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An Update Regarding the Pedagogical Efficiency of Continuous vs. Discrete User Interactions with Computer Simulations

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An Update Regarding the Pedagogical Efficiency of Continuous vs. Discrete User Interactions with Computer Simulations

Abstract

Computer-based simulations and other enrichment media have become key components of the modern classroom. In this work, a computer-based simulation with two different methods of interaction was tested. The first interface, “discrete input,” involved entering desired parameters with a keyboard and requesting an updated output with a button click. The second, “continuous input,” involved setting the desired parameters using interactive sliders with the output updating continuously and immediately. Sixty-two test participants explored the dynamics of a vehicle suspension when hitting a “bump” using one of the two interfaces. Results suggest that the objective learning of the students using the continuous interface, as measured by four assessment questions, was improved with a 14% higher mean score versus the students using the discrete interface. A one-tailed test of the results suggests a statistically significant difference among the cohorts and a medium effect size ($p = 0.0087$, $d = 0.63$). In addition to the difference in learning attainment, on average, the higher performing users of the continuous interface also spent less time running simulations to build their understanding ($p = 0.043$). The study also suggests that users of the continuous interface report more confidence and self-perceived a higher level of attainment or understanding than users of the discrete interface ($p = 0.027$). Future analysis of the current data will explore how other dimensions impact the objective performance attainment with the different interfaces. Results from this study and future studies could be important in the investment and design of future computer-based labs and simulation experiences for active learning classrooms.

Introduction

Computer-based simulations, interactive textbook simulation exercises, and on-line courses with interactive content have become key components of modern education, boosting student interest and learning outcomes relative to conventional lecture-based classes. Many examples of these computer-based teaching tools exist, and the manner of student interaction with simulation programs can vary from something as simple as text input to more advanced methods such as software-implemented sliders or graphical “what-you-see-is-what-you-get" input interfaces. Computer-based simulations as an augmentation to traditional narrative course materials (e.g. print or digital textbooks) can be an important resource in an active learning environment. Gen Alpha students (those born in or after 2010), often referred to as “digital natives,” have never known a world without an iPad. Many have also experienced education with one-to-one (1:1) device or technology programs in place. A 2017 report [1] found that more than 50% of K-12 teachers taught in 1:1 classroom environments and a meta-analysis of 15 years of research studies [2] reported increased student engagement and persistence in 1:1 classrooms and suggested the increased use of student-centered pedagogies in 1:1 technology-enriched classrooms may have contributed to the increased engagement.

In an exploration of the effects on learning owing to the move from print to digital textbooks, one study [3] reports that today's learners prefer reading digitally and have an increased likelihood of reading or engaging with digital vs. print content. However, the study also reports that while there was no statistical significance when measuring the students' ability to identify main themes when reading across different media, it also found that students were much better at recalling other relevant information when reading in print versus a digital medium. Computer-based simulations could play an important future role in meeting digital natives in their "comfort zone" while providing the support to help them draw connections and develop a more complete understanding of the subject matter.

In a previous study [4], the authors explored different methods of interacting with computer simulations and their effect on student comprehension and efficacy beliefs. Two different methods of interacting with a simulation were compared. The first, which we call "discrete input," involved typing the desired parameters of a simulation in input boxes and then pressing a simulate button. The second, which we call "continuous input," involved setting the desired parameters using sliders while the output was continuously and immediately updated, obviating the need for a simulate button. The first method is much simpler to program and quite common in browser-based simulations, but the authors hypothesized that the second method would result in superior intuition of cause and effect relationships. This previous study did suggest that continuous, slider-based inputs were superior to discrete, text-based inputs for teaching phasor concepts, however a power-test indicated that sample sizes were insufficient to achieve statistical significance of the apparent results. Additionally, during the presentation of the results at an ASEE Computers in Education conference session, questions arose about the time it takes for a student to create a scenario in each simulation, and it was hypothesized that the difference in performance could have resulted from students using the continuous interface running more hypothetical scenarios or explorations during the fixed time study.

Stemming from the findings and open questions from the previous study, the authors developed a new simulation program to explore the impact of the various interfaces. The software allows users to explore second order models of the transient response of an automotive suspension. The software exists in a discrete and continuous form and was designed to make more direct, quantitative measures of the students' interactions with the simulation environment and the amount of time or effort they spend exploring virtual models and scenarios to understand a concept or relationship. The tool measures the students' self-efficacy beliefs with respect to their knowledge gained from using the tool, and objectively measures their understanding of the concepts as well as their confidence in their understanding.

The Methods section details the study instruments and the software tools developed. The Results section provides details on the recorded differences in student learning attainment as measured by student performance on the interactive posttest. Multiple factors affecting student performance including time spent exploring the software tool and interface type (continuous vs discrete) were explored. The new direct metric of student interaction time combined with the increased sample size afforded by the change in topic inform the analysis regarding whether the added cost and development time needed to provide interfaces such as continuous sliders for simulation inputs are justified and have a direct impact on learning. The paper concludes with a discussion of findings based on the initial results and next steps for the work.

Methods

For the exercise under test, students learn about the purpose of an automobile suspension system and how damping and stiffness parameters for the suspension can be tuned to vary overall vehicle dynamics to ultimately improve the handling of a moving vehicle as well as the comfort of passengers in the vehicle by affecting the vertical and angular displacements of the body of the automobile. The provided tutorial examined the vertical displacements of the car as it goes over a bump, known as its step response. The tutorial explains the concepts of final vertical displacement, maximum overshoot, period of oscillation, and rise time as key parameters by which the response of the suspension could be quantified. Following the reading assignment of the brief two-page tutorial, students were given access to an interactive computer model to develop their intuitive understanding of the two main parameters that affect suspension performance: spring tension and damping coefficient. Students were given access to one of two different user interfaces for the computer interaction (continuous or discrete) and their performance was used as the basis for measuring the pedagogical efficacy of the interface. The remainder of this section details the procedure for conducting the survey and an explanation of the questions included in the interactive survey instrument.

Step 1: Informed Consent and Written Tutorial

The instructor discussed the study procedures and expectations and provided students with an informed consent document. Students who agreed to participate were provided access to a PDF tutorial with a link to either the continuous or discrete simulation tool. Assignment was random with roughly half of the group using each tool. Directions on how to access the simulation tool were embedded in the tutorial and provided at the end. The time students had to read the tutorial was not measured or controlled.

Step 2: Use of Computer Simulation Tool with Embedded Survey

After opening the simulation tool, students provided demographic information in questions 1-4. Following the demographic questions, students were presented with the suspension simulation interface and a question to demonstrate their understanding of the concepts and interactions discussed in the tutorial and explored via simulation. A total of four scenarios and queries of the students' comprehension were presented in questions 5-8. Following each conceptual question, students were asked to rate their overall confidence in their answer in questions 5a-8a. The time students spent using the interface and answering each question was measured and recorded by the simulation software. Students were instructed to spend as much time as they wished with the tool to answer the questions.

Figure 1 shows the continuous and discrete interfaces, for the first question posed in the simulation tool. The four learning comprehension questions are listed below the figure and an explanation of the Likert scale used to measure student response confidence is provided.

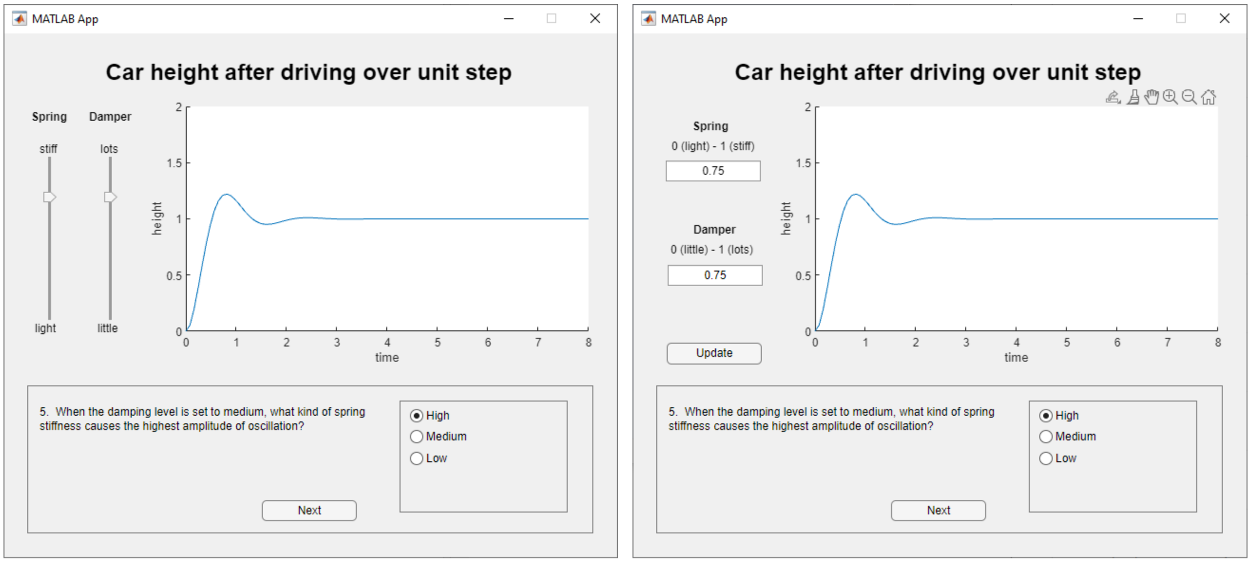

Figure 1 - User interfaces for the automobile suspension computer-based simulation tool, with the continuous interface at left, and the discrete interface to the right.

Simulation questions included:

5. When the damping coefficient is set to medium, what kind of spring stiffness causes the highest amplitude of oscillation?
6. With the spring stiffness level set to medium, what kind of damping causes the highest amplitude of oscillations?
7. What settings give the highest frequency of oscillations?
8. What settings create the greatest amount of overshoot (that is, the highest level that the car goes, even if only temporarily)?

5a. How confident are you about your previous answer? *(Repeated after each question above)*
Likert scale: (1 = High, 2 = Somewhat high, 3 = Neutral, 4 = Somewhat low, 5 = Low)

Step 3: Complete Survey Summative Questions

Following completion of the simulation and answering the four objective learning questions, students were asked two summative questions (questions 9 and 10) regarding their estimation of their overall performance on the questions and their enjoyment of using the simulation software. Upon answering these questions, their collected, anonymized data was uploaded automatically to the host server by the simulation tool.

Results

The primary purpose of this effort was to determine if the continuous user interface resulted in demonstrable improvement in student learning attainment versus students using a discrete interface. The exploration of this question occurred in the context of an interactive computer simulation that included four questions about vehicle suspension motion as a function of varying spring stiffness and damping coefficients. Unlike the previous study, time constraints were removed to allow for the additional time it may take students to use the interfaces. Secondary questions involve exploring whether students reported greater confidence in their responses, or greater enjoyment of the exercise, based on the varying interfaces. Lastly, dimensions regarding the students' usage of the interface to learn, as measured by time spent using the tool per question, were explored. To explore the significance of any of the reported trends observed, the Discrete user cohort was considered as the baseline performance group and a one-tailed t-test was used to determine whether improvements through use of the Continuous interface were of significance.

Sixty-two students participated in this study, with thirty respondents using the continuous interface and thirty-two respondents using the discrete interface. Table 1 details the demographic breakdown based on the simulation tool used and Figure 2 shows the results of the respondents' self-assessment with respect to enjoyment and self-estimated performance.

Table 1 - Demographic information of survey participants.

Characteristic	**Continuous**	**Discrete**
Class Year	12 Fr, 2 Soph, 2 Jr, 14 Sr	14 Fr, 2 Soph, 1 Jr, 15 Sr
Major	6 ECE, 24 ME	10 ECE, 22 ME
Gender	29 Male, 1 Female	29 Male, 3 Female

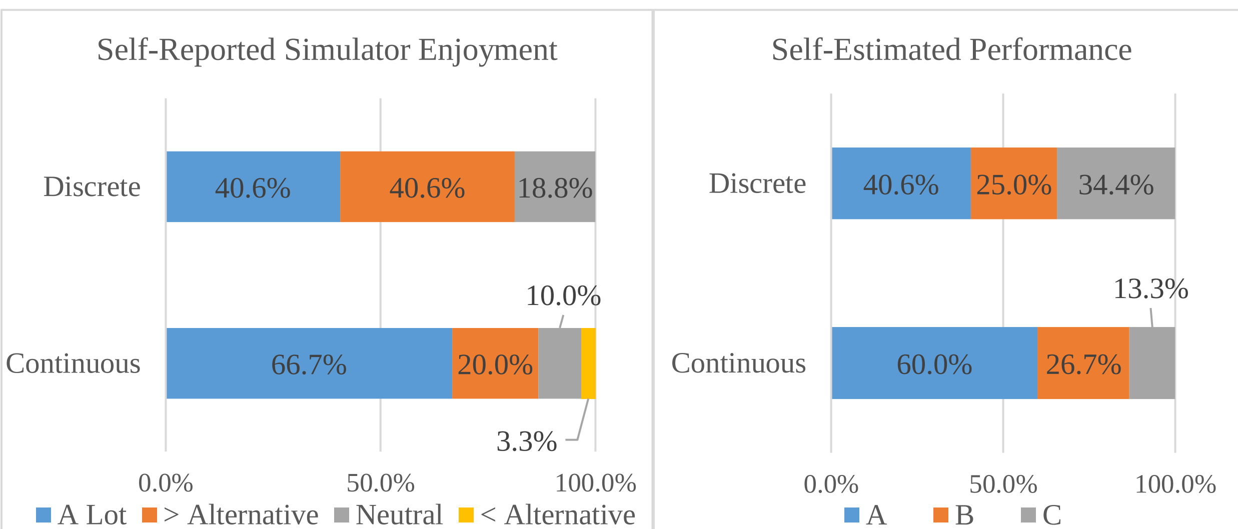

Figure 2 - Self-reported enjoyment of use of the continuous and discrete simulators (left), and self-estimated performance on the objective learning questions for users of each tool (right).

The descriptive statistics in Table 1 are provided to inform about the groups who participated in the study, to show the breakdown that resulted from the random assignment of participants into the two test groups, and to show the limitations of the current study with respect to the ability to analyze results based on specific demographic characteristics. The results in Table 1 and Figure 2 demonstrate that the demographics of the two groups are similar in terms of breakdown based on gender and class year. However, the percentage of respondents from the ECE major is slightly higher in the discrete group than in the continuous group (~31% vs 20%). In regards to the student self-reported enjoyment of using the simulation tools to learn, the responses from the users of the continuous group are skewed higher than that from the discrete group. The average self-estimated grade from the Continuous group was around a B+ and the average self-estimated performance from the Discrete group was a B. Using a one-tailed t-test, the resultant p-value of 0.027 suggests a self-perceived higher level of attainment or performance by the Continuous group. When analyzing the students' self-reported enjoyment of the computer based simulation, it is important to recall that each student only experienced one interface, and the responses greater than or less than the alternatives are in reference to learning about the concept through traditional classroom techniques that do not involve a computer-based simulation.

Table 2, below, shows results for the study. The percent of respondents who answered each question correctly is reported along with the descriptive statistics of the time spent running scenarios and answering the questions, the mean confidence in the response on a scale from 1 to 5, with 1 indicating highest confidence, and the standard deviation of the confidence responses. The delta or difference between each performance metric computed by subtracting the discrete results from the continuous results is perhaps the most illustrative lens for exploring the results.

Table 2 - Table of objective performance results from users of the simulation tools.

Question Performance	Percent Correct [%]	Mean Time [s]	Median Time [s]	Std Dev Time [s]	Mean Confidence	Std Dev Confidence
Q1 Cont.	86.67	66.05	42.26	60.58	1.63	0.93
Q1 Discrete	71.88	81.35	75.91	44.83	2.19	1.15
Q1 Delta	**14.79**	**-15.30**	**-33.65**	**15.76**	**-0.55**	**-0.22**
Q2 Cont.	90.00	24.33	19.43	21.27	1.40	0.77
Q2 Discrete	81.25	29.81	24.96	16.80	1.59	1.01
Q2 Delta	**8.75**	**-5.48**	**-5.53**	**4.48**	**-0.19**	**-0.24**
Q3 Cont.	93.33	25.66	22.48	15.19	1.27	0.52
Q3 Discrete	90.63	44.64	35.48	35.79	1.53	0.76
Q3 Delta	**2.71**	**-18.98**	**-13.00**	**-20.60**	**-0.27**	**-0.24**
Q4 Cont.	90.00	41.34	29.24	35.30	1.87	0.94
Q4 Discrete	59.38	35.26	30.40	23.01	1.97	1.00
Q4 Delta	**30.63**	**6.08**	**-1.16**	**12.29**	**-0.10**	**-0.06**

In examining Table 2, it is interesting to note that for each of the four questions, the performance by the Continuous group is higher than that of the Discrete group. Additionally, it is worth exploring the performance difference of 30% for question 4. Question 4 involves one of the more complex relationships—a connection of the concepts explored by questions 1 and 2. Additionally, for all of the questions, the continuous group reported higher confidence in their responses (lower number is higher confidence) and had less variance in the reported confidence than the Discrete interface users. For three of the four questions, the users of the Continuous interface spent less time exploring the scenario and answering the question. The exception to this trend, was Question 4. It is unclear why, but one hypothesis is that the complex connection of the two factors explored in the question was not as obvious in the Discrete interface so the users may have stopped exploring sooner. Another possibility is that they were simply tired with using the interface.

Figures 3 and 4 below show the mean of the composite performance on the four objective learning questions and the mean total time spent exploring scenarios and answering the questions.

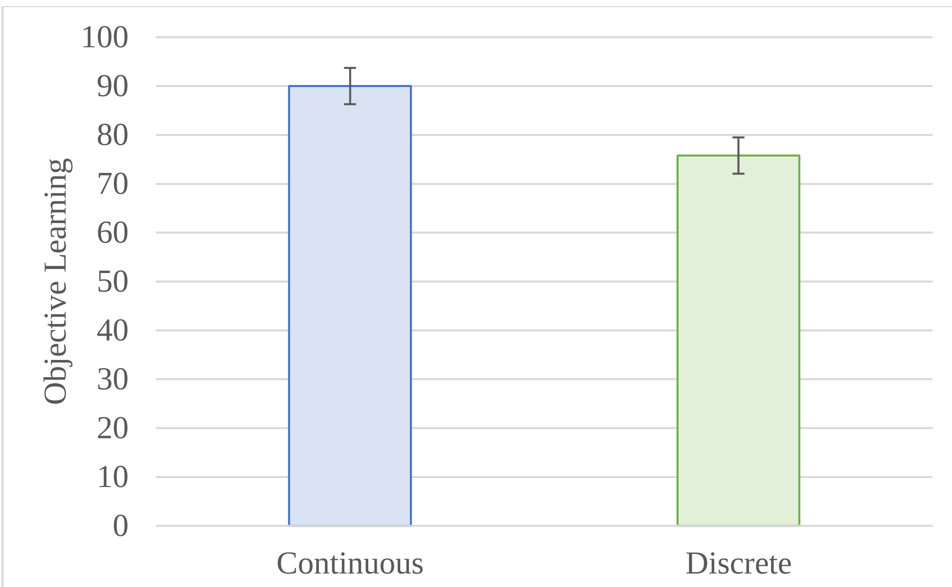

Figure 3 - Objective learning as measured by the mean overall score on four survey questions for users of the continuous and discrete simulation interfaces, with standard error (SEM) indicated.

Figure 3 shows the mean performance or objective learning scores for the two groups, with the error bars for each representing the calculated standard error. The average objective learning score for students using the continuous app was higher than the score for the students using the discrete app. Additionally, the performance variability was wider among the users of the discrete app. A one-tailed t-test resulted in a p-value of 0.00867, so it is suggested that the observed performance advantage of the continuous interface is statistically significant.

Figure 4 shows the total time students spent exploring the simulation and answering the objective learning questions for the two groups, with the error bars for each showing the calculated standard error. The average time spent answering the questions was lower for students using the continuous app, and their objective learning average was also greater. Examining the error bars shows a wider time performance variation among the continuous users. A one-tailed t-test resulted in a p-value of 0.0432, so it is also suggested that the observed time advantage of the continuous interface is statistically significant.

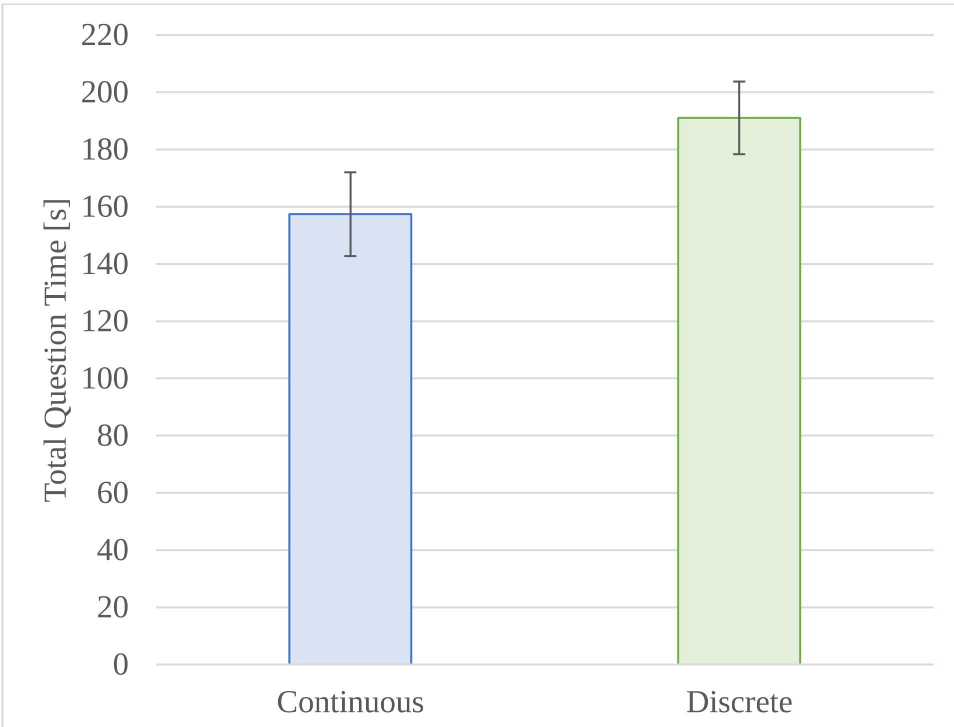

Figure 4 - Comparison of mean time exploring the interface and answering four questions for users of the continuous and discrete simulation tools, with standard error (SEM) indicated.

Conclusions

Initial tests conducted using a vehicle suspension simulation tool utilizing either a continuous user interface or a discrete user interface suggest that the hypothesis that simulations employing continuous user interfaces result in better learning outcomes than simulations with a discrete user interface has merit. The results show that the mean performance of the users of the continuous interface was approximately 14% higher than users of the discrete interface with a p-value of 0.00867. The Cohen's effect size $d = 0.627$ for the study, indicating a medium effect size. The power for the result of the one-tailed t-test with that effect size is 0.787, close to the suggested target of 0.80. In addition to the improvement in learning attainment, the study also suggests that users of the continuous interface report more confidence (higher mean confidence score for each of four questions) and self-perceived a higher level of attainment or understanding than users of the discrete interface. Users of the continuous interface also reported more enjoyment of the exercise.

Future data collection and analysis of the current data will explore how dimensions (major, class year) impact the objective performance attainment with the different interfaces. Unlike the previous study, students were given an unrestricted amount of time to complete the exploration to account for the fact that running a scenario in the discrete software would take more time to setup. Even though this time was "unrestricted" by the study parameters, students' willingness to spend the time, particularly when they observe others in the class have already finished, could have been an influencing factor. Lastly, there is an opportunity to explore relationships between performance and confidence in performance, based on the many dimensions discussed. Results from this study and future studies could be especially important in the investment and design of future computer-based labs and simulation experiences for active learning classrooms.

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