AC 2011-707: THE VALUE OF INTERACTIVE SIMULATIONS USED IN AN UNDERGRADUATE MATH CLASS

Seung Youn Chyung, Boise State University

Seung Youn (Yonnie) Chyung is a professor in the Department of Instructional and Performance Technology in the College of Engineering at Boise State University. She teaches graduate-level courses on evaluation methodology and e-learning. Her research interests include the development of self-regulated e-learning strategies for adult learners and the pedagogical use of technology.

Joe Guarino, Boise State University

Joe Guarino is a Professor of Mechanical and Biomedical Engineering at Boise State University. His research interests include educational aspects of cloud computing, vibrations, acoustics, and dynamics.

Marion Scheepers, Department of Mathematics, Boise State University

Educational Background: Ph.D. in Mathematics (1988) from The University of Kansas. Advisor: Fred Galvin.

Current Employment: Professor, Department of Mathematics, Boise State University, Boise, ID 83725

Rey DeLeon, Boise State University, Mechanical & Biomedical Engineering Dept.

Anthony Rey DeLeon is graduate research assistant with the Mechanical & Biomedical Engineering Department at Boise State University. His current research involves GPU-accelerated computational fluid dynamics. Past research included the software development of MATLAB simulations for abstract math concepts deployed on cloud computing resources.

Charles Adams, Boise State University

Charles Adams Undergraduate Research Assistant Mechanical & Biomedical Engineering Boise State University Boise, ID

Paul Williams, Boise State University

Graduate Researcher- Mechanical & Biomedical Engineering Boise State University Boise, ID

The Value of Interactive Simulations Used in an Undergraduate Math Class

Abstract

With Hewlett Packard grants awarded to Boise State University, we are working on developing best practices for creating and sustaining virtual learning and teaching communities through a cloud computing service (Blade servers) and enhancing student motivation and performance in Math by using interactive simulation programs. As part of the project, we have developed a series of MATLAB-based simulations delivered through our Blade servers to help students better conceptualize abstract Math concepts. During the fall semester of 2010, we implemented 12 simulations in a Multivariable & Vector Calculus class in which 117 students were enrolled. To better understand the overall program usability via Blade servers and the value of the simulations from the student perspective, we conducted an evaluation study and answered the following three questions: 1. How do students perceive the use of interactive simulations in their Math class? 2. How do students' motivational characteristics (e.g., intrinsic and extrinsic goal orientations and confidence levels in studying science, math and engineering) relate to their perceptions in using simulations during the Math class? and 3. What aspects of the simulation programs should be improved? The study revealed that about 74% of students rated the value of simulations as high or moderate. The simulations tend to be attractive to students with high intrinsic goal orientation, while their value perceptions were not related to students' extrinsic goal orientation and confidence levels. The data also showed areas for improvement, based on which we have generated a 'things to do' list to make the simulation programs more easily accessible and valuable to students in the future semesters.

Introduction

To effectively teach highly abstract concepts of Science, Engineering, and Mathematics, educators often seek ways to present theoretical abstract information in a concrete manner. One such method is to use simulations, and MATLAB™[1] has been widely used for developing computer simulations for students in the Science, Engineering, and Math classrooms. Several examples include simulations of flat fading[2], second order linear time invariant system[3], various topics in structural engineering[4], communication systems[5], autonomous robotics[6], and power electronic curcuits[7]. Educational researchers have shown advantages and positive effects of using MATLAB simulations in Science, Engineering, and Math classrooms[8, 9]. For example, one study showed that students in a Digital Signal Processing course who used a MATLAB simulation performed significantly better on an achievement test than those who did not use it.[10]

It is common for colleges to make MATLAB-based simulations available to students in their computer labs. Our institution, Boise State University, has offered such simulations in our labs until we received two grants from Hewlett Packard in 2009 and 2010 to create a cloud computing system consisting of 16 Blade servers. These Blade servers, which are stripped down versions of regular workstations to conserve space and power, offer software as a service that constitutes our cloud computing resource. This *application cloud* provides users with remote access to software applications and facilitates shared use of the applications. The ultimate goal with this computing system is to develop virtual learning communities among a wide demographic (K-20) and geographic range of audiences. With this cloud technology, students have access to the learning resources we have developed not only from our computer labs but also from anywhere through the Internet (Figure 1). We, a multidisciplinary team of three faculty members and three graduate students from the departments of Mechanical Engineering, Mathematics, and Instructional and Performance Technology, developed a series of MATLAB-based simulations and implemented them in a Multivariable & Vector Calculus class to improve students' conceptualization of abstract Math concepts. To better understand the value of the simulations from the student perspective and to improve their overall quality, we conducted an evaluation study. The following sections of this paper provide examples of the simulations we used and the results of the evaluation we conducted in the Math class.

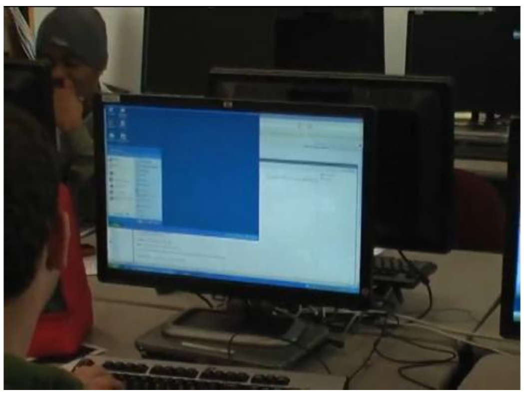

Figure 1. Students logging onto a Blade server.

Simulation Exercises

We developed 12 simulations (as listed below) and asked students in the Multivariable & Vector Calculus class to use the simulations as required homework assignments. The programs allow students to collaborate with classmates (up to three users) through an individual Blade server. While collaborating with classmates, each student creates his or her own username, giving the student a sense of ownership of their individual input. As shown in Figure 2, a username prompt appears at the beginning of each simulation. In the following, we will provide detailed descriptions about three of the 12 exercises used in the study.

1. Curl
2. Directional Derivatives
3. Divergence
4. Double Integrals
5. Gradients
6. Line Integrals
7. Lines and Planes
8. Module 4 Review
9. Moments of Inertia
10. Tangent Planes
11. Triple Integral Boundaries
12. Vector Valued Functions

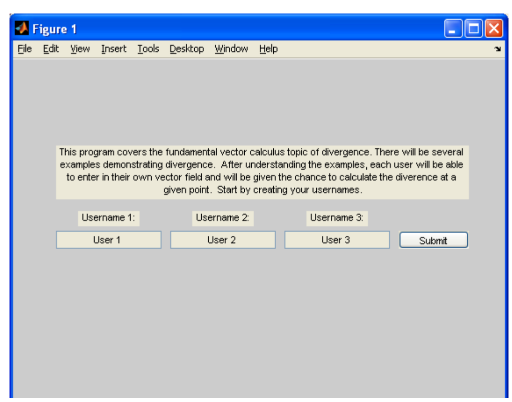

Figure 2. Each student enters a username.

Curl Exercise

The Curl exercise is designed with a guided discovery approach. After users launch the program, it provides a description of curl tying together the mathematical operation and concept with the physical meaning (Figure 3). Then, users are encouraged to visualize the curl of the vector field plot (Figure 4) before the plot is generated (Figure 5).

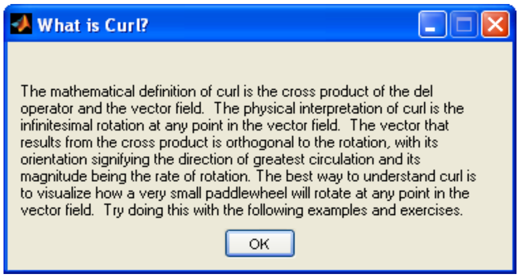

Figure 3. A description of Curl.

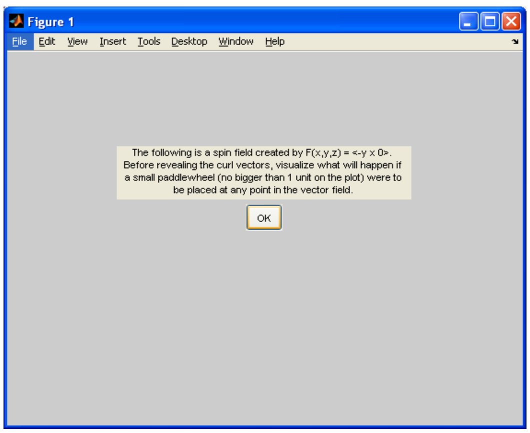

Figure 4. Guide to visualize the curl of the vector field.

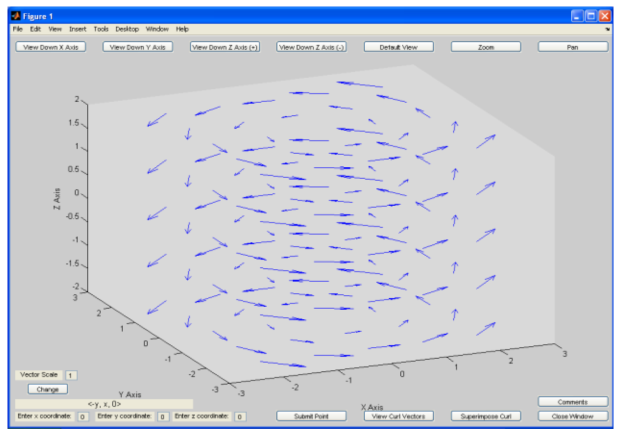

Figure 5. Vector field plot generated.

Using the toggle buttons located at the bottom of the screen, the users can observe the curl vectors of the vector field either in isolation (Figure 6) or superimposed on the original vector field (Figure 7). The users can then choose a point in the vector field. The program randomly prompts one of the users for an exact calculation of the curl at the chosen point. Once the correct answer is entered, the users can continue on to similar examples that encourage the users to visualize the curl first and then perform the calculation.

Once all the examples are completed, the users are asked to create their own vector fields. Each user is responsible for one component of the vector field function. Again, using the toggle buttons, the users can observe the curl vectors of the vector field in isolation or superimposed on the original vector field. Figure 8 shows the curl vectors (red arrows) superimposed on a user-created vector field (blue arrows). The users then choose a point at which to calculate the curl. The program subsequently prompts the first user to calculate and input the exact value of the curl at the chosen point as shown in Figure 9. If the user answers correctly, the program continues onto the next round. In the next round, the users enter a new vector field and the process repeats itself. There are three rounds in total, ensuring each user receives an opportunity at the curl computation.

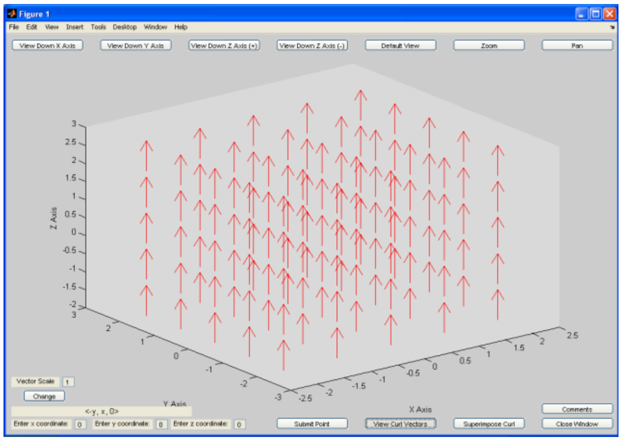

Figure 6. Plot depicting the curl vectors only.

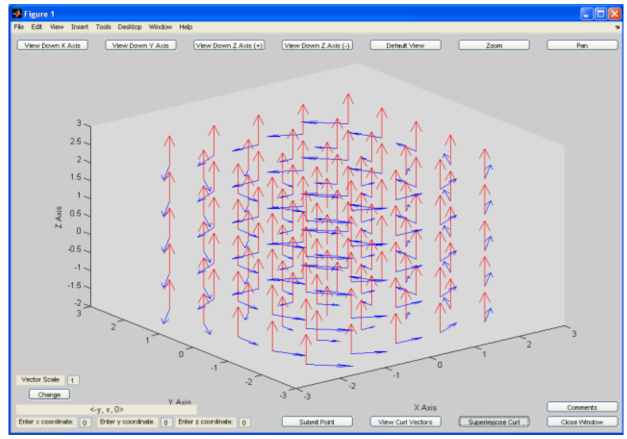

Figure 7. Curl vectors superimposed on the original vector field.

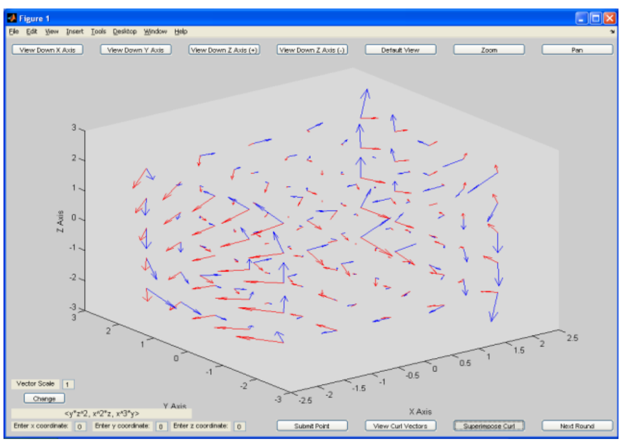

Figure 8. Curl vectors superimposed on a user-created vector field.

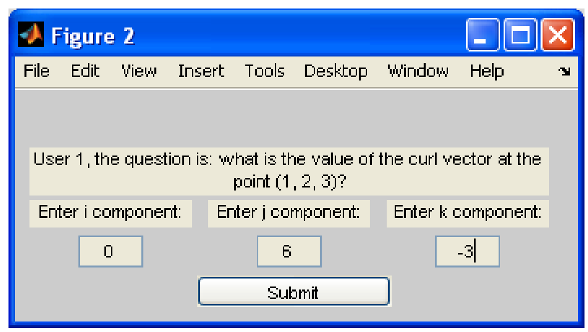

Figure 9. Calculating the value of the curl.

Divergence Exercise

The purpose of the Divergence exercise is to demonstrate the concept of divergence of a vector field. The users enter the components of a vector field which are then plotted as shown in Figure 10. The users are given a “control volume” whose location can be chosen by the users. The purpose of this “control volume” is to provide a means to visualize whether the vector field is converging or diverging at a particular location. Once the users choose a point that they desire, one user is prompted for an exact calculation of the divergence at the control volume’s location. If the user answers correctly, the program continues to the next round. In the next round, a new vector field is entered and a different user is prompted for the divergence calculation. There are three rounds total, ensuring each user receives an opportunity at the divergence computation.

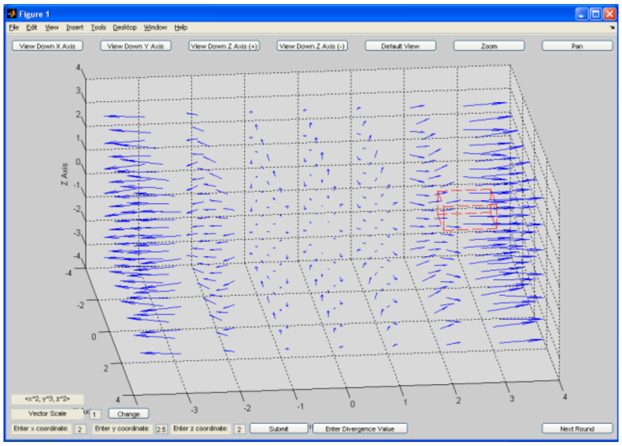

Figure 10. Divergence exercise.

Triple Integrals Boundaries Exercise

This exercise helps the users visualize the limits of integration for triple integrals (see Figure 11). The three users are asked to each enter in one or two surface functions. The program plots the surfaces. The users can use the buttons to toggle the visibility of different surfaces to identify the function associated with the surface. With the surface plots, the users can visualize the limits of integration for a triple integral. If the surfaces do not form a closed region, the program allows for the input of new functions until an enclosed region is created.

Once the desired region has been achieved, the users select the Triple Integral button, and they are prompted to enter the order and limits of integration (Figure 12). Each user is responsible for two different orders of integration. The goal is to have all six possible orders of integration result in the same answer. With the help of the plots, the users can algebraically manipulate the limits of integration to achieve this goal.

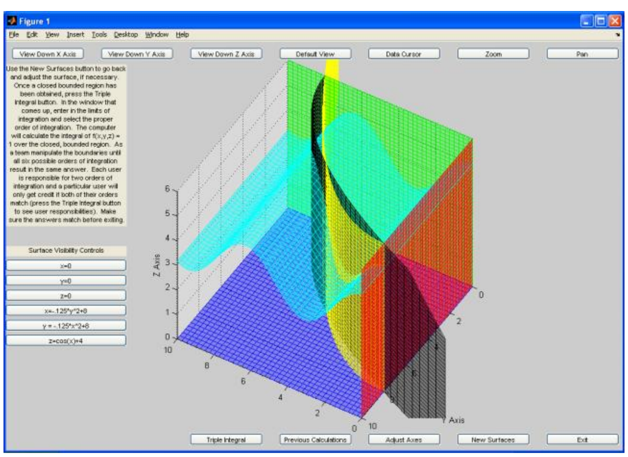

Figure 11. Triple Integrals exercise.

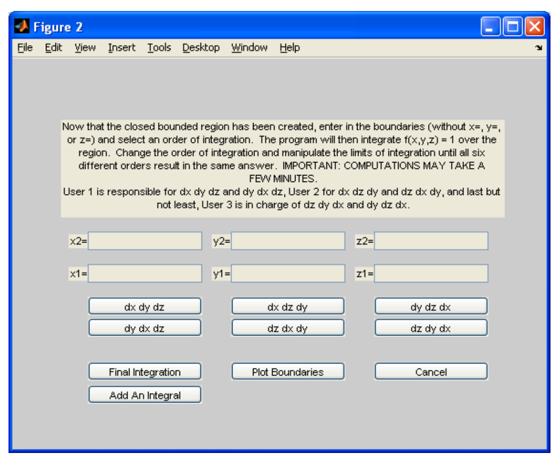

Figure 12. Entering the limits and order of integration during Triple Integrals exercise.

Evaluation Method

Evaluation Questions

To assess the overall usability of simulations and to evaluate the value of the simulation programs from the student perspective, we conducted an evaluation study with the following three questions:

1. How do students perceive the use of interactive simulations in their Math class?
2. How do students' motivational characteristics (i.e., intrinsic and extrinsic goal orientations and confidence levels in studying science, math and engineering) relate to their perceptions in using simulations during the Math class?
3. What aspects of the simulation programs should be improved?

Participants

The simulations were used in MATH 275 Multivariate & Vector Calculus class during Fall of 2010. Among 117 students who were enrolled in the class, 96 students (82%) voluntarily participated in the study by signing their informed consent form. Their majors were Mechanical Engineering (n = 37), Civil Engineering (n = 26), Electrical Engineering (n = 7), Materials Science and Engineering (n = 7), Mathematics (n = 5), Engineering-general (n = 4), Physics (n = 2), Chemistry (n = 2), Computer Science (n = 2) and other fields (n = 4). About 37% were sophomores, 33% juniors, 20% seniors, 5% freshmen, and 4% unknown.

Instruments and Procedure

We administered a 10-question survey (see Appendix A) via an audience response system (a.k.a. a clicker system) in the classroom three times during the semester (approximately once a month). The purpose of these formative surveys was to collect information about how students were using the simulations, especially if they had any difficulty accessing and completing the simulations through the Blade server. At the end of the course, we administered a web-based survey to measure students' motivational characteristics such as intrinsic and extrinsic goal orientations using the Motivated Strategies for Learning Questionnaire (MSLQ)[11] and their confidence levels in studying Science, Engineering, and Math adopted from Witt-Rose (2003)[12], as well as their perceptions of task value in using simulation programs. A 7-point scale was used in the survey questions (1 representing "not at all true of me" and 7 representing "very true of me"). SPSS v. 18[13] was used to analyze quantitative data. The overall study procedure is presented in Figure 13.

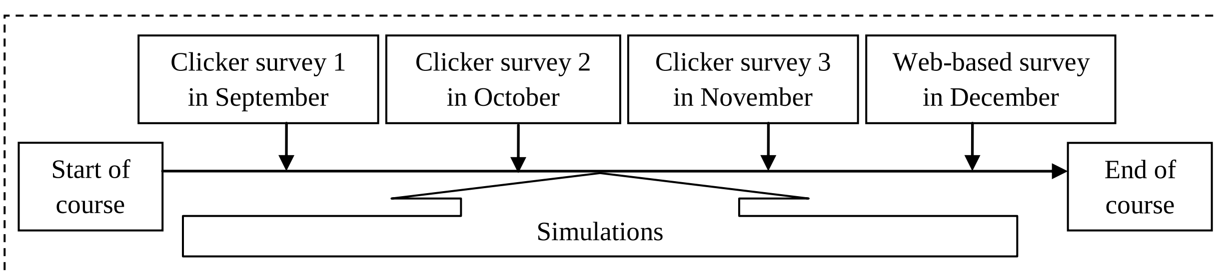

Figure 13. Study procedure.

Evaluation Results

Overall Evaluative Rubric

All survey questions used in this study were measured with a 7-point scale, 1 being the lowest score and 7 being the highest score. A couple of evaluative words (low, moderate, and high) that we are using in this report are based on the average scores obtained from the survey evaluated against the following three-level rubric:

- The average score between 5.0 and 7.0 - High
- The average score between 3.0 and 4.9 - Moderate
- The average score between 1.0 and 2.9 - Low

Students' Interests in Science, Engineering, and Math

Of the 96 participants, 88 (92%) submitted the web-based survey. Overall, the MATH 275 students were highly interested in studying Science, Engineering, and Math, and pursuing careers involving these topics (*M* = 5.72, 6.12, 5.56, and 6.56 respectively, as shown in Table 1). Students liked studying engineering the most (*M* = 6.12), which supports the fact that a majority (85%) of the students were engineering majors.

Table 1. Students' Interests in Science, Engineering and Math

Survey Question	Min.	Max.	Mean	SD
• How much do you like studying Science?	1	7	5.72	1.38
• How much do you like studying Engineering?	4	7	6.12	0.95
• How much do you like studying Math?	2	7	5.56	1.19
• How much do you want to pursue Science, Engineering, or Math as your career?	3	7	6.56	0.75

Evaluation Questions and Findings

1. How do students perceive the use of interactive simulations in their class?

We measured students' perceptions about the task value of the simulation programs in terms of interest, importance, and utility. We adopted six questions used in the MSLQ's task value section by specifically referring to the use of simulations. The Cronbach's Alpha level representing reliability among the modified six questions was .948. As shown in Table 2, students' task value scores were spread out through low, moderate, and high levels in a bell-curve shape. Overall, students perceived the value of the simulation programs to be a moderate level, *M* = 3.99. See Table 3.

Table 2. Frequency of Three Task Value Groups

Task Value	Low	Moderate	High
Frequency	*n* = 23	*n* = 36	*n* = 29

Table 3. Task Value of Using Simulation Programs

Survey Question	Min.	Max.	Mean	SD
• I think I will be able to use what I learn from the simulations in this course in other courses.	1	7	4.31	1.65
• It was important for me to learn the course material through simulations in this class.	1	7	3.91	1.76
• I was very interested in the simulations provided in this course.	1	7	3.82	1.63
• I think the simulations provided in this class are useful for me to learn the course material.	1	7	4.10	1.61
• I like the simulations used in this course.	1	7	3.90	1.71
• Understanding the subject matter of this course through simulations is very important to me.	1	7	3.88	1.75
Average	-	-	3.99	1.49

2. How do students' motivational characteristics (i.e., intrinsic and extrinsic goal orientations and confidence levels in studying science, math and engineering) relate to their perceptions in using simulations during the Math class?

Intrinsic goal orientation and task value of simulations - We measured students' intrinsic goal orientation using four questions in the MSLQ's intrinsic goal orientation section. The Cronbach's Alpha level representing reliability among the four questions was .814.

In this Math class, students were highly intrinsically goal-oriented, $M = 5.11$ (see Table 4). The direction of the correlation between the students' intrinsic goal-orientation and task value of using simulations was positive, $r_s(88) = .456$, $p < .01$. According to Cohen's guidelines[14] as shown in Table 5, the effect size is considered "larger than typical." That is, the more intrinsically goal-oriented the students were, the higher their task value of using the simulation programs was. A scatter plot presenting the correlationship between the two variables is shown in Figure 14.

Table 4. Students' Intrinsic Goal Orientation

Survey Question	Min.	Max.	Mean	SD
• In a class like this, I prefer course material that really challenges me so I can learn new things.	1	7	5.07	1.16
• In a class like this, I prefer course material that arouses my curiosity, even if it is difficult to learn.	1	7	5.46	1.03
• The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible.	1	7	5.22	1.36
• When I have the opportunity in this class, I choose course assignments that I can learn from even if they don't guarantee a good grade.	1	7	4.67	1.23
Average	-	-	5.11	0.96

Table 5. Interpretation of the Strength of a Relationship (Effect Size) [14]

General Interpretation of the Strength of a Relationship	The *r* Family
• Much larger than typical	|.70| or higher
• Large or larger than typical	around |.50|
• Medium or typical	around |.30|
• Small or smaller than typical	around |.10|

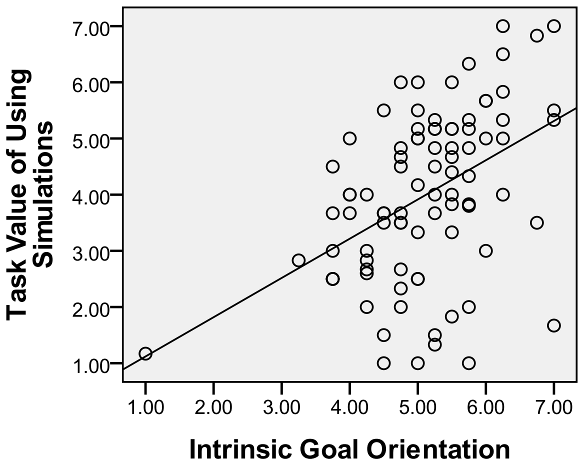

Figure 14. A scatter plot of intrinsic goal orientation and simulation task value.

Extrinsic goal orientation and task value of simulations - We measured students' extrinsic goal orientation using four questions in the MSLQ's extrinsic goal orientation section. The Cronbach's Alpha level representing reliability among the four questions was .787.

The students in this course were highly extrinsically goal-oriented as well, $M = 5.32$ (see Table 6). However, although the direction of the correlation between their extrinsic goal orientation and their task value of using the simulation programs was positive, the effect size was small, r_s (88) = .176, $p > .05$.

Table 6. Students' Extrinsic Goal Orientation

Survey Question	Min.	Max.	Mean	SD
• Getting a good grade in this class is the most satisfying thing for me right now.	1	7	5.38	1.38
• The most important thing for me right now is improving my overall grade point average, so my main concern in this class is getting a good grade.	1	7	5.11	1.65
• If I can, I want to get better grades in this class than most of the other students.	1	7	5.63	1.42
• I want to do well in this class because it is important to show my ability to my family, friends, employer, or others.	1	7	5.18	1.60
Average	-	-	5.32	1.18

Confidence levels in Science, Engineering and Math and task value of simulations - We measured students' confidence levels in studying Science, Engineering or Math with the 15-question survey adopted from Witt-Rose's instrument[12]. The Cronbach's Alpha level representing reliability of the revised instrument was .922. The correlation between students' overall confidence levels in studying Science, Engineering and Math and their task value of using the simulation programs was positive, but the effect size was small, r_s (88) = .182, p >.05.

However, students' levels of interest in studying Science, Engineering, or Math were positively correlated with their task value of using simulations, and the effect sizes were medium or high medium levels (Table 7).

Table 7. Correlations between Interests in Science, Engineering and Math and Task Value of Using Simulations

Survey Question	Task Value of Simulations
• Like studying Science	$.340^{**}$
• Like studying Engineering	$.405^{**}$
• Like studying Math	$.319^{**}$
• Want to pursue Science, Math, or Engineering as a career	$.257^{*}$

** Significant at the 0.01 level (2-tailed)
* Significant at the 0.05 level (2-tailed)

3. What aspects of the simulation programs should be improved?

The three formative clicker surveys conducted during the course revealed that the initial tasks of logging into the Blade server and starting simulation programs became much easier as students used the system more (Figures 15 and 16). The third clicker survey showed that some students still had difficulty with the log-in and start-up procedures (5.9% and 21.2%, respectively). We noted this area to be investigated in order to eliminate barriers to accessing the learning tools.

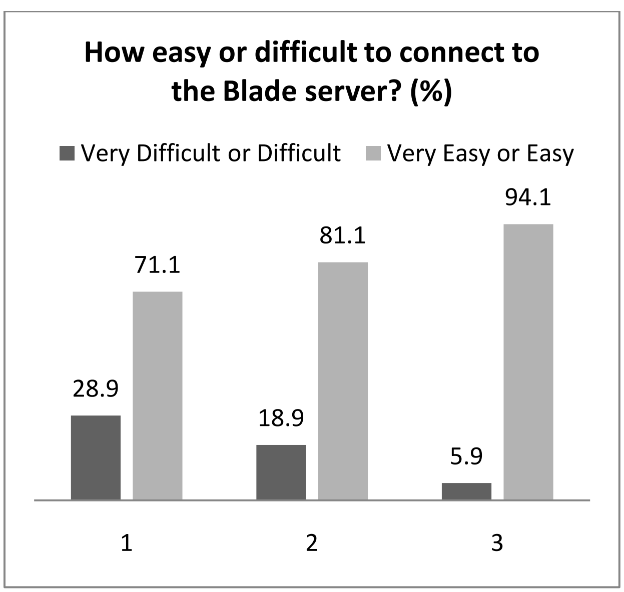

Figure 15. How difficult to connect to the server?

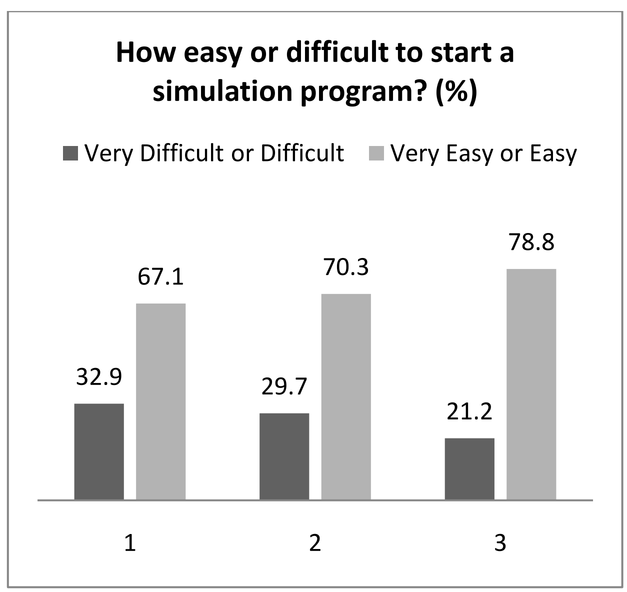

Figure 16. How difficult to start a simulation?

In the clicker surveys, students were asked whether they prefer using simulations alone or with classmates. As shown in Figure 17, students gradually liked collaborating with classmates more than using the simulations alone. However, the third clicker survey showed that 21.7% of the students still preferred using simulations alone, while 56.6% preferred collaborating with classmates.

The clicker surveys also asked students how much they liked using simulations as a learning tool in a Math class. As shown in Figure 18, the first clicker survey conducted in the early part of the course showed that about 2/3 of the students liked using the simulations programs as a learning tool. However, both the second and third click surveys showed that students' reactions changed and split in half. These two groups' (like vs. dislike) task values were significantly different at a 0.01 level, t (77) = -6.93. Understandably, the 'like' group's task value scores were higher than the 'dislike' group (M = 4.92 and M = 3.02, respectively).

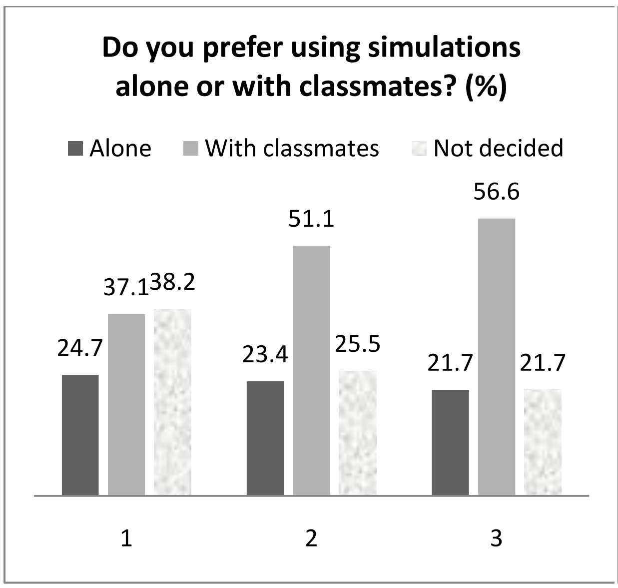

Figure 17. Preference in collaboration

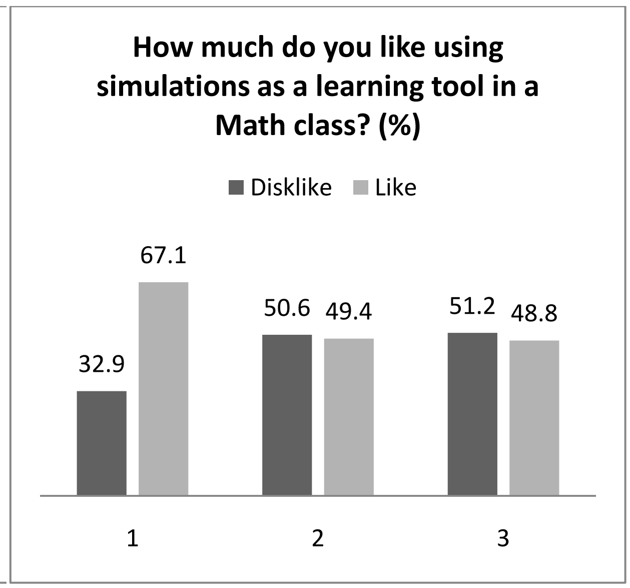

Figure 18. How much do you like using simulations?

To investigate the reasons for their attitudes toward using simulations, we analyzed students' qualitative survey comments. Among the study participants, 28 of them provided qualitative comments on the simulation programs. After sorting their comments according to their task value scores and grouping them into the three categories (high, moderate, and low), there seems a pattern in terms of the reasoning behind their value perceptions toward the use of the simulations. Sample student comments are provided in Table 8.

- The high task value group (M = 5.0 - 7.0) appreciated that the simulations' visual representations of the concepts and step-by-step instructions made learning valuable.
- The moderate task value group (M = 3.0 - 4.9) thought that most simulations were valuable and also appreciated the visual representations of the abstract concepts, but they had difficulty in using some of the programs, which caused confusion and frustration.
- The low task value group (M = 1.0 - 2.9) expressed that it was confusing and frustrating to make simulations work; therefore, the simulations did not contribute to learning.

Table 8. Students' Comments on Simulation Task Value

Task Value	Low	Moderate	High
Example of Student Comments	"They are not really that effective in teaching - just another thing to have to cram into a schedule." "Complete waste of my time. I gained nothing from the simulations other than aggravation and frustration. They were of no use as a learning tool. If you do not know how to calculate something like a gradient or curl of a function, then a simulation that requires you to do so, but does not help you learn how to, does no good." "There were a lot of bugs in the program at first. This made it difficult to really focus on what was trying to be taught." "plugging in my own values made it too easy" "The simulations did not really help me learn the course material. Some of the simulations were confusing and frustrating." "The simulations were confusing. Some didn't work properly. "	"The simulations have some value. They were done quite well for the most part. The difficulty in relying heavily on simulations is the difficulty of adequately grasping a student's comprehension." "Most of them were good but the first few were a little tough to start. Near the end of the class they were much more organized." "I know the simulations helped me, and I am very sure the future will be based on simulated assignments, however, I am a lot more confident in doing assignments from the book or on paper. The whole computer thing is different and I am not very comfortable with it for some reason." "Good for visualizing level curves and surfaces or for visualizing curl, flux and circulation. Not good for actually calculating answers... too buggy and specific. Makes for frustrating experiences."	"The way the curl simulation was set up worked the best for me. It provided a step by step tutorial about the subject before beginning the assignment. When trying to learn new subjects I try to reach out to as many resources as I can in attempt to get different interpretations. The curl simulation did this and really helped tie things together. None of the simulations before curl used this tutorial technique, or was cryptic in attempting it." "Understanding the material was the most important objective for me. Oftentimes, visual representations are the best and most expedient way to learn and understand new concepts." "They provided a simple way to visualize the concepts we were covering in class and helped further my understanding of the subject." "The simulations on MatLab would be better with preset equations, because when we have to make-up our own equations they are either really easy or impossible to solve."

Conclusions

It was the first time we implemented the simulation programs in the Math class. Students' input collected from this evaluation study was invaluable for detecting both the value of, and the areas for improvement in, the simulations. The data indicates merits in using simulations as a learning tool to help students better conceptualize abstract Math concepts – about 74% of students rated the value of simulations as high or moderate. The data showed that most students valued the collaborative and interactive aspects of the simulations as intended. The data also showed that the simulations tend to be attractive to students with high intrinsic goal orientation, while their value perceptions were not related to students' extrinsic goal orientation and confidence levels. This suggests that it is appropriate to encourage students to use simulations by promoting their curiosity and deep learning of the subject and by encouraging them to challenge themselves to learn in new ways.

The factors that caused to reduce the overall task value of the simulations seem to be external to the programs, such as accessibility problems, a lack of clear directions, and users' readiness in entering appropriate parameters required in the programs, rather than internal design issues. Based on students' input, we have generated a 'things to do' list to make the simulation programs more easily accessible and valuable to students in the future semesters:

- Provide clearer directions and more tutorials to students.
- Provide demonstrations of using simulations in class, before having students try out the simulations alone or with classmates.
- Provide video demonstrations on the website which students can review before or while they use simulations.
- Continue to provide options to use simulations alone or with classmates, acknowledging user preference.
- Provide preset equations in the simulations while still allowing students to change them to their own.
- Present a 'difficulty level' indicator next to each simulation program to set expectations for time and effort required for solving the problem.
- Test programs more rigorously to find and eliminate possible sources of difficulty (e.g., programming bugs) with the program before deployment.

By implementing the above strategies, we hope to reduce or eliminate low ratings (currently 26%) and improve the overall task value of simulations from a moderate to a high level. We will continue to develop more simulations and expand the use of simulations to multiple courses. We are also making them freely available via the Web for any users outside specific courses or our institution, contributing to achieving the overall goal of the project; that is, to develop virtual learning communities among a wide demographic and geographic range of audiences through cloud computing resources.

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Appendix A. Formative Clicker Survey

1. How easy or difficult was it to connect to the Blade server?

1	2	3	4	5
Very Difficult	Difficult	Easy	Very Easy	Not applicable (I have not logged into the Blade server.)

2. Once you log into the Blade server, how easy or difficult was it to start a simulation program?

1	2	3	4	5
Very Difficult	Difficult	Easy	Very Easy	Not applicable (I have not started a simulation program.)

3. How easy or difficult was it to connect remotely with classmates?

1	2	3	4	5
Very Difficult	Difficult	Easy	Very Easy	Not applicable (I have not connected remotely with classmates.)

4. How easy or difficult was it to complete a simulation alone?

1	2	3	4	5
Very Difficult	Difficult	Easy	Very Easy	Not applicable (I have not completed a simulation alone.)

5. How easy or difficult was it to complete a simulation with classmates?

1	2	3	4	5
Very Difficult	Difficult	Easy	Very Easy	Not applicable (I have not completed a simulation with classmates.)

6. How much do you like using this type of simulations as a learning tool in a Math class?

1	2	3	4	5
Dislike it very much	Dislike it	Like it	Like it very much	Not applicable (I have not used a simulation in a Math class.)

7. How much do you like using this type of simulations with classmates?

1	2	3	4	5
Dislike it very much	Dislike it	Like it	Like it very much	Not applicable (I have not used a simulation in a Math class.)

8. Do you prefer using this type of simulations alone or with classmates?

1	2	3
Alone	With classmates	Not decided

9. Since the beginning of this class, approximately how many simulations have you used so far?

___ simulations

10. Since the beginning of this class, approximately how many hours have you spent on using simulations so far?

___ hours