group displayed higher scores. This finding suggests that the students in the experimental group had improved their higher-order cognitive skills, concentration, student enjoyment, and subject matter learning while using the Simulink tutor [27]; also, they had higher scores on the Robot Lab Quiz and assignment than did the control group.

Table 2. Mean comparisons among several outcome variables for the Simulink tutor

Variables		M	SD	N	t	df	p
Higher-Order Cognitive Skills	Control	2.93	0.930	46	-2.03	89.00	***0.046****
	Experimental	3.28	0.696	45			
Concentration	Control	2.75	0.959	46	-2.43	89.00	***0.017****
	Experimental	3.18	0.720	45			
Student Enjoyment	Control	2.75	0.956	46	-2.73	89.00	***0.026****
	Experimental	3.18	0.860	45			
Perceived Subject Matter Learning	Control	2.90	0.904	46	-2.24	89.00	***0.028****
	Experimental	3.29	0.731	45			
Robot Lab Quiz Score (Max 10)	Control	6.80	1.614	46	-4.89	89.00	***.000******
	Experimental	8.29	1.255	45			
Robot Lab Assignments Score (Max 50)	Control	28.81	6.559	46	9.03	89.00	***.000******
	Experimental	47.28	12.195	45			

*Note. *p<.05, **p<.01, ***p<.001*

5.1.2 Summary and Findings from Simulink Tutor Evaluation

We found several significant differences during the data analysis for our 4P model, and we observed several non-significant mean comparisons—meaningful observations that can potentially provide guidance for instructors trying to improve their instructional materials and researchers seeking to conduct experiments involving comparison of multiple instructional materials.

5.2 Qualitative:

The students involved in this study were asked to provide an input regarding their experience with the tutor through a survey. The answers to the survey questions brought to light areas where the tutor can be improved. These areas include voice used, video speed, game quality, and material details that should be included. This evaluation can help improve the tutor so that it meets the students' needs. In this way, the production is student-centered, and it involves them in the process of creating the applications.

Some of the comments from the students in the control group were as follows: "[I] didn't find the learning module very helpful—had seen this for many years beforehand, and the material wasn't presented in a new or intriguing way" and "[I] felt it really hard to concentrate on if I didn't feel as if I was learning anything new." These comments clearly show the need for change in the lecture method of teaching.

Open-ended responses were collected from the students while testing the Simulink tutor for programming LEGO robots. Students found the use of Simulink tutor beneficial. One student said, "I felt like the presentation of information was fine, [and] I liked the idea of games instead of simple tests." Students indicated that the tutors were fun and enjoyable. Another student said "the Simulink robot labs were definitely my favorites so far. The programing was very informative and well taught." Student comments also indicated that the Simulink tutors provided a challenging and problem-solving environment.

The instructors conducting the learning modules reported another benefit of the tutor: a shift in the type of questions the students asked while working on their assignment. The students in the experimental sections asked more questions about the logic problems in their assignment, while the students in the control sections required more guidance with the interface.

6. Conclusion:

Students who feel overwhelmed with lecture material need additional support by refreshing their understanding of the prerequisite concepts upon which the course is built. A concept tutor is a supplemental step-by-step learning tool with a game and a self-assessment measurement incorporated. It can cater to a class with any number of students. The instructors can customize the content of the concept tutor according the course or chapter requirements and learning objectives. Our work explains the development, implementation, and evaluation of a Simulink tutor and evaluates the effectiveness of the concept tutors using a 4P model. Both the qualitative and quantitative results show that the students enjoyed the concept tutors. We found that students who used the concept tutors perform and learn better than the students who did not. Also, students who use the concept tutors perceive themselves as working with higher levels of concentration. The higher concentration when learning a concept could generate interest and lead to better understanding of the concept. The quantitative results for perceived subject learning of the experimental group could suggest that the students have gained a better understanding of the topic. The higher scores of concentration on the topic and higher order cognitive skills for the students exposed to the concept tutor could be factors for their better performance. We hope that our work can encourage instructors to create more concept tutors to teach complex engineering concepts to improve students' understanding of concepts and problem-solving skills.

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