

THE TRANSPARENCY PARADOX: COMPUTATIONAL SIMULATIONS AS
LEARNING TOOLS FOR ENGINEERING GRADUATE EDUCATION

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Abstract

Computational simulations have become a critical part of computational science, which is being described as the third leg in this century's methodologies of science.

Computational simulations have also become a critical element of learning experiences as they can provide engineering students with the ability to do things that they could not do in the real world. This study explores engineering graduate students' perceptions related to aspects associated to the transparency of the simulation tools. The results of this study show that most of the students interviewed found using computational simulations as useful for their learning. However, a transparency paradox was identified. A proposed solution to the transparency paradox may be the implementation of scaffolds together with three different levels of transparency.

Introduction

Computational simulations have become a critical part of computational science, which is being described as the third leg in this century's methodologies of science (Sabelli, 2006). Computational simulations have also become a critical element of learning experiences (Magana, Brophy, & Bodner, 2008). Furthermore, computer

simulation tools can provide engineering students with the ability to do things that they could not do in the real world (Winn, 2002). This study builds upon the body of knowledge of the use of computer and computational simulation tools for learning. In particular, this study focuses on issues of transparency that may impact the uses of computational simulations as learning tools.

Background

Cannon-Bowers and Bowers (2007, p. 318) defined simulations as “a working representation of reality; used in training to represent devices and processes and may be low or high in terms of physical or functional fidelity (p. 318).” Alessi (2002, p. 177) proposed that simulations are “any program which incorporates an interactive model (one which can be repeatedly changed and rerun) and where the learning objective is for students to understand that model, whether through discovery, experimentation, demonstration, or other methods (p. 177).” Based on these definitions, we define computational simulations as working representation(s) of reality; used in training, research, and education to represent physical phenomena, devices, and/or processes through mathematical models and numerical solution techniques using computers. These computational simulations are used as tools to analyze and solve scientific and engineering problems.

Alessi (2002) distinguished between “building” simulations and “using” simulations. This distinction was well-described by Clariana and Strobel (2007) in which building simulations refers to computer software modeling tools designed to build and run dynamic models, while using simulations are computer software tools designed under others’ own understanding of a model that allow users to manipulate its processes or

variables and observe the output results (R. B. Clariana, 1989; Reigeluth & Schwartz, 1989). Alessi (2002) made clear that not all educational simulations can be divided cleanly into using or building simulations; instead, they form a continuum.

This study explores engineering graduate students' perceptions and experiences of computational simulations in the context of five different homework assignments involving either *using* or *building* simulations. In particular, this study focuses on students' perceptions related to aspects associated to the transparency of the simulation tools. Tanimoto (2004) defined transparency as a property of some systems where the inner workings and the design of the system are visible to users (p.1). This study reports a transparency paradox identified through students' experiences and perceptions and proposes potential pedagogical approaches to overcome it. The guiding research question for this study is:

What are engineering students' perceptions and experiences using computational simulations as learning tools?

Method

Cross-case analysis design was employed as the method of inquiry. According to Eisenhardt (1989), the case study is a research strategy focused on understanding the dynamics within single settings. In this case, the setting focused on engineering students' experiences using computational simulations. Cross-case analysis then followed within-case analysis. These analyses resulted in common themes and patterns among students.

Data was collected through interviews with students from three different engineering courses offered in the Fall of 2008 (see Table 1). Classroom observation was also conducted throughout the entire semester. The interviews focused on students'

perceptions of using simulation tools in a particular homework assignment. For example we asked them: What was your experience of using the simulation tool as part of your homework assignment? What do you think was the purpose of the homework activity using the simulation tool? What the professor wanted you to learn? Which portion of the assignment did you find the most challenging? How did you overcome those challenges? When you were solving the homework assignment, how confident were you with the required knowledge to solve it? After completing the activity, what was new for you that you did not know before? Why are you taking this course? The interviews lasted approximately one hour and were conducted at different points during the semester. In particular, for Course 1, we interviewed six students after the first homework assignment and another set of five students towards the end of the semester. For Course 2, five students were interviewed after the mid-term exam and four more towards the end of the semester. For Course 3, five students were interviewed towards the end of the semester. Each student was interviewed one single time and even though they may have done two homework assignments, the interview was focused on one particular assignment. Therefore, these students described their experiences of using computational simulations as learning tools in the context of five different homework assignments where they primarily *used, built or used and built* simulation tools¹. . In total, we interviewed 25 students who were randomly selected.

Classroom observation was also conducted throughout the entire semester for the three different courses. The purpose for these observations was to identify how instructors incorporated the simulation tools as part of their learning activities. These

for building simulations students also used it after having built them. However in most of the cases the primary goal was focused on learning the computational techniques to build those simulations.

observations were useful not only to identify instructors' pedagogical practices with simulation tools, but also they allowed us to establish rapport with students and gain a general understanding of the subject matter.

Table 1. Participants Per Course and Per Homework Assignment

Courses	Course 1		Course 2		Course 3
Homework Assignments	HW_A Using	HW_B Using	HW_C Building	HW_D Building	HW_E Building-Using
Students	Libo_A John_A Isison_A Arash_A Valerie_A Joe_A	Howard_B Jack_B Jonathan_B Allison_B Maria_B	Jake_C Drew_C Jim_C Uday_C Kyle_C	Lawrence_D Rajiv_D Melanie_D Robert_D	Dimitris_E Tom_E Connor_E Maurice_E Steve_E

The analysis started with open coding followed by axial coding. While in open coding we conducted the first level of abstraction in conceptualizing major ideas, in axial coding we reassembled the data so explanations and relationships of the data were done. Major advantages and disadvantages of using computational simulations as learning tools were identified. Themes of students' experiences with simulation tools were grouped together. Next, individual cases were compared to general patterns across cases. When a pattern from one data source was corroborated by the evidence from another, the finding became stronger and better grounded in the data (Merriam, 1988).

nanoHUB Simulation Tools

The Network for Computational Nanotechnology developed an infrastructure network called nanoHUB to help transform nanoscience to nanotechnology through online simulation and training. The nanoHUB website provides research-quality simulations that experts in nanoscience commonly use to build knowledge in their field (see example Figure 1). NanoHUB leverages an advanced cyber-infrastructure and

middleware tools to provide seamless access to these simulations. Key characteristics of the nanoHUB simulation tools that make them good resources for incorporation into classroom environments are: (a) they were produced by researchers in the NCN focus areas, (b) they are easily accessed online from a web browser powered by a highly sophisticated architecture that taps into national grid resources, and (c) they provide a consistent interactive graphical user interface known as Rappture, which makes esoteric computational models approachable to non-experts. Rappture is a toolkit that allows the incorporation of a friendly graphical user interface with the simulation tools in the nanoHUB (McLennan, 2005).

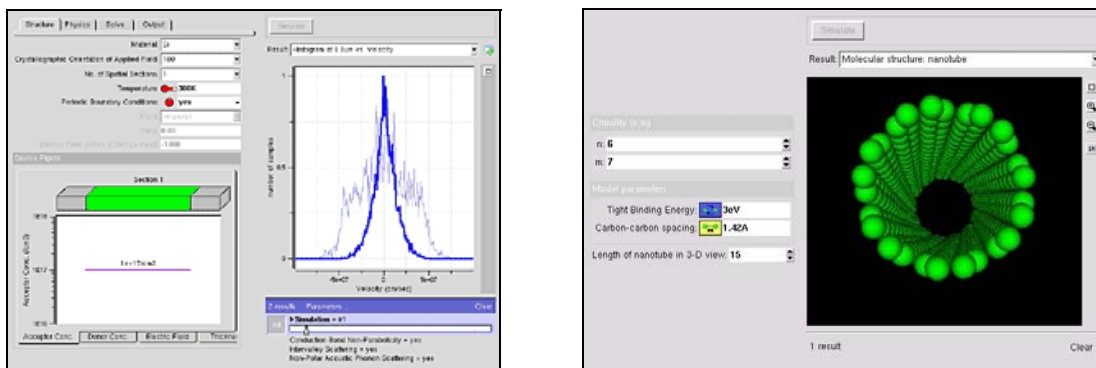


Figure 1. Sample nanoHUB Simulation Tools

Results

Overview Homework Assignments

By means of classroom observations we were able to identify two major focuses or themes for incorporating simulation tools into their instructional activities; while some instructors focused more on conceptual understanding and engineering skills, others emphasized the computational techniques. Therefore, two general methods for incorporating simulation tools into higher education courses were identified; simulations used to predict system performance relative to a design task (Course 1), simulations built

as part of a modeling task to predict model performance relative to observed phenomena (Course 2), and a combination of these two (Course 3). The main instructional approach instructors followed was to first introduce in class the physical principles defining the behavior of a device, material, or phenomenon and then have students apply these principles with the homework assignments using or building the simulation tools.

Students' Perceptions of Simulation Tools

In general, most students interviewed found using computational simulations as useful for their learning. Sixty four percent (64%) of the interviewed students mentioned the output of the simulation helped them realize how each input affects the output. They explained that the simulation gave them some sense of how the physical phenomena behave as conditions (inputs) are changed.

Melanie_D: ...I think sometimes when using the simulation it helps me to understand the physics as well, instead of using the output to explain the physics I will use the output to understand the physics behind it, because it is easier for me to visualize something using a graph than using nothing, like at this point they give your maximum or whatever I can tell, and as I look at the graph I can see this happens at this point, why is it happening, something like that.

Howard_B: ...sometimes if you are thinking a problem with the functions, you will be not so, so clear or some obvious, like if I change one parameter how the curve will change. If you just want to see the functions, that would be not very direct, maybe a change where you can set this parameter by different values and look at the curve, you explicitly

know what is happening there and how it has changed. I think that is one thing that helps you to know...

Drew_C: In my learning of the topic oh— Actually, so I would say that simulation is the only way to learn hum— so if we had not done these simulations, hum— although we would know the concepts from talking, sort of surface knowledge of what everything is and what is molecular dynamics how it is simulated, but when you are doing simulations you understand what the more scientific aspect and more quantitatively what is molecular dynamics... So although all that was taught in concept in slides it is only through simulation that we finally understand what is the meaning of each of these things.

Some students (24%) found simulation tools convenient for solving hard and complex calculations. By having the computational power to solve those calculations students were able to study the models without any of the simplifications usually done with analytical solutions:

Joe_A: How did it help me the most? Hum— well it's definitely a lot faster than trying to solve equations especially when they are nonlinear and very difficult to solve analytically, so I mean it made it possible to solve some of these problems I think.

However, students faced some challenges. Seventy three percent of students whose homework assignments focused on *using* simulations reported wanting to have more transparency of the simulations. They mentioned wanting to “see” the calculations

being done and assumptions behind the simulation tools. Further more than a quarter of the students reported wanting to program their own simulation tools.

Kyle_C: I have an idea of what's happening behind but I'm not exactly sure. I'm not 100 percent sure of what's going on because I've run similar simulations using similar techniques but I, I didn't learn anything about making a simulation, all I learned was about running one. The problem I had was that it wasn't *transparent* (emphasis added). I couldn't see what was going on, so I didn't know, and that also made, for me it made uh— understanding whether something was actually physical or not, made it a little, a little less, or made it a little more difficult for me to understand it.

Maria_B: Um...maybe um, in this particular case maybe making a little bit of the source code known to us so that might help to figure out what exactly it is doing, but that may or may not help because it could be a very long code and you won't be able to make out all that is happening, but seeing it for those who are interested can go through and really understand what is happening, maybe that option would help.

On the other hand, over half the students (57%) whose homework assignments focused on *building* and *building and using* simulations reported problems implementing the model in a computer programming script (e.g. MATLAB).

Tom_E: ... it was like my first time kinda' working on MATLAB, and I was excited about this class.

I felt like I knew what everything meant, but I couldn't get it.

So, yeah, I was a little disappointed. I was kinda' frustrated, but, I was alright. 'Cause I'm not very ... I think we had to use arrays and our arrays were different sizes. And, and I kept messing that up, so that was the most difficult part for me, I think, was just trying to keep track of ...the programming.

Students were able to overcome these challenges by means of just-in-time scaffolds provided by their instructors. For the case of students who *used* simulations, they were provided with online lectures that guided them when approaching the solution to their homework assignments.

Jim_C: Hum— first, we got some theoretical background from professor's lectures and then we got the nanoHUB and the presentation by professor and we, it is about how to run the molecular dynamics simulation toolkit on nanoHUB and uh, by viewing that presentation we know how to use the toolkit and finally when we are doing the project, we uh, we got more detail information how the simulation was run exactly...

For the case of students who *built* simulations, they were provided with templates of programming scripts to initiate their path toward a solution. The template served as blueprints for approaching the programming component of their homework assignment.

Lawrence_D: Hum— well from the physics standpoint I was very confident and with the mathematics too, but my background is in physics and math, but it isn't in computation which is the reason I am taking this course is to try and learn how to implement the physics and

math but I wasn't confident at all really in the computational stuff. If he [the instructor] wouldn't have given us the blueprint to start with, I wouldn't have had a clue where to begin doing the problem.

Discussion and Implications

Two general methods for incorporating simulation tools into engineering education courses were identified; simulations used to predict system performance relative to a design task, simulations built as part of a modeling task to predict model performance relative to observed phenomena, and a combination of these two. These two general trends are analogous and can be aligned with using versus building simulation tools (Alessi, 2000) and learning from models and learning by modeling (de Jong & van Joolingen, 2007b).

On the other hand, Students reported benefitting from using simulation tools because they found them convenient and helpful at the same time. They found them convenient because simulation tools solved difficult and complex calculations for them and because the simulations helped them simplify the complex models. The output of the simulation helped them to realize how each factor affects the output giving them some sense of the physical phenomena. However, we identified a polarity here called the transparency paradox, where the amount of information provided to students around a simulation task, can be either too much or too little, and therefore can cause limitations in students' learning. For example, students who used simulation tools as a black box indicated that they needed more knowledge of the underlying models that drive the simulations. On the other hand, students who were exposed to the model behind a simulation tool and who implement their own code desired more assistance creating their

own simulation tools. That is, while the students who only used the simulation tools as a black-box model wanted more “transparency” of the model governing the behavior of the simulation tools (i.e. equations being solved, underlying assumptions, computational implementation, etc.); the students who had modeled their own simulation (or portions of their own simulations) and then used the simulations in a computer programming script (e.g. MATLAB) commented on their difficulties implementing the computational part of the assignments. Therefore, a balance is needed between the complexity of the task and supports provided to students. Part of this need was fulfilled for the students by incorporating scaffolds discussed next.

Researchers have emphasized that successful inquiry learning with simulation tools needs adequate but not intrusive scaffolding (de Jong & van Joolingen, 2007a; Mayer, 2004; Njoo & de Jong, 1993; Reid, J, & Chen, 2003; van Joolingen, de Jong, & Dimitrakopoulout, 2007; Winn, 2002). Students received scaffolds during their processes of solving their homework assignment. Students identified two general types of scaffolds that were very useful at the moment they approached the solution to the homework assignments. One scaffold was the online lectures instructors posted on the nanoHUB.org. These lectures functioned as an embedded expert guidance that helped students in activating their prior knowledge (Quintana, et al., 2004). The second scaffold was the use of templates of programming scripts that served as blueprints to initiate their path toward a solution.

Other aspect to be considered is the level of transparency of the simulation tool. The two most common approaches for simulation transparency are the black box and the glass box simulations (Resnick, Berg, & Eisenberg, 2000). The glass box simulations

differ from the black box simulations by providing learners with visibility (Du Boulay, O'Shea, & Monk, 1999); i.e., the ability to inspect and modify the equations that constitute the simulation's model (Murray, Winship, Bellin, & Cornell, 2001). For this study, a potential instructional strategy to overcome transparency paradox may be through the implementation of an instructional overlay (Reigeluth & Schwartz, 1989) as part of nanoHUB interface. This instructional overlay should make transparent the phenomenon being modeled at three different levels of transparency. One level relates to how the phenomenon is represented through physical models. The second level relates to how those physical models are solved mathematically. The third level relates to how those mathematical models can be turned into numerical solutions implemented through computational techniques. Providing engineering students the ability to “see” behind the simulation tools at these three different levels of transparency may result in benefits in their learning. These three different levels of transparency can be implemented through pop-up windows, online lectures, manuals and/or tutorials. The appropriate level of transparency to choose may be related to the instructors' learning goals and/or pedagogical philosophy. These suggested supports may enhance students' learning by: a) making science accessible (Kali & Linn, 2007), b) using of multiple representations that make explicit properties of underlying data (Quintana, et al., 2004), and c) embedding expert guidance about scientific practices (Quintana, et al., 2004).

Implications for Education in the Professions with Simulation Tools

Engineering students need scaffolds and transparency of the simulation tools so they can benefit in their learning with simulations. Engineering students would learn more if they are able to “see” behind the simulation tools. That is, to be able to “see” the

underlying model, the assumptions, the equations solved, and the algorithms.

Engineering students would learn more if appropriate scaffolds that implement a guided approach are leveraged. One scaffolding method is to run simulations coupled with online lectures about the theory and/or tutorials explaining how to use the tools and well written examples illustrating how it is used in practice. These self-paced lessons focus on the conceptual aspect of the theories and models and the operational aspect of the computational tool. Scaffolds for assignments involving building simulations are templates containing some initial code or a given code that students need to modify.

These starting points give students a stimulus to react to and requires them to critically evaluate what the initial code can do, interpret the goals of what it is required to do, and design a solution that achieve these goals. Several methods can be used to facilitate this process lead by the student including online lectures or tutorials focused on the conceptual and operational aspect of the simulation tool. For engineering students scaffolds such as online lectures and programming scripts serve as a very useful just-in-time support as they approach the solution to the homework assignments.

References:

- Alessi, S. (2000). Building versus using simulations. *Integrated and Holistic Perspectives on Learning, Instruction and Technology*, 175-196.
- Alessi, S. (2002). Building versus using simulations *Integrated and Holistic Perspectives on Learning, Instruction and Technology* (pp. 175-196): Springer Netherlands.
- Cannon-Bowers, J. A., & Bowers, C. A. (2007). Handbook of Educational Communications and Technology. In J. M. Spector, M. D. Merrill, J. J. G. van Merriënboer & M. P. Driscoll (Eds.), (pp. 317-327): Mahawa, NJ: Lawrence Erlbaum Associates.

- Clariana, R., & Strobel, J. (2007). AECT Handbook of Educational Communications and Technology. 3rd. Ed. In J. M. Spector, M. D. Merrill, J. J. G. van Merriënboer & M. P. Driscoll (Eds.), (pp. 329-344): Mahwah, NJ: Lawrence Erlbaum Associates.
- Clariana, R. B. (1989). Computer Simulations of Laboratory Experiences. *Journal of Computers in Mathematics and Science Teaching*, 8, 14-19.
- de Jong, T., & van Joolingen, W. R. (2007a). AECT Handbook of Educational Communications and Technology. 3rd. Ed. In J. M. Spector, M. D. Merrill, J. J. G. van Merriënboer & M. P. Driscoll (Eds.), (pp. 457-468): Mahwah, NJ: Lawrence Erlbaum Associates.
- de Jong, T., & van Joolingen, W. R. (2007b). Model-Facilitated Learning. In J. M. Spector, M. D. Merrill, J. J. G. van Merriënboer & M. P. Driscoll (Eds.), *AECT Handbook of Educational Communications and Technology*. 3rd. Ed (pp. 457-468): Mahwah, NJ: Lawrence Erlbaum Associates.
- Du Boulay, B., O'Shea, T., & Monk, J. (1999). The black box inside the glass box: presenting computing concepts to novices. *International Journal of Human-Computer Studies*, 51(2), 265--277.
- Eisenhardt, K. M. (1989). Building Theories from case Study Research. *Academy of Management Review*, 14(4), 532-550.
- Kali, Y., & Linn, M. C. (2007). Technology-enhanced support strategies for inquiry learning. In J. M. Spector, M. D. Merrill, J. J. G. van Merriënboer & M. P. Driscoll (Eds.), *Handbook of Research on Educational Communications and Technology* (3rd. ed.): Lawrence Erlbaum Associates.
- Magana, A. J., Brophy, S., & Bodner, G. M. (2008). *Professors' Instructional Approaches and Students' Perceptions of nanoHUB Simulations as Learning Tools*. Paper presented at the ASEE Conference and Exposition. June 22-25. , Pittsburgh, PA.
- Mayer, R. E. (2004). Should there be a three-strikes rule against prue discovery learning? *American Psychology*, 59, 14-19.
- McLennan, M. (2005, Nov). Add Rapture to Your Software Development, from <http://www.nanohub.org/resources/240/>

- Merriam, S. B. (1988). *Case Study Research in Education. A Qualitative Approach*. San Francisco, CA: Jossey-Bass.
- Murray, T., Winship, L., Bellin, R., & Cornell, M. (2001). Toward Glass Box Educational Simulations: Reifying Models for Inspection and Design. *2001 Workshop, External Representations in AIED: Multiple Forms and Multiple Roles San Antonio, Texas.*[Fichier, 2003: <http://www.psychology.nottingham.ac.uk/research/credit/AIED-ER/murray.pdf>).
- Njoo, M., & de Jong, T. (1993). Exploratory Learning with a Computer Simulation for Control Theory: Learning Processes and Instructional Support. *Journal of Research in Science Teaching*, 30(8), 821--844.
- Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., et al. (2004). A Scaffolding Design Framework for Software to Support Science Inquiry. *The Journal of the Learning Sciences*, 13(3), 337--386.
- Reid, D. J., J, Z., & Chen, Q. (2003). Supporting scientific discovery learning in a simulation environment. *Journal of Computer Assisted Learning*, 19, 9-20.
- Reigeluth, C. M., & Schwartz, E. (1989). An Instructional Theory for the Design of Computer-Based Simulations. *Journal of Computer-Based Instruction*, 16(1), 1--10.
- Resnick, M., Berg, R., & Eisenberg, M. (2000). Beyond Black Boxes: Bringing Transparency and Aesthetics Back to Scientific Investigation. *The Journal of the Learning Sciences*, 9(1), 7--30.
- Sabelli, N. (2006). Understanding Complex Systems Strand: Complexity, Technology, Science, and Education *The Journal of the Learning Sciences*, 15(1), 5-9.
- van Joolingen, W. R., de Jong, T., & Dimitrakopoulout, A. (2007). Issues in computer supported inquiry learning in science. *Journal of Computer Assisted Learning*, 23, 111-119.
- Winn, W. (2002). Research into Practice: Current Trends in Educational Technology Research: The Study of Learning Environments. *Educational Psychology Review*, 14(3), 331--351.