AC 2012-5123: INTERACTIVE SIMULATIONS COUPLED WITH REAL-TIME FORMATIVE ASSESSMENT TO ENHANCE STUDENT LEARNING

Dr. Tracy Q. Gardner, Colorado School of Mines

Tracy Q. Gardner graduated from the Colorado School of Mines (CSM) with B.S. degrees in chemical engineering and petroleum refining (CEPR) and in mathematical and computer sciences (MCS) in 1996 and with an M.S. degree in CEPR in 1998. She then got my Ph.D. in chemical engineering, studying transport in zeolite membranes, from CU, Boulder, in 2002. She did a postdoc at TUDelft in the Netherlands in 2002 and 2003, studying oxygen conducting mixed oxide membranes and teaching reactor engineering, and she has been teaching back at CSM since 2004. I am now a Teaching Associate Professor and the Assistant Department Head of the Chemical and Biological Engineering Department at CSM. My primary research focus is in pedagogy, specifically in utilizing tablets and other technology and different teaching methods to increase student engagement and reduce/eliminate lecturing in the classroom. She likes to play with her kids, play racquetball, run, bike, swim, and play pool in her free time.

Susan E. Kowalski, Colorado School of Mines
Prof. Frank V. Kowalski, Colorado School of Mines

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Interactive Simulations Coupled with Real-Time Formative Assessment to Enhance Student Learning

Abstract:
An innovative pedagogical method of coupling interactive computer simulations (sims) with real-time formative assessment using pen-enabled mobile technology was used to improve learning gains in two core Chemical Engineering courses – Fluid Mechanics and Process Dynamics and Control. Students' understanding of concepts, calculations, etc. demonstrated by the simulations was tested 1) with pretests before they saw the sims (PRE), 2) after independent free play with the sims (AFP), and 3) after instructor guided play (AGP) with the sims in class. From experimenting with the sims on their own, with instructions that they were to *fully explore the sims to the point where they thought they understood as much from them as they could*, students' scores increased from pretest averages in the 30's to 50's up to averages in the 50's to 70's. The average increase from PRE to AFP on a given sim for the six topics presented here was ~12%, or one letter grade (if letter grades below 60% were differentiated!). The scores then further increased to AGP averages in the 70's to high 80's, by an average of 21% more, or *two more letter grades*, after the students played with the sims again in class with guided questioning by the instructor. Coupling formative assessment using pen-based mobile technology in the classroom with exploration of interactive computer simulations thus lead to significantly increased learning gains over what was gained through unguided exploration of the sims alone.

Introduction:
It is well understood that students tend to learn more when they are actively engaged in their learning[1-3]. There are many teaching methods that attempt to get students actively engaged in their own learning, including two that have been coupled here to further increase learning gains. The first involves students exploring interactive computer simulations (sims), and the second is gathering information about student understanding in class and providing immediate feedback, in this case in the form of scaffolded questions directing the students' exploration of the sims. The latter is a real-time formative assessment technique that has the additional advantage of customizing the learning experience for individual learners, as quick students can move on to later questions while others are still working on earlier questions.

Interactive computer simulations (sims), for example showing graphical animations of effects on systems as process parameters are varied, are excellent active learning tools that allow students to explore, experiment through trial and error, take control of the learning process, and seek their own insights as they gain new knowledge. As they play with sims, students can visualize what the theory and equations they are studying really represent. This makes them more likely to understand the theory and calculations, and also more likely to remember it. Healy et al. state that "among cognitive benefits (of sims)… is that the graphic and interactive presentation format enhances semantic elaboration, leading to better long-term retention of the material."[4] However, there is evidence that students experimenting with sims without instructor guidance, even with "helpful" accompanying tutorials, often cannot correctly answer follow-up questions.[4] In some cases, the breadth of the explorable parameter space may be too large and students do not focus on the "right" things without proper guidance. Also, students may interpret a result in an interactive simulation differently than intended, and thus form misconceptions if this goes unchecked.[5] Lane and Peres conclude that "even a well-designed simulation is unlikely to be an effective teaching tool unless students' interaction with it is carefully structured."[6] This careful structuring can sometimes be done in the form of a tutorial, but instructor intervention – based on real-time assessment of students' expressed understanding, and given at the time conceptions are being formed – can be even more powerful. This coupling of interactive simulations and real-time formative assessment, and the consequent learning gains achieved, is the basis of this work. Results of 4 Process Dynamics and Control topics and 2 Fluid Mechanics topics taught with this coupled model are presented.

Methodology:
Process Dynamics and Control and Fluid Mechanics were the chosen courses for this study because historically in these courses students have had difficulties with visualizing the connections between the calculations and the physical processes. There were 40 students in the Fluid Mechanics course and 42 in the Process Dynamics and Control course. Table 1 gives a brief description of 6 topics in these courses taught using the coupled model described above.

Table 1 – Summarized descriptions of six topics* taught and assessed using the coupled interactive sims and real-time formative assessment model.

Sim	Questions Posed Before and After Sim Exploration
Controller Step Change (CONT)	Sketch controller output (CO), h_1, and h_2 vs. time for step increase and step decrease in CO. Make any time differences in behaviors of the controller setting and liquid levels clear on sketch. Annotate plot with words explaining anything necessary to explain. (Diagram of gravity-drained tanks system was given.)
Critically Damped 2nd Order Response (CRIT)	Sketch the second order response to a step input change of magnitude M assuming real and equal time constants, $\tau = \tau_1 = \tau_2$.
Overdamped 2nd Order Response (OVER)	Sketch the second order response to a step input change of magnitude M assuming real and unequal time constants, $\tau_1 > \tau_2$.
Underdamped 2nd Order Response (UNDER)	Sketch the second order response to a step input change of magnitude M assuming system is underdamped.
Closed-ended Manometer (MANOM)	Draw a closed-end mercury manometer in Denver that is open to the atmosphere on the other end on a day when the ambient pressure is 0.84 bar. Clearly indicate the height difference between the left and right sides with an equation and units.
Bubble Meter Ideal Gas Flow (IGL)	You are observing helium flowing up vertically in a clear glass tube with a soap film "bubble" that rises 100 ml in 28 seconds. The temperature in the room is 21 °C and the gauge pressure in the tube is 2 psig. You are at sea level, so the ambient pressure is 1 atm. Estimate the molar flow rate of helium, and tell why this is an "estimate".

* The coupled method described here was used to analyze student learning gains for a few more topics in these courses. Analysis of those data is pending.

Students were first given pretests to determine their level of understanding of the concepts before any exploration of the sims. Then they were asked to play with the sims with the goal of understanding as much as they could about the behavior of the systems. They were then given the same questions again, assessed this time as their After Free Play responses (AFP). Finally, *in class*, students were allowed to explore the same sims again while responding to a series of scaffolded questions, designed by the instructor to help the students better investigate the key concepts, calculations, assumptions, etc. These scaffolded questions were given to the students using web-based software called *InkSurvey* (http://ticc.mines.edu/csm/inksurvey/), which allows students to write open format answers, ask their own questions, provide their level of confidence in their own answer, or submit text answers as well. The students used pen-based Tablet PC's to provide their answers, and the instructor could instantly see and scroll through all students' answers to get a feel for what was understood and what was misunderstood. The "digital ink" answers to these questions could come in the form of equations, graphs, words, numbers, etc., as InkSurvey accepts free-form input. Based on the answers the students gave, other questions leading the students to the most interesting points were posed. Questions probing increasing depths of understanding were given as students worked at their own pace, thereby challenging students at all levels simultaneously. During this "guided play" time the students could talk to each other; they could ask the instructor questions, which the instructor could then use to come up with different *InkSurvey* questions to pose; and they could explore the sims again to address the questions. Finally, the students were given the same broad questions after the guided play, and these were assessed, resulting in the AGP scores. The questions were exactly or nearly exactly the same for all three assessments, and the same grading rubrics were used for all three assessments of each concept.

This interactive mode encourages all students not only to participate in answering the questions, but also in asking the instructor questions, as they can do so via *InkSurvey* without identifying themselves. Additionally, during these exercises, students spend a significant amount of time discussing with each other, which has proven to increase student learning and understanding of concepts. Tablet PC's were used in this study, but the pedagogical method and software infrastructure are sufficiently versatile that this model can be broadly used with other hardware such as slates, iPads, and even smart phones. Students participating in these activities were fully engaged and on task throughout the duration of class time. These guided sims explorations can be used 1) to elucidate and correct common misconceptions and, 2) to hone critical thinking skills in cases where processes are being modeled using equations that do not apply.

Results and Discussion:
Students' responses on the PRE, AFP, and AGP assessments, scored typically from 0 to 4 and then scaled to give a percentage score, on each topic listed in Table 1. The averaged scores are presented in Table 2, and also graphically in Figure 1. The uncertainty estimates in Table 2 were derived from t-tests, given the sample sizes and a desired 90% confidence level. "Learning gains" for each of the two phases, defined here as the differences between the AFP and PRE averages for the free play phase, and between the AGP and AFP averages for the guided play phase, are presented in Table 3. For three of the six topics presented here, the AFP averages were statistically greater than the PRE averages, indicating that free play with the simulations did

improve the students' understanding of the topics, and for all of these six topics the AGP averages were statistically higher than the AFP averages (and by larger margins in all but one case). In fact, across all six topics the average increase in score was ~12%, or a full grade level, after the free play, and an *additional* ~21%, or two more full grade levels, after the guided play! Granted the uncertainty due to the relatively small sample size and variability in the students' scores indicates potentially lower gains at each of these steps, but the gains from AFP to AGP are statistically significant in all cases. In addition, independent classroom observers noted that all students were completely engaged and on-task the entire time allotted to the simulations.

Table 2 – Average scores on four Process Dynamics and Control and two Fluid Mechanics topics 1) before seeing simulations (PRE), 2) after free play with computer simulations (AFP), and 3) after guided exploration of the simulations (AGP). Uncertainty was estimated using t-tests at a 90% confidence level.

Sim	Pretest (PRE)	After Free Play (AFP)	After Guided Play (AGP)
Controller Step Change (CONT)	57 ± 5	72 ± 5	84 ± 4
Critically Damped 2nd Order Response (CRIT)	38 ± 6	49 ± 6	71 ± 7
Overdamped 2nd Order Response (OVER)	33 ± 5	49 ± 7	66 ± 6
Underdamped 2nd Order Response (UNDER)	36 ± 7	55 ± 7	86 ± 6
Closed-ended Manometer (MANOM)	49 ± 8	54 ± 6	75 ± 5
Bubble Meter Ideal Gas Flow (IGL)	59 ± 9	66 ± 7	87 ± 6

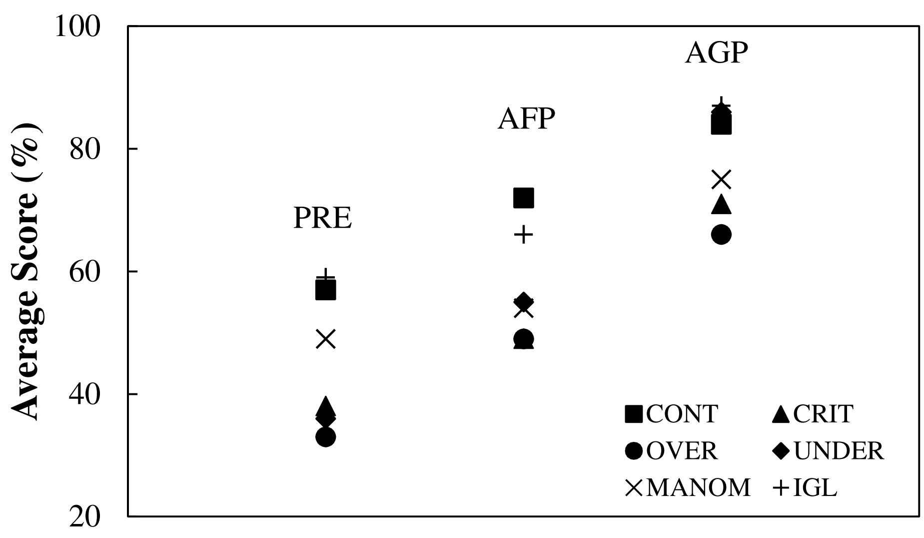

Figure 1 – Average scores on 6 topics from pretests (PRE), after free play (AFP), and after guided play (AGP) with computer simulations. Topic abbreviations in the legend are explained in Table 1. See Table 2 for error estimates from t-tests, as error bars were omitted for clarity.

It is true that students had more exposure to the sims overall after the guided play, since they first played with the sims unguided and then guided, and this extra time alone could lead to some better understanding of the topics. However, the students were asked to explore the sims on their own with the purpose of gaining as much understanding as possible. Also, when they were exploring the sims unguided, they already knew what question was going to be asked at the end since they had done the pre-tests. We therefore assume they tried to get as much out of the sim as they could without guidance during the free play. Furthermore, the in-class guided play time was less than the free play time, and in some cases the students were given as much time as they wanted to explore the sims in the free play phase (i.e. on their own outside of class as "homework"). Therefore, the fact that the learning gains during the guided play phase surpassed those from the free play phase, *despite the initial higher level of understanding at the onset of the AGP phase*, indicates how significant the guidance was in helping the students understand the topics. It is also important to note that the instructor never gave the answers to the assessment questions during the scaffolded questioning, and instead simply facilitated student discussions typically with more directed questions.

<u>Table 3</u> – "Learning gains", defined here as the differences between the AFP and PRE average scores and between the AGP and AFP average scores, based on the results in Table 2. Uncertainty estimates are simply the sums of the uncertainties of the two subtracted quantities.

Sim	PRE to AFP	AFP to AGP
Controller Step Change (CONT)	15 ± 10	12 ± 9
Critically Damped 2nd Order Response (CRIT)	11 ± 12	22 ± 13
Overdamped 2nd Order Response (OVER)	16 ± 12	17 ± 13
Underdamped 2nd Order Response (UNDER)	19 ± 14	31 ± 13
Closed-ended Manometer (MANOM)	5 ± 14	21 ± 11
Bubble Meter Ideal Gas Flow (IGL)	7 ± 16	21 ± 13
Average:	12	21

Though we can only qualitatively assess the level of difficulty of the concepts tested, it is noteworthy, though not surprising, that the smallest learning gains for the free play phase occurred for the more straightforward concepts (applying the ideal gas law to flow calculations, how a manometer works, and how a critically damped second order system responds to a step input change). Also note that the largest learning gains for the free play phase, 19%, occurred for the same topic (2nd order underdamped response to a step change) that had the largest gains with the guided play as well (31%). Based on previous teaching experiences, this was the most difficult topic on the list, and ultimately the students ended up understanding it as well as they did any of the topics!

Conclusions:

An innovative pedagogical method of coupling interactive simulations with real-time formative assessment (RTFA), carried out using *InkSurvey* web-based software and "digital ink" devices such as Tablet PC's, kept students completely engaged and on task during class and resulted in significant learning gains for selected topics from Process Dynamics and Control and Fluid Mechanics courses. After playing on their own with computer simulations, knowing what question would be asked at the end, students' average level of competence across the six topics presented here increased from ~45% to ~58%. That is, on average they still did not understand the concepts at a passing level after playing with the simulations in an unguided manner. Without the instructor ever telling students the answers to the questions, but instead posing scaffolded questions based on the students' immediate issues and misconceptions, students' understanding of these concepts increased to an average of ~78% across these same topics. This teaching model, coupling sims and real-time formative assessment, further allowed students at all levels to become and remain engaged in their own learning.

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Bibliography

1. Bransford, J.D., Brown, A.L., & Cocking, R.R. (eds.), *How People Learn: Brain, Mind, Experience, and School*, Washington D.C.: National Academy Press, 1999.

2. Hake, R.R., "Interactive-Engagement vs. Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses," *American Journal of Physics*, **66**(1), 1998, pp. 64-74.

3. Bain, K., *What the Best College Teachers Do*, Cambridge, MA: Harvard University Press, 2004.

4. Healy, M.R., Berger, D.E., Romero, V.L., Aberson, C.L., & Saw, A., "Evaluating Java Applets for Teaching on the Internet", *Proceedings of the Scuola Superiore G. Reis Romoli Advances in Ingrastructure for e-Business, e-Education, E-Science, and E-Medicine on the Internet International Conference*, 2002.

5. Wieman, C.E., Perkins, K.K., & Adams, W.K., "Oersted Medal Lecture 2007: Interactive Simulations for Teaching Physics: What Works, What Doesn't, and Why", *American Journal of Physics*, **76**(4&5), April/May 2008. Available online at: http://www.colorado.edu/AcademicAffairs/ScienceEducationProject/documents/Wieman_2007_Oersted_Medal_Lecture.pdf.

6. Lane, D., & Peres, S.C., "Interactive Simulations in the Teaching of Statistics: Promise and Pitfalls," *ICOTS* **7**, 2006.