Pedagogical Efficiency of Continuous vs. Discrete User Interaction with Computer Simulations

Abstract:

Pedagogical efficiency of computer-based simulations is explored for simulations using one of two types of user interface: discrete, where the user inputs numerical and text based parameters directly, or continuous, where highly interactive features such as software-implemented sliders determine the simulation parameters. This investigation builds on previous work in which it was shown that differences in objective learning between a discrete version of a phasor simulation app and a continuous version were statistically insignificant. Based on an expanded cohort, it was determined that for the case of students age 19 or younger, the superiority of the continuous version of the simulation relative to objective learning very nearly attained statistical significance with a p-value of 0.051. For older students no statistically significant difference in objective learning scores between the continuous and discrete versions of the simulation was measured. Finally, it was shown that for younger students, self-assessed knowledge was lower for the continuous version of the simulation than for the discrete version, in direct opposition to their actual objective learning performance.

Introduction:

Computer-based simulations and simulation games [6], as well as on-line courses with interactive content, have become an important component of modern education, boosting student interest and learning outcomes relative to conventional lecture-based classes [1]-[4]. 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 virtual reality interfaces [5]. Simulations that make use of discrete inputs such as numerical values or text require little effort for the development of the user interface compared to simulations that update while the interface is being manipulated. As a result, this style of interface is common in simulations used for education, with applications in chemistry [7], biology [8], electronics [9], and mechanics [10], to name a few. More advanced user interfaces can be realized using sliders and virtual knobs to enable students to create continuous values of inputs to a simulation, allowing for greater interaction between students and the simulation, ostensibly leading to better learning. Clearly, the investment in development for continuous interfaces is higher than that for discrete input user interfaces; however, in areas such as power amplifier design [11]-[12], HVAC, and control system design [1], the more sophisticated continuous user interface provides students with a richer method to interact with dynamic systems.

Research by Salise [13] on the characteristics of effective computer tools for teaching emphasizes that user interactivity with the simulations in many modes can increase student engagement and improve learning. Use of continuous inputs such as sliders, knobs and mouse-based selection of data from operating curves all serve to keep students engaged with the simulation program, enhancing the potential for learning. In a study by Fang and Tjavadi [14] it was shown that a computer simulation with continuous inputs (sliders) resulted in higher cognitive functioning based on the Revised Bloom Taxonomy than classical textbook based courses. While no comparison to discrete input simulations was made, Fang does emphasize the need for a rich interface environment to maintain students in an active learning mode.

Currently there are no conclusive studies indicating which method of student interaction with simulation software, continuous or discrete, results in the best learning performance. Since it is more difficult to develop user interfaces with continuous input, as compared to those using discrete input data only, this question is a relevant one both from the aspect of learning expectations and economic implications. In a previous study by the authors, discrete input was compared to slider-based, or continuous input, for a simulation tool that was developed to help students learn phasor analysis. While the study seemed to indicate that indeed the continuous user interface was superior relative to learning outcomes for students, statistical significance of the results could not be demonstrated. In the current work, the study was expanded to include a greater number of test subjects to see if statistical significance of the results could be established.

The following paper documents this expanded study and consists of three sections; Methods, Results and Conclusions. In the Methods section, the phasor simulation experiment, and the assessment tool used to measure student learning are both described in detail. Objective learning measurements, as well as subjective student assessed measures of learning and simulation usefulness, are presented for discrete and continuous user interfaces in the Results section. Finally in the Conclusions section, additional questions concerning the characteristics of simulation user interfaces are summarized for future work.

Methods:

Phasor analysis uses complex numbers as a means to represent waveforms in electronic systems, steady state mechanical vibrations, and can even be used to perform kinematic analysis of linkages for mechanical design applications. In this work, students learn about phasor concepts using one of two phasor simulation apps: one simulation in which the user enters phase and magnitude information manually (discrete user interface) and the other in which the user slides a phasor around in the complex plane with a mouse (continuous user interface). Following a period of simulation-based explorations, students are given a brief quiz to assess their knowledge of phasors, providing a basis from which to measure the pedagogical efficacy of continuous vs discrete user interfaces. In the following discussions, procedures for conducting the study are detailed, followed by an explanation of the questions included in the quiz.

Step1: Written tutorial (10 minutes)

At the beginning of the experiment the instructor passes out a 3 page tutorial to the class, (tutorial available at https://www.jimsquire.com/research/phasors/tutorial1.pdf). The first two pages of the tutorial introduce the use of phasors to represent sinusoidal waveforms, and in particular how the phase angles and magnitude of sinusoids "look" in the complex plane.

Step 2: Simulation based exploration of phasors (10 minutes)

At this point, students download either version “C” or “D” of a phasor simulation app from the instructor’s website, then, based on prompts from page three of the tutorial, they explore different characteristics of the phasor. Program version “C” features a continuous user interface in which the students can change phase and magnitude values by “sliding” the terminal point of the phasor around the complex plane with their mouse (see Figure 1). The user interface shows the corresponding amplitude and phase information on the right hand side of the screen in real time, while a time domain plot of the sinusoidal wave the phasor describes is plotted down the lower left hand side of the screen. Program version D has a discrete user interface in which the students must change values of the phase and magnitude using two dialog boxes at the right side of the screen. To see the effects of the parameters they entered, students must then hit the “Enter” button at the lower right side of the screen (see Figure 2). During prompted exploration, students are asked to look at what happens to the waveform as phase is changed, then as amplitude is changed. Additionally the students are asked to play with the interface, setting the phasor to a particular configuration to see if they can predict the resultant waveform.

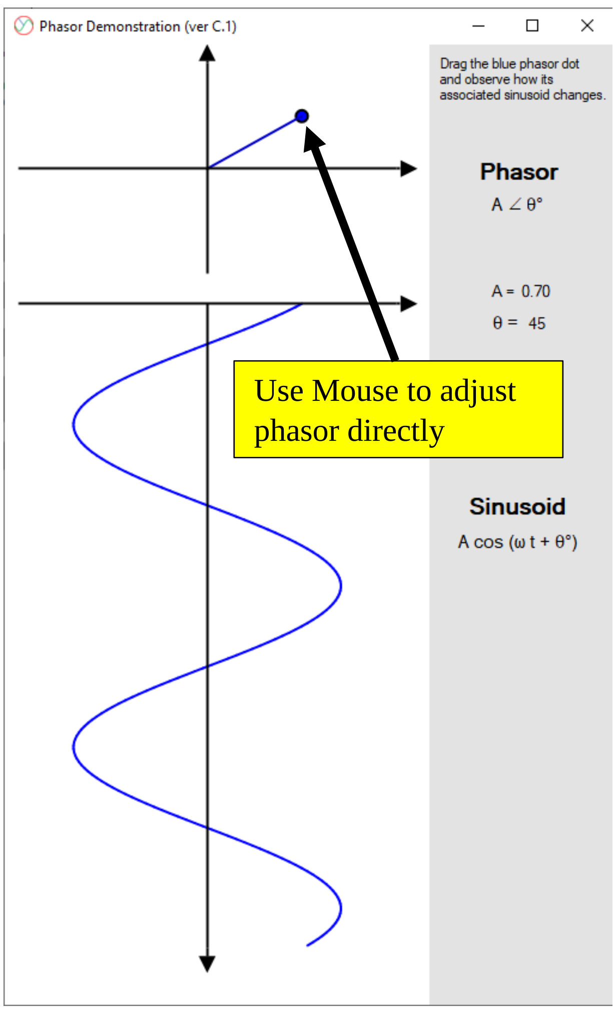


Figure 1: Phasor Simulation version C, with Continuous User Interface

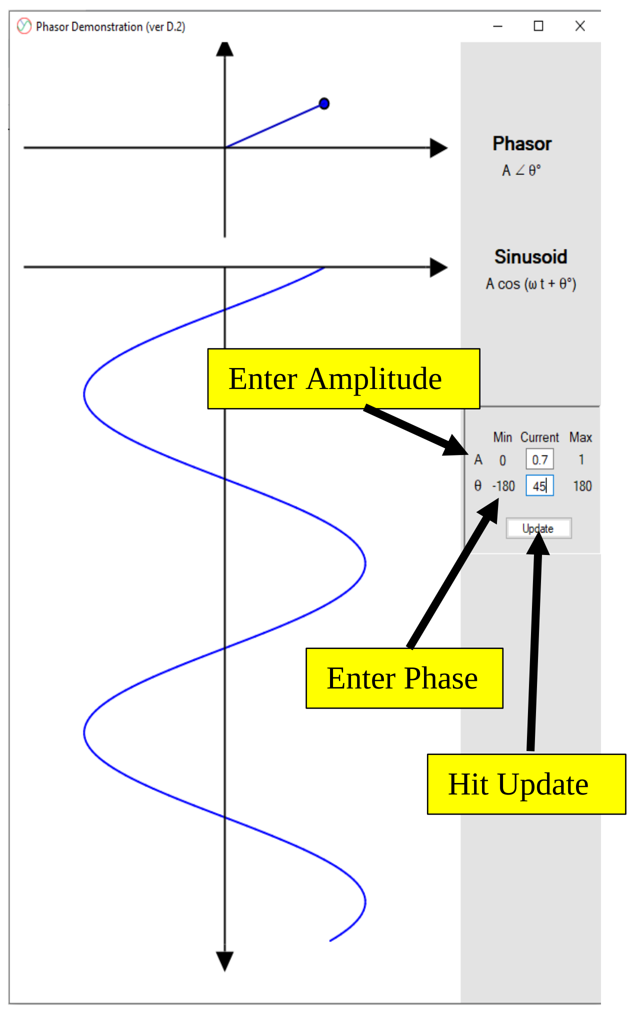


Figure 2: Phasor Simulation version D, with Discrete User Interface

Step-3: Take the quiz (10 minutes)

The quiz (available at https://www.jimsquire.com/research/phasors/questionnaire1.pdf) consists of 15 questions, all of which must be completed without using the simulation. Questions 1-5 provide background information such as which version of the simulation the student used (C or D), major, class year, age and gender. Question 6 provides an assessment of the students' subjective knowledge of phasors (i.e. how well do students *feel* they understand phasors), while question 7 asks students to subjectively rate how useful the simulations were in learning the phasor material. Both questions use a Likert scale to capture students' beliefs about a particular question. For example on question 6:

> "*How well do you feel you understand the relationship between a phasor and its associated sinusoid?*"

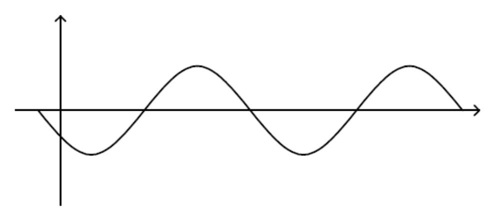
Students may choose from among 5 answers:

a. Not sure at all
b. Slightly confident
c. Fairly confident
d. Very confident
e. Extremely confident

Choice "a" corresponds to a numerical score of zero, and choice "e" corresponds to a value of 4.

Questions 8-14, are multiple choice questions on phasor concepts, and provide an objective measure of the students' knowledge of phasors. For example in question 9, the students are asked to match a sinusoidal waveform to one of a set of given phasors labeled A-F:

9. Circle the letter below of the phasor above corresponding to the sinusoid on the right
A, B, C, D, E, F



Finally, question 15 asks the students how effective they felt that simulations were for teaching phasor concepts when compared to more conventional techniques such as lectures and textbooks. This question amounts to a post quiz subjective assessment of value of simulations. In effect, did the perceived difficulty or simplicity of the conceptual questions on the quiz change students' opinions as to value of simulations for teaching abstract material such as phasors?

Results:

The primary purpose of this work was to determine if a continuous user interface could be demonstrated to promote objective learning with greater efficacy than a discrete user interface for the case of the phasor simulation app. The results of a previous study by the authors suggested that objective learning for students using the continuous app was superior to the case when students used the discrete app. With 91 students in this initial study, however, there was insufficient data to establish statistical significance for greater pedagogical efficacy of the continuous app. In the current follow up study, 137 students took part in the experiment, of which 75 students used the continuous version of the simulation app and 62 students used the discrete version.

In Figure 3, the average objective learning score is shown for the continuous app and the discrete app with error bars for each consisting of the calculated standard error. While the average objective learning score for students using the continuous app was higher than the scores for students using the discrete app, there is considerable variability in the results as indicated by the size of the error bars. A one-tailed t-test resulted in a p-value of 0.14, so it cannot be concluded that the observed advantage of the continuous interface is statistically significant.

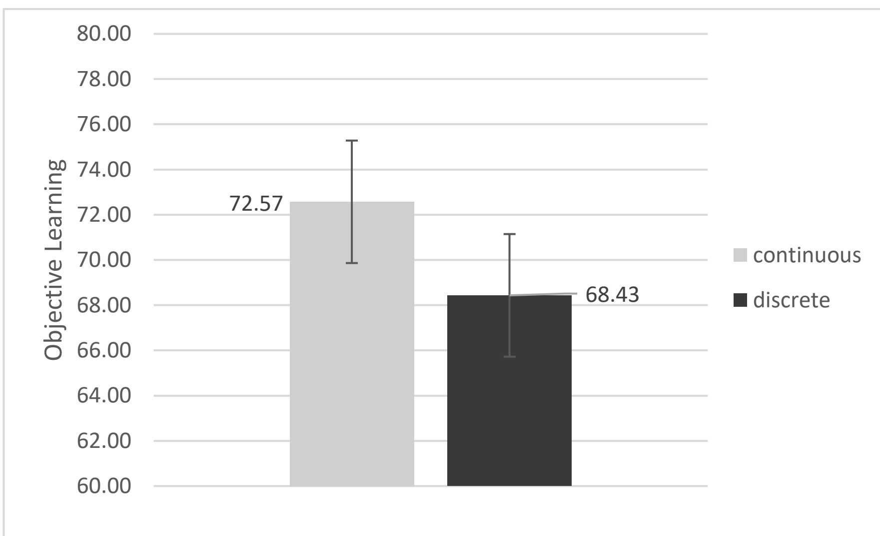


Figure 3: Average Objective Learning Scores for Continuous and Discrete User Interfaces

Interestingly, if the data is parsed according to the age of students, with one group consisting of students 19 or younger, hereafter referred to as underclassmen, and another group consisting of students 20 or older, and hereafter referred to as upperclassmen, a different trend emerges. As shown in Figure 4, objective learning scores for underclassmen strongly support the superiority of the continuous vs. the discrete app:

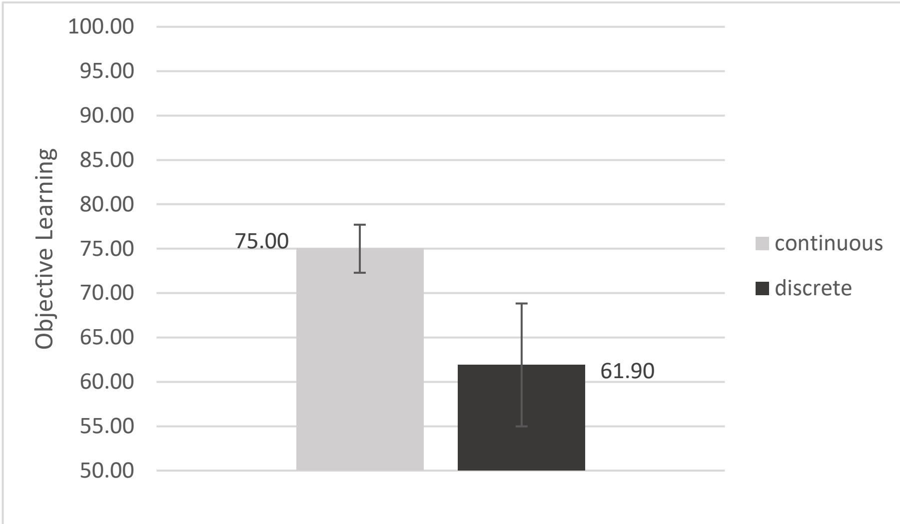


Figure 4: Average Objective Learning for Continuous and Discrete User Interfaces for Underclassmen

The significance level for a one-tailed t-test is p=0.051, coming very close to showing statistical significance for the superiority of the continuous app with underclassmen. In contrast, Figure 5 shows that the scores for objective learning in the case of the upperclassmen are not largely differentiated in the case of either the continuous or discrete interfaces.

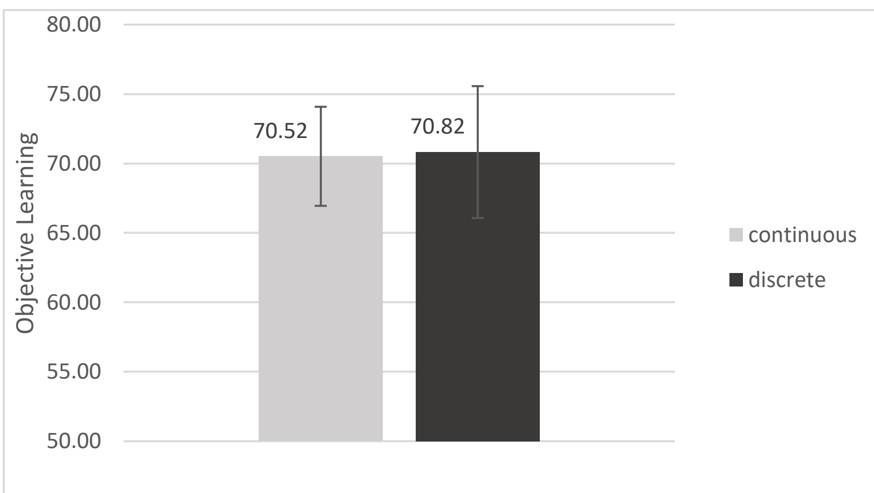


Figure 5: Average Objective Learning for Continuous and Discrete User Interfaces for Upper Classmen

In the upperclassmen case, the p-value is almost 0.50, indicating no statistical significance in the difference between discrete or continuous interfaces relative to objective learning.

More insight into the differences between underclassmen and upperclassmen in this study may be obtained by looking at the self-assessed learning scores and objective scores together as shown in Figure 6. Self-assessed learning (question 6) measures the confidence of students about their knowledge of phasor concepts following use of the phasor simulation apps.

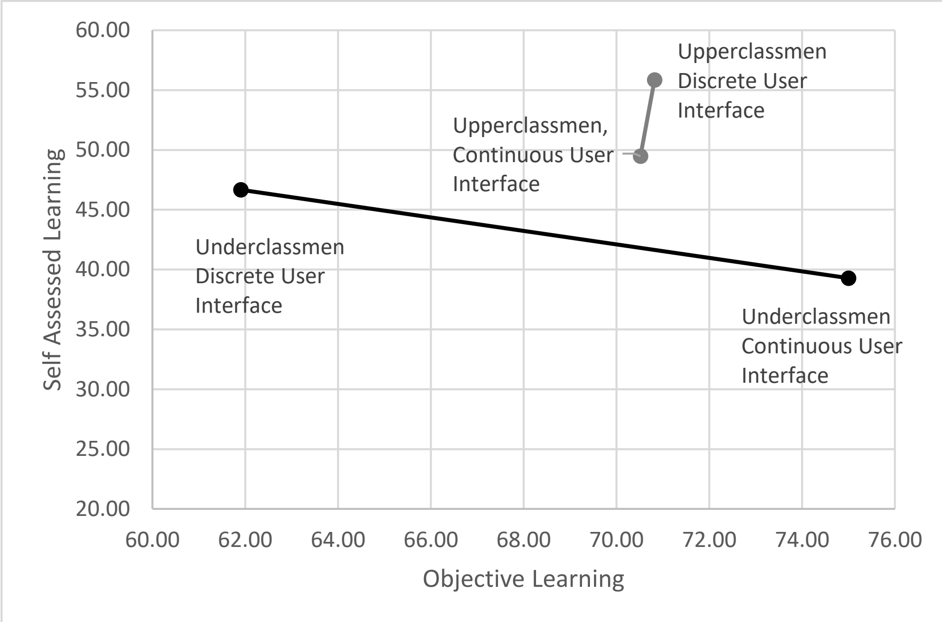


Figure 6: Self Assessed Learning vs Objective Learning for Underclassmen and Upperclassmen

When self-assessed learning scores are plotted against objective learning scores for underclassmen and upperclassmen, it is apparent that the objective knowledge of upperclassmen was largely independent of whether they used the discrete or continuous version of the simulation app. Additionally, self-assessed knowledge for the upperclassmen was consistently higher than that of the underclassmen, indicating that they were more confident of the knowledge they obtained from the simulations than the underclassman. Conversely, the objective knowledge of underclassmen was strongly dependent on the type of simulation used, with the continuous simulation app resulting in an objective learning score almost 13 points higher on average than the discrete version. Notably, self-assessed learning scores were lowest for the continuous simulation app even though objective learning scores were highest for underclassmen in this case. One possible explanation for this behavior is that the richer information content in the continuous simulation may cause anxiety and an associated lack of confidence in the younger students, while still aiding their acquisition of concepts. In contrast, more experienced students have a considerable history of coursework and analytical skills lending greater confidence regardless of the type of the simulation app.

Interestingly, student attitudes concerning the simulation apps consistently improved from their qualitative assessments made before and after the concept questions on the quiz about the usefulness of the apps, regardless of the version of the simulation app used or the age of the student. In Figures 7 and 8 qualitative assessments of the usefulness of the discrete app before and after answering conceptual questions are shown for underclassmen and upperclassmen respectively. Subsequently in Figures 9 and 10, usefulness assessments of the continuous app before and after the concept quiz are given for underclassmen and upperclassmen.

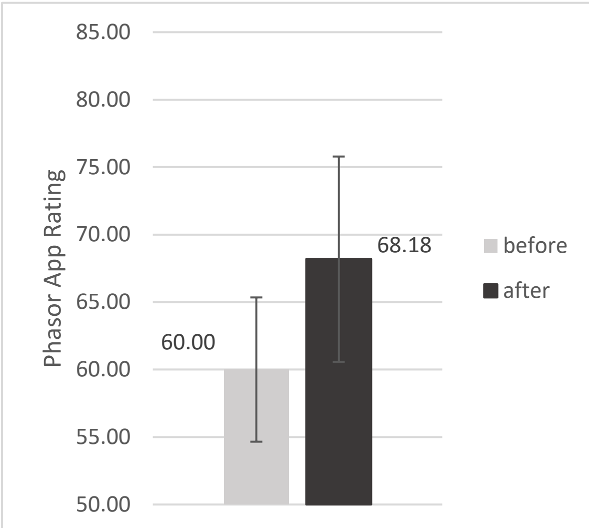


Figure 7: Rating of the Discrete Simulation App Usefulness for Underclassmen Before and After Conceptual Questions

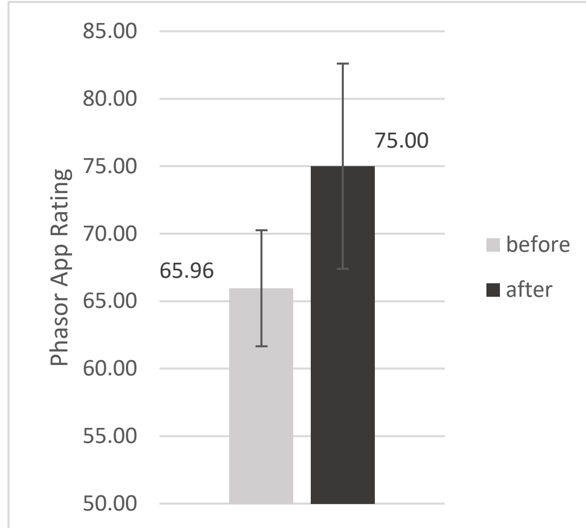


Figure 8: Rating of the Discrete Simulation App Usefulness for Upperclassmen Before and After Conceptual Questions

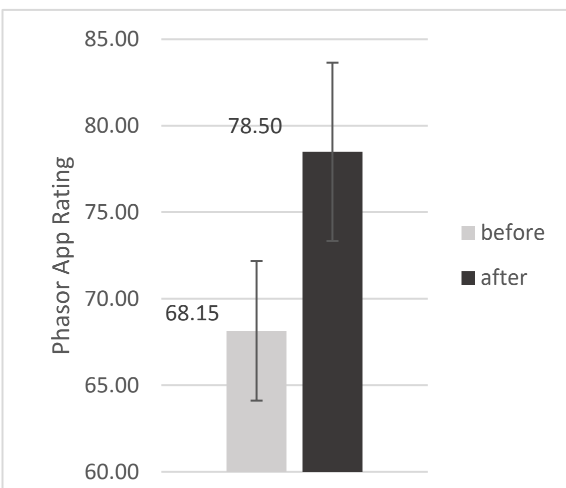


Figure 9: Rating of the Continuous Simulation App Usefulness for Underclassmen Before and After Conceptual Questions

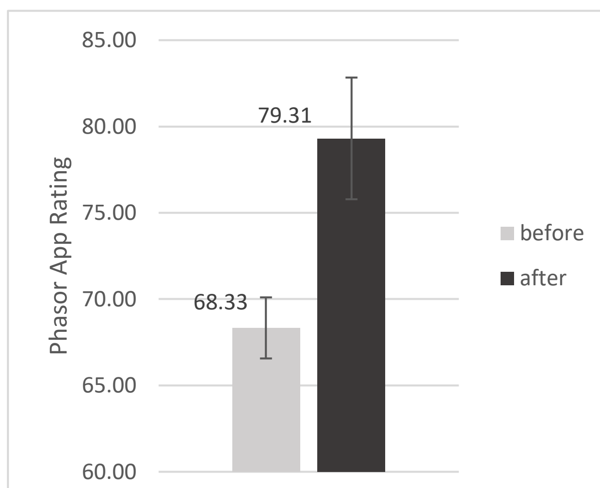


Figure 10: Rating of the Continuous Simulation App Usefulness for Upperclassmen Before and After Conceptual Questions

In all cases, students rated the simulation apps more highly after the conceptual questions on the quiz than they did before these questions, indicating that they felt the simulations were actually helpful in learning the phasor material. While variability in the data was large, in particular for underclassmen, the continuous app has the highest qualitative ratings for usefulness with a one-sided p-value of 0.003 for upperclassmen.

Conclusions:

In this work, data from phasor simulations utilizing either a continuous user interface or a discrete user interface were used to test the hypothesis that simulations employing continuous user interfaces result in better learning outcomes than simulations with a discrete user interface. While an earlier study by the authors suggested that this would be the case if a larger data set had been available, the additional data gathered in the current study showed that the differences between objective learning for simulations using a continuous interface versus a discrete interface were not statistically significant. Further investigation of the data showed that for underclassmen (students aged 19 or less), a p-value of 0.051 was obtained from a one-tailed t-test examining the hypothesis that the continuous user interface resulted in higher objective scores than the discrete user interface. Additional data showed that underclassmen exhibited less confidence than the upperclassmen in the study, consistently rating their knowledge of phasors after taking part in a simulation based tutorial as less than that of the upperclassmen. This phenomenon may have been influenced by prior learning experiences of the upperclassmen either with phasors in the case of electrical engineering students or with the familiarity of the upperclassmen with vector concepts. It is also possible that heightened mental arousal associated with a quiz for which underclassmen had no previous background allowed the younger students to better exploit the rich information stream available from the continuous user interface, resulting in higher objective learning scores for the continuous user interface than for the discrete user interface. In the future, additional data will be collected to examine age dependency on the efficacy of discrete vs continuous simulation interfaces, and to determine if statistically significant results can be obtained. An analysis of the power for the t-test comparing objective learning by underclassmen for discrete and continuous simulations, showed that a sample size of 80 will be required to obtain a significance level of .05 at a power greater than .8. Results from these studies would be especially important in the design of computer-based labs and simulation experiences for first year programs.

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