Professors' Instructional Approaches and Students' Perceptions of nanoHUB Simulations as Learning Tools.

Introduction

Simulations can provide a critical element of learning experiences. Simulations are also becoming a critical part of computational science, which is being described as the third-leg in this century's methodologies of science (Sabelli, et. al, 2005)[1]. Opportunities exist to use the same simulation as both a tool for experts and a learning environment of novices. What needs to be done to accomplish this duality of a simulation resource?

The Network for Computational Nanotechnology (NCN) has developed an infrastructure network to help transform nanoscience to nanotechnology through online simulation and training. Called nanoHUB.org, the web portal delivers high-end, research quality, online simulations and tutorials to over 25,000 users annually (personal communication Gerhard Klimeck). These users include researchers, experimentalists, professors and students who, as a community of practice, collaborate and learn by sharing ideas, finding solutions, and building innovations in nanotechnology. The nanoHUB.org was initially focused on pioneering the development of nanotechnology from science to manufacturing through innovative theory, exploratory simulation, and novel cyber infrastructure. Recently, it has also become an outstanding educational source in nanotechnology-related concepts and theory. Our ultimate goal is to analyze how experts use these tools for research activities, so that we can better inform individuals developing materials to facilitate their use for educational purposes.

Review of the Literature

Experts use visual imagery such as models, as well as graphs, symbols and other representational systems, to help them represent and understand problems and facilitate solutions (Lehrer & Schauble, 2000[2]; Nersessian, 1992[3]). Because of the strong relationship between models and simulations, Mayer (1992)[4] defined a model as a representation that involves visualizing the principle-based mechanism between interacting components that represent the functionality or operation of a portion of the natural world. This visualization can concretize phenomena that are not directly observable.

In contrast, Nersessian (1992)[3], argued that experts use models and simulations to construct mental representations and simulations that can be used to comprehend the system Operating on these mental representation involve the construction of analogical models and inferring through analogical reasoning. Nersessian also suggested that "these techniques involve a process of abstracting from phenomena or existing representations and creating a schematic or idealized model to reason with and quantify" (p. 65, 1992)[3]. Sabelli (2006)[5] noted that the addition of computer visualization to the simulation of complex phenomena allows for a visual exploration of the phenomena and overcomes the limits of models. As noted previously she described simulations as the third-leg in this century's methodologies of science, arguing that theory and physical experimentation, by themselves, no longer suffice.

Studies such as those conducted by Williamson and Abraham (1995) [6] have shown that the use of computer-interactive animation technology and dynamic, three-dimensional presentations led to significant improvements in students' understanding of the concept in question. They argued that this increased understanding may be due to the superiority of the formation of more expert-like, dynamic mental models.

The nanoHUB provides research-quality simulations that experts in nanoscience use to build knowledge in their field. NanoHUB simulation tools therefore can be characterized as the type of scientific discovery learning simulations (de Jong & van Joolingen, 1998) [7] Alessi and Trollip (2001) [8] described as an environment in which "the learner is essentially engaging in simulated scientific research, applying a scientific method and performing repeated experiments to arrive at an understanding of the underlining model of a scientific phenomenon" (p.218). The NanoHUB leverages an advanced cyber-infrastructure and middleware tools to provide seamless access to these simulations. As described on the nanoHUB.org website, key characteristics of the nanoHUB simulation tools that make them good resources for incorporation into classroom environments are: a) they have been produced by research in the NCN focus areas, b) they are flexible for running online from a web browser powered by a highly sophisticated architecture that lets the user tap into national grid resources, and c) they provide a friendly and interactive graphical user interface that allows the tools to be operated by non-experts (see Figure 1).

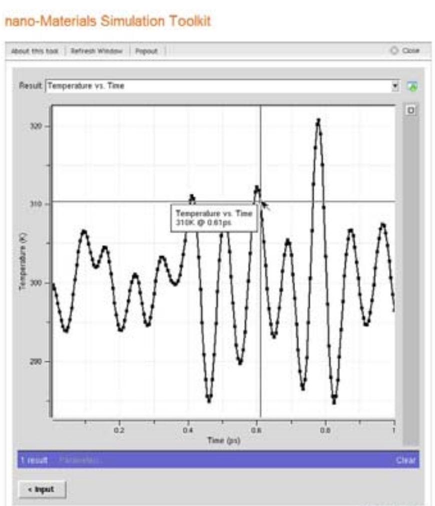

Figure 1a: nano-Materials simulation toolkit

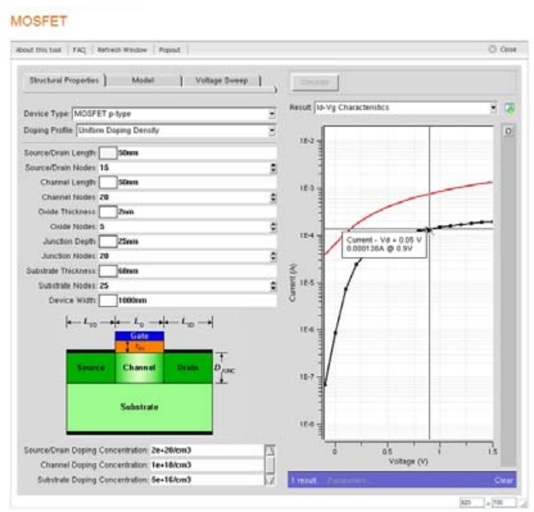

Figure 1b: MOSFET

Figure 1: Samples of interfaces of nanoHUB simulation tools

The nanoHUB continues to grow in its volume of resources and learning materials. In particular, recent years has seen an increase in investigators and graduate students accessing these resources in an attempt to increase their understanding. Our goal is to investigate how these experts are using the HUB for their own continued learning and how can nanoHUB be integrated into formal and informal learning environments.

Our work will test the conjecture that the nanoHUB resource supports learners' goals and expectations for learning in a course because the nanoHUB provides an excellent platform for meeting instructor's goals of conceptual understanding and metacognitive skills for exploring new concepts. We are conducting multiple studies of how these resources can be used as a learning resource for students from undergraduate to graduate levels and scientists interested in learning more about nanotechnology. Our initial efforts concentrate on identifying professors' instructional goals and approaches and students' perceptions of using the nanoHUB's simulation tools. In particular, we are trying to answer the following questions:

> How do instructors integrate nanoHUB resources into their instructional practice?
> What are students' perceptions of using nanHUB simulation tools?

In this study, we describe two instructors' approach to incorporating the simulation tools in their courses and students' response to this learning experience.

Method

Selection of Participants

The professors interviewed and the surveyed students were chosen using purposeful sampling. The participants for the study included professors who are part of the Network for Computational Nanotechnology (NCN) and students who are enrolled in the graduate level classes these professors teach. The initial phase consisted of collecting surveys from students at four different universities. These students were part of six different engineering courses in graduate level. In total, 129 students were surveyed. The initial phase served to a) identify professors whose students noted that the simulation tools helped them comprehend concepts better than using homework and lectures only, b) who pointed out that when they used the simulation tools they generated questions that guided their thinking, and c) who had no trouble interpreting the output of the simulation tools. We also considered factors such as whether they considered the course engaging by incorporating the simulation tools and in general that they expressed using the nanoHUB as a positive experience. In addition, we considered what students reported about considering nanoHUB simulation tools intuitive to use. Although other professors met the above-mentioned characteristics, for this initial study two professors were selected and interviews were conducted to gain insight in their approach of incorporating simulation tools as part of their learning strategies.

The sample included 34 graduate students who are pursuing engineering degrees; 19 in materials engineering and 15 in electrical engineering. The first group of students was exposed to an atomistic approach in which fundamental concepts of physical properties of solids were related to thermal and mechanical treatments. The second group of students focused on examining the device physics of advanced transistors and the process, device, circuit, and systems considerations that enter into the development of new integrated circuit technologies. Both classes used the simulations hosted at www.nanoHUB.org website as part of their instruction. While instructor A used only one simulation tool kit (i.e. Figure 1a) in one learning experience, instructor B used about 5 different simulation tools (e.g. Figure 1b) in approximately 7 learning experiences among the entire semester.

Data Collection and Procedures

The directors of the Network for Computational Nanotechnology invited all faculty members using the nanoHUB simulations as instructional tools to participate in this study. Faculty who agreed to participate, requested students to complete a survey of their perceptions for using nanoHUB resources for learning. A survey seemed to be an appropriate way for collecting initial information from so many students located in different parts of the country. The design of the survey focused on three different areas: (1) whether and how students perceive simulation tools as useful for their learning, (2) whether and how students thought the simulation tools were relevant , and (3) usability aspects; in particular how intuitive the tools are. The survey items consisted of statements related to experiences students might have had in the course. Students responded by indicating the level with the statement based on their experience. Students responded in a scale from one to four: strongly agree, agree, disagree, and strongly disagree to each question. The average score for these questions were assigned in the following way: 4=strongly agree, 3=agree, 2=disagree and 1=strongly disagree. We chose to go to a four point scale to encourage students to be more decisive.

The results of this initial phase served two purposes: (1) they gave us an opportunity to identify our guiding questions for interviewing professors, and (2) they served as an initial indicator of students' perceptions of professors' incorporation of simulation tools to the learning experiences. Descriptive statistics was used to analyze the surveys. Because of time constraints, results of only two faculty members are reported in this study. Each professor participated in semi-structured interviews that focused on identifying their goals and instructional approaches in incorporating nanoHUB simulations as part of their learning activities. The researchers also had the professors carry out a think-aloud protocols while interacting with the simulation tools.

Data Analysis and Results

Wiggins and McTighe's backward design was used as a framework for analyzing the interviews with professors together with the survey results of students these professors teach. Wiggins and McTighe (1997) [9] present a "backward design process" (p.9) composed of three main stages. These stages are: a) identifying the desired learning outcomes, b) determining the acceptable evidence of that learning, and c) planning the experiences and instruction. In identifying the desired results, Wiggins and McTighe [9] provide a further classification of three levels for establishing curricular priorities one embedded inside another and ranging from knowledge worth being familiar with to enduring understanding.

Learning Outcome

For the case of both instructors, it has been identified that learning experiences accompanied by simulation tools were used to convey concepts having “endurance value beyond the classroom” (Wiggins and McTighe, p.10) [9] . While instructor A used the simulation tool to cover one specific learning goal of the course curriculum, instructor B made an intensive use of the simulation tools within the entire semester following a progression of complex activities culminating in a design challenge.

Instructor A as well as Instructor B reported that their goal while using the simulation tools was to give their students a sense on how investigations must be conducted in their areas of expertise as well as ways in which professionals work on those disciplines. Instructor A made an emphasis that the cognitive benefit for students is to help them develop a more intuitive understanding on what is happening from a molecular point of view. This knowledge can be applicable in identifying what are the fundamental atomic level mechanisms that govern how materials behave; and therefore be able to design better materials. Instructor B, on the other hand, focused on helping students develop a more intuitive feel for the process of designing semiconductor devices by identifying and manipulating the important parameters and measurements to be considered in a model, and why that is important for circuit designers.

We considered as an indicator of students’ recognition of the topic related to the simulation as having endurance value beyond the classroom if a) students considered the activity as highly relevant to their areas of interest and b) if students reported that using the nanoHUB was a very positive experience. Students reported positively with an average score of 3.2 that using nanoHUB is a very positive experience, and with an average score of 2.9 that nanoHUB simulation tools are highly relevant to their areas of interest. For individual responses of each instructor’s responses see Figure 2.

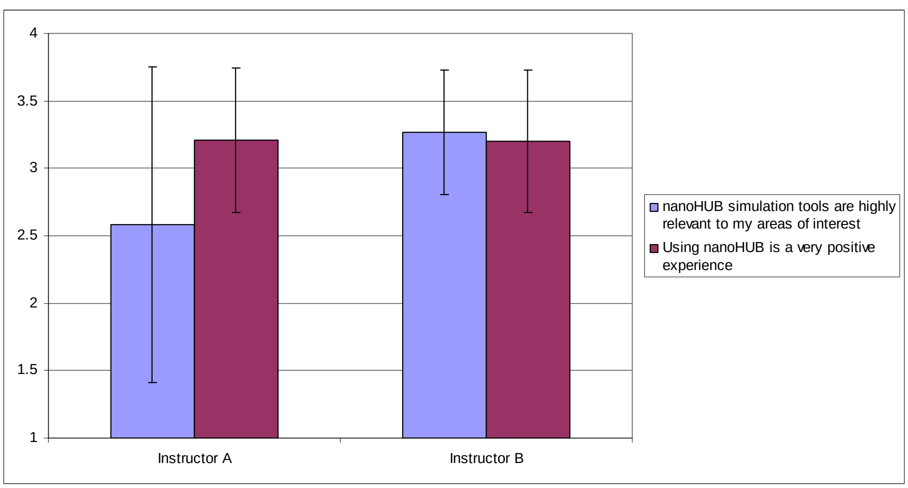

Figure 2: Students’ responses related to the learning outcome

Evidence of Learning

Wiggins and McTighe [9] second stage is to identify acceptable evidence on knowing what students have achieved. Both instructors, A and B designed assessments of the types of performance tasks featuring real challenges. In particular, instructor A focused his assessment in predicting behavior of materials according to specific parameters and comparing them with experimental values. In addition, instructor A gave as an option to his students to read a journal article and predict parameters of a specific material using the simulation tool and then compare his solution with the solution given by the authors. Instructor B focused his assessment in student's designing devices to meeting industry target parameters. While in one assignment instructor B asked his students to "look at a paper that presents some measured data from a current generation" and asked them to "tweak the parameters in the model so they can get a best fit"; in the final assessment he goes beyond making it a "design challenge", asking his students to meet parameters of a next generation device.

Two indicators we selected from students' surveys as evidence of their learning were identified as whether they have trouble interpreting the output of the tools and whether they can comprehend the concepts better by using the simulation tool compared to lectures and readings only. Students reported their perception of nanoHUB simulation tools as useful for their learning with a an average score of 3.2 in their ability to comprehend concepts better by using the nanoHUB simulations compared to lectures and readings only. They also reported with an average score of 3.0 that they do not have trouble interpreting the output of the nanoHUB simulation tool. For individual responses of each instructor's students see Figure 3.

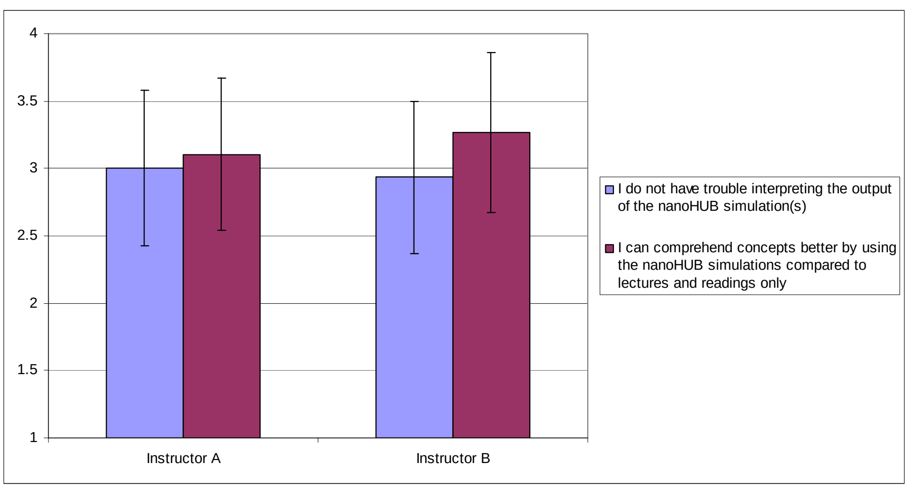

Figure 3: Students' responses related to the evidence of the learning

Instructional Approach

The final stage in the Background Design Process is the planning of learning experiences and instruction. When instruction is accompanied by a complex simulation tool, both instructors pointed out they not only take the time to explain concepts related to the phenomena in study, but also they had to spend some time explaining how to operate the simulation tool. The overall approach for Instructor A and Instructor B for instruction was to first introduce the basic concepts in class, describing the models and analytical and practical ways in which those models could be solved, and then solve the same models by simulation. Then they elicited from their students to compare the approximations done in class versus the exact solutions computed by the simulation tools.

Students' survey indicators related to professors' instructional approaches were related to students' ability to generate questions that guided their thinking and whether students found using the nanoHUB in the course more engaging compare to those courses that only use lectures, homework and readings. The students reported that when they used nanoHUB simulation tools they generated questions that guided their thinking with a rank of 3.0. These students also reported with an average score of 3.1 considering using the nanoHUB simulation tools a lot more engaging compared to courses that only use homework, readings and lectures.   For individual responses of each instructor's students see Figure 4.

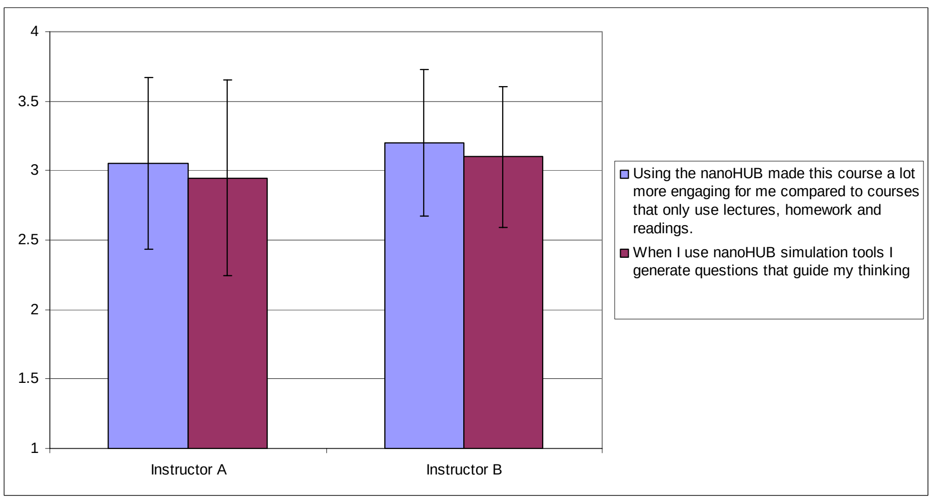

Figure 4: Students' responses related to the professors' instructional approaches

Rationale for the Instructors of incorporating these tools includes first of all the flexibility of the application to compute the exact solutions as we have explained above. Second, the flexibility of the tool in allowing students test and analyze several models with different types of outputs and graphs. Third, the capability of the tool to analyze the model at different steps or points in time, which compared to a physical model this cannot be done. And fourth, the simulation tool provides the user the capability to "see" what in a physical model cannot be seen. For example, Instructor A emphasized the idea to "see how atoms behave" and Instructor B emphasized that "what the simulation allows you to do is to look inside the device". In addition, each nanoHUB simulation tool includes pre-built-in models, which serve as scaffold for students within their initial interactions with the simulation tools.

An indicator of students' perception of the above mentioned features was identified by asking them whether they consider nanoHUB as easy to use. Students responded positively by indicating with a 3.2 average score that nanoHUB is easy to use.

Instructor A and instructor B seem to incorporate the simulation tools in an efficient way. Efficient in the sense that students are able to apply their knowledge to solve practical situations close related to students' areas of interest, as well as efficient in the sense that they provide to their students opportunities to reinforce concepts learned in class with homework assignments that allow students multiple opportunities to practice, comparison, and reflection. Regarding to the tool, nanoHUB resource appears to be an appropriate tool for academic use because the students report that it is accessible to their current skill levels. This may be due to the fact that both instructors A and B devote class time to demonstrate and explain the simulation tool. This may also be due to the particular characteristics of nanoHUB simulation tools of having an intuitive user interface. Finally, the difference reported by instructor A students' in ranking with an average score of 2.6 the relevance of the simulation tool to their areas of interest may be correlated with the frequency of use, because while instructor A students' used one time during the semester, instructor B students' used it in almost every homework assignment.

Conclusions

Preliminary results indicate the potential of integrating the nanoHUB simulation tools into formal learning experiences. Instructors interviewed have leveraged its potential using nanoHUB simulation tools in providing students with authentic learning experiences in which knowledge was successfully applied to practical applications. The students' surveys show favorable results in how professors incorporate nanoHUB simulation tools to learning experiences in different disciplines. Some of the differences between the groups may be related to the type of discipline which is being taught, as well as to different instructional approaches. Perhaps the role of the user interface is also playing an important role. But clearly more detailed research studies are required aiming to identify if instructors who teach undergraduate level courses follow similar approaches, and if these undergraduate students perceive the learning experiences favorable. Therefore, next steps include a) interview and conduction think aloud protocols with students from undergraduate and graduate level courses, b) interview the rest of the professors in order to make a deeper analysis identifying factors of success and failure and c) identify and interview professors who teach undergraduate level courses and who are incorporating nanoHUB simulation tools. Informed by these results, interventions will be designed considering factors found to be of success; these interventions will be mainly focused to undergraduate level courses as well as courses in which students' expectations range from moderate to low.

Future research topics that will inform better ways of incorporating simulation tools to learning experiences will include to ways in which we can increase nanoHUB potential as a learning resource that is developmentally appropriate as well as ways in which experts use the nanoHUB as an expert tool to think with. It is anticipated that the results from this research, will provide curriculum developers as well as computational simulation tools developers with a stronger foundation from which to design simulations for learning as well as the instructional materials that accompany them.

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