Engineering and Science Instructors’ Intended Learning Outcomes with Computational Simulations as Learning Tools

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Agenda

• Motivation for nanoHUB
• What is nanoHUB?
• Research agenda and research study
• Distinction between computer simulations and computational simulations
• Method
• Results
• Discussion
• Implications
• Conclusion
Motivation for nanoHUB

- Nanotechnology has revolutionized the world of information theory, computers and other important disciplines.
- It is important for people working in nanotechnology to better understand basic concepts to be more creative and productive.
- The USA National Science Foundation has created the Network for Computational Nanotechnology (NCN).
- The dissemination of all NCN’s participants is enabled by the community website www.nanoHUB.org.

What is nanoHUB?

- It is a rich, web-based resource for research, education and collaboration in nanotechnology.
- It hosts over 1600 resources, including online presentations, courses, learning modules, podcasts, animations, teaching materials, etc.
- It offers simulation tools accessible from a web browser
- Number of users = 153,704 (11,675 are registered users).
Motivation for the Study

- Progress has been made on research that examines students’ learning with computer simulations.

- Less progress has been made toward understanding instructors’ goals for incorporating computational simulations into their teaching.

- Little is known about how instructors’ specific learning goals inform their pedagogical approaches when incorporating simulation tools, of any kind, into their teaching and learning.
Main Contributions

It focuses on:

- what instructors chose to do based on their actual experiences, not what prior work on simulations suggests they should do,
- practicing engineering and science research faculty rather than engineering and science educators,
- advanced undergraduate and graduate courses rather than introductory courses for middle-school or high-school students, and
- a naturalistic, operating classroom environment rather than a quasi-experimental/experimental intervention.

Computer Simulations Vs. Computational Simulations

Computer simulations have been created and used for educational purposes in both formal and informal learning environments.

“working representation[s] of reality; used in training to represent devices and processes and may be low or high in terms of physical or functional fidelity”

Computer Simulations Vs. Computational Simulations

“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”

(Alessi, 2000, p. 177).

nanoHUB Computational simulations were:
• originally developed for use by subject-matter experts as research tools, and
• then implemented in a classroom setting.

Computational simulation tools are based on mathematical models that require extensive calculations executed on supercomputers or distributed computer platforms.
Definition of Computational Simulations

“working representations of reality that are used to represent physical phenomena, devices, and/or processes based on mathematical models and numerical solution techniques executed on supercomputers or distributed-computing platforms.”

(Magana, Brophy & Bodner, in review)

Characteristics of nanoHUB tools for learning:

(1) produced by researchers for domain specific NCN areas,
(2) easily accessed online from a web browser
(3) powered by a highly sophisticated architecture that taps into national grid resources, and
(4) they provide a consistent interactive user-friendly graphical user interface (Rappture)
Method

Research Question:
What were the intended learning outcomes that guided the instructors’ use of computational simulations as learning tools?

Methodological Framework:
Phenomenography
(Marton, 1981)

Phenomenography

“Phenomenography is the empirical study of the limited number of qualitatively different ways in which various phenomena in, and aspects of, the world around us are experienced, conceptualized, understood, perceived, and apprehended”

Method

Participants:
14 faculty who used nanoHUB simulation tools

<table>
<thead>
<tr>
<th>Instructor</th>
<th>Graduate</th>
<th>Undergraduate</th>
<th>Discipline</th>
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<tbody>
<tr>
<td>Dr. Bowen</td>
<td></td>
<td>x</td>
<td>ECE</td>
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<tr>
<td>Dr. Chaffee</td>
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<td>x</td>
<td>ECE</td>
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<tr>
<td>Dr. Denner</td>
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<tr>
<td>Dr. Forney</td>
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<tr>
<td>Dr. Hansen</td>
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<td>x</td>
<td>Chemistry</td>
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<tr>
<td>Dr. Brown</td>
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<td>ECE</td>
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<tr>
<td>Dr. Hass</td>
<td>x</td>
<td>x</td>
<td>MSE</td>
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<tr>
<td>Dr. Lawson</td>
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<tr>
<td>Dr. Clase</td>
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<tr>
<td>Dr. Doyle</td>
<td>x</td>
<td></td>
<td>Physics</td>
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<tr>
<td>Dr. Grissom</td>
<td>x</td>
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<td>ECE</td>
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<tr>
<td>Dr. Richardson</td>
<td>x</td>
<td></td>
<td>MSE</td>
</tr>
<tr>
<td>Dr. Sanders</td>
<td>x</td>
<td></td>
<td>ECE</td>
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<tr>
<td>Dr. Shaw</td>
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<td>ECE</td>
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Data Collection Method:
semi-structured, open-ended interviews

Data Analysis Method:
based on a grounded-theory approach
(Strauss and Corbin, 1990)
following Marton’s guidelines for
conducting an inductive data analysis
(Marton, 1997; Patton, 2002)
Eight categories (A-H) of descriptions of goals for using computational simulations as learning tools were identified.

These 8 categories can be summarized as:

a) Simulations *used* to predict system performance relative to a design task.

b) Simulations *built* as part of a modeling task to predict model performance relative to observed phenomena.

A. To recognize and be aware of the potential role of computational simulations in a particular field of science or engineering.

Chaffee:  
*So that’s the kind of things we do at the freshmen level. It’s an exposure thing.* They see the word nanotechnology, they know engineering, they know the science, and they get to know a place [nanoHUB] that’s kind of cool where, if they wanted to learn more, they could.
B. To measure materials or devices by collecting data as in a laboratory experiment

Sanders: They logged onto the nanoHUB, they ran the simulation, and then just answered some questions — so this was sort of as you went to a lab and did a measurement of a transistor and see how these things function.

Interviewer: so loosely a kind of a virtual lab, where you use the simulations as a way to generate the data?

Sanders: Right, ... so the whole point is that they will get some feeling for what the electrical characteristics of these devices look like without any of the theory as to why it does this, just see what a typical one looks like and get calibrated.

C. To explain the cause-effect relationship of the underlying model governing a simulation

Hass:
... and even though students are not experts in the actual methodology to do the simulations, they understand what the approximations are and what is the accuracy that they would expect, how realistic description we do. And then, once the simulation is done, and they look at the results, they can look at, for example, the load versus deformation curve stress strain and then they can look at what the atoms, the location of all the atoms are at different stages.
Results

D. To test the accuracy of a given model and/or its computational implementation

Richardson:
And one of the things we have discussed recently is, let’s see, how do I put it? I want them to realize that they should always be suspicious of what they program. And that they should not trust it, and they should test — find as many tests experimental, and theoretical, until they’re satisfied enough.

Results

E. To validate the results or performance of the product of a design task

Sanders:
So in this design problem, they take the bigger device that behaves properly, they shrink it and they should understand now that I need to do these half-dozen key measurements and look at these half-dozen key parameters and they’re going to tell me everything I need to know about what’s happening with this device — and then you look at, OK, which one is the biggest problem and that’s how I’m going to work on the first.
F. To implement computational techniques in a modeling task

Grissom:  
*In some cases they had to develop their own code, which was like to learn what’s in the guts of the program, the simulations, so they have a better appreciation.*

G. To predict the results of an experiment in a design task

Shaw:  
*Number one, from a predefined device, they have to understand what are the novel phenomena. Number two, they have to design the device. Like they have to optimize the configuration. They have to vary the device, things like that. So that they have to optimize characteristics. So they have to simulate, you know, lot of simulations.*
H. To discriminate between different models to represent a given physical phenomenon

Brown:
To understand the physical based device simulation, it’s not only important to have the software available to you, you really have to know the software in a sense that if the device is huge, you’re going to use one model to model that particular device. If it’s small, the device, then you need to choose a different model.
### Findings Previous Work

<table>
<thead>
<tr>
<th>Two trends of incorporating simulation tools were identified:</th>
<th>Approaches for incorporating simulations into learning environments:</th>
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<tbody>
<tr>
<td>a) Simulations used to predict system performance relative to a design task.</td>
<td>a) Using versus building simulation tools (Alessi, 2000)</td>
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<tr>
<td>b) Simulations built as part of a modeling task to predict model performance relative to observed phenomena.</td>
<td>b) Learning from models versus learning by modeling (de Jong &amp; van Joolingen, 2007b).</td>
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### Categories of Description:

- to collect data as in a laboratory experiment
- to understand the cause-effect relationship of the underlying model

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### The Dual Search model (SDDS):

- searching in the experiment space
  - data driven or induction
  - followed by experimenters
- Searching in the hypothesis space
  - theory driven or deduction
  - followed by experimenters

(Klahr and Dunbar, 1988; Klahr and Simon, 1999; Langley et al., 1987)
Inquiry Learning (AAAS, 1989)
- Collect data and calibrate instruments

Engineering Instructional Laboratories (Feisel & Rosa, 2005)
- Instrumentation to apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities.

**Discussion**

<table>
<thead>
<tr>
<th>Inquiry Learning (AAAS, 1989)</th>
<th>Engineering Instructional Laboratories (Feisel &amp; Rosa, 2005)</th>
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<tbody>
<tr>
<td>• Exploration and observation</td>
<td>• Data analysis to demonstrate the ability to collect, analyze, and interpret data, and to form and support conclusions; to make order of magnitude judgments, and know measurement unit systems and conversions.</td>
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Discussion

Inquiry Learning (AAAS, 1989) | Engineering Instructional Laboratories (Feisel & Rosa, 2005)
---|---
- Rework of task and testing of ideas | *learning from failure* to recognize unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions.

- Construct mathematical models | *experiment* to devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize an engineering material, component, or system.
Inquiry Learning (AAAS, 1989) Engineering Instructional Laboratories (Feisel & Rosa, 2005)

- Build things
  - design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements.

- Construct mathematical models
  - Use models to identify the strengths and limitations of theoretical models as predictors of real-world behaviors.
Implications

Design of learning objectives that encompass some of the outcomes A–K of Criterion 3 of the ABET engineering criteria (Felder and Brent 2003):

• apply knowledge of mathematics, science, and engineering,
• design and conduct experiments as well as analyze and interpret data,
• design a system, component, or process to meet desired needs,
• identify, formulate, and solve engineering problems, and
• use the techniques, skills, and modern engineering tools necessary for engineering practice.

Conclusion

The results of this study could therefore serve toward the development of:

• a common language about learning goals to facilitate communication across persons, subject matter, and grade levels;
• a basis for determining congruent educational objectives, activities, and assessments in a unit, course, or curriculum; and
• a panorama of the range of educational possibilities against which the limited breadth and depth that any particular computational simulation could provide as teaching or learning tool (Krathwohl 2002)
Acknowledgements

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