Fall 2014

Online Simulations For Conceptual Understanding Of Thermoelectric Devices

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Recommended Citation

Uribe, Maria de Rosario, "Online Simulations For Conceptual Understanding Of Thermoelectric Devices" (2014). *Open Access Theses*. 390.
https://docs.lib.purdue.edu/open_access_theses/390

Graduate School Form 30
(Updated 11/20/2014)

PURDUE UNIVERSITY
GRADUATE SCHOOL
Thesis/Dissertation Acceptance

This is to certify that the thesis/dissertation prepared

By Maria del Rosario Uribe

Entitled
ONLINE SIMULATIONS FOR CONCEPTUAL UNDERSTANDING OF THERMOELECTRIC DEVICES

For the degree of Master of Science

Is approved by the final examining committee:

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Head of the Department Graduate Program Date

ONLINE SIMULATIONS FOR CONCEPTUAL UNDERSTANDING OF THERMOELECTRIC DEVICES

A Thesis
Submitted to the Faculty
of
Purdue University
by
Maria del Rosario Uribe

In Partial Fulfillment of the
Requirements for the Degree
of
Master of Science

December 2014
Purdue University
West Lafayette, Indiana

To my dad, my mom, my sister and Milito

ACKNOWLEDGEMENTS

First, I would like to thank my beloved husband for his unconditional help.

I would like to express my most sincere thanks to Prof. Alejandra Magana for her constant support as my major professor.

I would like to thank Dr. Ali Shakouri and Dr. Je-Hyeong Bahk for their interest in this project.

I am grateful to Dr. Benes for being part of my graduate committee and for providing his advice to the improvement of this thesis.

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LIST OF ABBREVIATIONS

HP – High Performers

LP – Low Performers

TAM – Technology Acceptance Model

TE Device - Thin-Film and Multi-Element Thermoelectric Devices Simulator

TE Material Properties - Linearized Boltzmann transport calculator for thermoelectric materials

TE System Optimization - Thermoelectric Power Generator System Optimization and Cost Analysis

GLOSSARY

adoption – “a decision to make full use of an innovation as the best course of action available” (Rogers, 2003, p. 473).

computer simulations- “interactive computational model with user control of specific variables (inputs) and multiple methods for displaying common relationships of interests (outputs, e.g. graphs) to expert scientist perfecting the models or engineers using them to design devices)” (Magana, Brophy and Bodner, 2009, p.2).

inquiry-based learning – “learning- mechanism by which a person learns through the active exploration and interpretation of the natural or material world” (Exploratorium Institute of Inquiry, 1996).

thermoelectric devices- “semiconductor systems that can directly convert electricity into thermal energy for cooling or heating or recover waste heat and convert it into electrical power” (Bell, 2008, p. 1457).

ABSTRACT

Uribe, Maria del Rosario. M.S., Purdue University, December 2014. Online Simulations for Conceptual Understanding of Thermoelectric Devices. Major Professor: Alejandra J. Magana, Ph.D.

Computer simulations have been extensively used with educational purposes. However, the successful implementation in order to improve learning has been a matter of debate in research in education. The purpose of this case study is to analyze how a set of computer simulations can improve student understanding of thermoelectric devices. The study was developed in a learning context characterized by the advanced degree of difficulty of the topics treated, the high academic level of education of the students, and the online nature of the learning environment. As part of the course, students were provided with instructional materials that guided the simulation practice; a homework assignment and an instructional assessment were the strategies used for this purpose. Learning gains, instructional support effect, and students' perceptions about the course were investigated.

Students significantly improved their conceptual understanding of thermoelectric devices. Yet, the overall performance was considered as moderate. Neither the homework assignment nor the instructional assessment had an effect on the learning gains of the students. Student perceptions about the simulations were positive. This satisfaction was not associated with the student performance on the learning tasks.

These results support the agreement that computer simulations have positive effects on student learning gains. The controversy of the instructional support findings can be explained by the difference on the learning context in which this study was developed when compared to the existing research on this field. Further research is recommended on how to enhance the user experience with the simulation through the use of different strategies for inquiry-based learning. Particularly, more studies for higher education and online learning are encouraged.

CHAPTER 1. INTRODUCTION

1.1 Introduction

The last decades have witnessed the expeditious and vast expansion of computer technologies. Computers and the internet have spread around the world, increasing their availability to inhabitants from every region. As in many other areas, the field of education has been directly influenced by this technological growth (Vogel et al., 2006). Computational and web-based tools have been widely employed as teaching materials (Jimoyiannis & Komis, 2001), and one of the most common examples of this influence is the introduction of computer simulations in educational environments (Adams et al., 2008a). Computer simulations have been defined as computer-based interactive tools that represent the model of a system. The simulations allow the users to control some input parameters in order to obtain and analyze the corresponding output (Magana, Brophy , & Bodner, 2009). The hidden mechanism in which its operation is based encourages students to discover the underlying conceptual principles of the system studied (Alessi, 2000).

This approach also supports inquiry learning by the process in which the students formulate questions and hypotheses, test parameters, and state conclusions (Magana et al., 2009; Trundle & Bell, 2010). As a result, these tools have been claimed by researchers and educators as an opportunity for students to study systems that in the real world cannot be operated, or for complex phenomena that are not easy represent and are often hard to understand during a traditional lecture (Magana, Brophy, & Bodner, 2012). Examples of these situations are the un-observable phenomena and the experimentation in distant learning (Campbell et al., 2002). Additionally, a recognized advantage of computer-based simulations over hands-on laboratories is the possibility to simplify the modeled system and highlight specific elements and relations for the learner (de Jong, Linn, & Zacharia, 2013).

Several researchers have explored the impact of using computer simulations for educational purposes (Smetana & Bell, 2012). Whether they increase student understanding or not is one of the most explored questions when using these tools, either as a complement or a replacement of traditional teaching materials. The results are controversial. Although most of the published studies demonstrate the positive effects of computer simulations on student learning (Rutten, van Joolingen, & van der Veen, 2012; Smetana & Bell, 2012), there are some cases in which simulations have not shown a positive impact on learning. Moreover, researchers and experts have highlighted the importance of a structured instructional support for the students using these tools (Njoo & de Jong, 1993; Winn, 2002; Trundle & Bell, 2010; de Jong et al., 2013). Assignments, scaffolding and experimentation hints are some of the strategies that have been successfully used for student guidance (de Jong, 2006). When these techniques are compared, no significant differences on their effect on student learning have been found (D’Angelo et al., 2014).

Another crucial component in the achievement of learning goals is student motivation for operating the simulation (Dickey, 2005; Adams et al., 2008a). The individual perceptions are imperative in the assessment and the prediction of future use of the tool. There is a long history of research on the elements that influence the decision of the user to accept and adopt an innovative technological product. In general, previous research has shown that student attitudes toward the operation of simulations are positive. Nevertheless, this view is clearly subject to the design and performance of a specific tool (Adams et al., 2008b). An adequate interface design and instructional motivation are key elements in student engagement with the simulation (Adams et al., 2008a).

1.2 Significance

Experimentation boosts inquiry learning processes, and therefore, it has been demonstrated to improve student conceptual understanding (de Jong et al., 2013). Virtual experimentation with online simulations seeks to provide students with a similar experience to that offered by real laboratories in situations where the physical experimentation is not possible. Simulations provide the advantage that students can "experiment" with non-visible phenomena or from a distant location (Ma and Nickerson, 2006).

In the specific case of engineering, simulations help students visualize and understand a system's working principles and design. In fields such as nanotechnology or thermoelectricity, they represent a huge opportunity to illustrate systems that are not possible to be seen and manipulate in the real world, or that would be too complex or expensive to be taken to a learning environment (Magana et al., 2012; Bahk et al., 2013). Providing students with this type of experimentation has been shown to be an essential part of student training in engineering tasks and to promote student inquiry learning (Baltzis and Koukias, 2009). In spite of these advantages, there is still controversy on their effectiveness for educational purposes. The advantages that these tools represent highlight the need to understand how they should be implemented in education in order to achieve the desired learning outcomes.

This case study explored the effect of implementing a set of computer simulations, which were originally created with research purposes, in a learning context characterized by (1) the expense in visualizing the system that is being studied, (2) the high level of difficulty of the concepts to be taught, (3) the graduate and higher level of education of the students, and (4) the online nature of the learning environment. Few research studies have been developed to investigate the last two components.

1.3 Statement of purpose

This case study aimed to identify the effects of computer simulations in supporting the conceptual understanding of thermoelectric devices. The study hypothesized that, by incorporating a set of computer simulation tools in an online thermoelectricity course, student understanding of thermoelectric devices is enriched. Student learning gains after being exposed to the computer simulations in the course were evaluated. The role of instructional support and advantages for different learning conditions were also analyzed.

Student perceptions helped to identify the user acceptance towards the technological innovation. Participants' comments about the simulations give an insight concerning the characteristics of the simulations that determine their engagement and motivation to continue using the tools. Furthermore, these feedback can contribute to the improvement of the design of the simulations and its incorporation into the course.

1.4 Scope

This study was developed in the context of the online course "Thermoelectricity: From atoms to systems", in the instructor led section offered by nanoHUB-U during October-December, 2013. Within this course, three computer simulations were introduced with the objective of providing students with a virtual type of experimentation. The goal of this case study is to uncover students' learning improvements and perceptions about the computer simulations they used as part of this course.

1.5 Research Questions

The guiding research questions for this study were:

1. Can the use of computer simulations in an online course improve student understanding of thermoelectric devices?
2. What are student perceptions about the incorporation of computer simulations in an online thermoelectricity course?

1.6 Assumptions

This study is based on the following assumptions:

1. Participants have previous knowledge on thermoelectricity, with a level similar to the requested in the course description. The level corresponds to senior undergraduate and graduate students, and researchers in the field of engineering and thermoelectricity.
2. Students were honest and gave their best effort in their responses to the learning assessment materials.
3. Students completed all the learning materials in the requested order.
4. Students have experience in the use of computers and internet.
5. Students' participation on the study did not affect the final grade obtained in the course. Therefore, voluntariness is valuable.

1.7 Limitations

This study has the following limitations:

1. The study was developed in an online course in the field of thermoelectricity.
2. The study was developed for three computer simulations related to thermoelectric devices.
3. The participants are senior undergraduate and graduate students, and professionals working in the field of thermoelectricity.
4. The data was collected on the fall semester of 2013.

1.8 Delimitations

This research has the following delimitations:

1. The study attempts to analyze the effect of the use of computer simulations on the specific field of thermoelectricity.
2. The study was designed for students with a high level of technical background.
3. The analysis is based on the data collected from learning assessment materials in the course.

1.9 Summary

Computer simulations offer several advantages for STEM education. Their accessibility, flexibility and interactivity make them a great opportunity to introduce phenomena that otherwise would be unavailable to students. Educational research aimed at assessing the relevance of these tools has not been conclusive. Instructional design and student engagement are some of the factors that influence the results.

The purpose of the present case study is to assess the effects of integrating computer simulations for learning in an online thermoelectricity course. The context of the study is characterized by the advanced academic level of the topic and the online nature of the learning environment. Conceptual understanding and perception measures will be analyzed in order to assess the impact of these simulations in the specific context of this course.

The following chapter is a review of the existing literature about the implementation of computer simulations in the field of education. An outline of relevant research studies is presented as a basis for the current case study.

CHAPTER 2. LITERATURE REVIEW

Computer- based tools are becoming more widespread around the world every day, with several known applications in the industrial and scientific fields (Marepalli, Magana, Taleyarkhan, Sambamurthy, & Clark, 2010; Lindgren & Schwartz, 2009). As a result of their increased availability and rapid development, they have gained great relevance in education (Rutten et al., 2012). Computer simulations are some of the technological tools most commonly developed as instructional materials (Adams et al., 2008a). De Jong and van Joolingen (1998), defined a computer simulation as “a program that contains a model of a system (natural or artificial; e.g., equipment) or a process” (p.180). However, Magana et al. (2009) proposed a definition that takes these computational tools more closely related to the educational field. They defined it as an “interactive computational model with user control of specific variables (inputs) and multiple methods for displaying common relationships of interests (outputs, e.g. graphs) to expert scientist perfecting the models or engineers using them to design devices)” (p. 2). In a more practical context, Cannon-Bowers and Bowers (2007, p. 318) stated that they are “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” (as cited in Magana, Brophy, and Bodner, 2010, p. 2).

De Jong and van Joolingen (1998) classified computer simulations for educational purposes in two categories, which correspond to conceptual and operational simulations. The first type illustrates concepts and the second type demonstrates procedures. This last category mentioned is usually intended to train people on a specific new task from their own area of expertise (Lindgren & Schwartz, 2009). For the purposes of this manuscript, the focus will be on the first type; the conceptual simulations.

The goal of conceptual simulations in education is for students to actively explore and understand a system's behavior; and lately, particularly in engineering, how its design can be modified and/or enhanced (Alessi, 2000). The general working mechanism consists of a predetermined system model, where the user is able to modify certain parameters and receive an output. The format of the output could vary from graphs, images, charts, and tables (de Jong & van Joolingen, 1998). These visual results generate an idea to the user on how the system changes according to the information inserted (Brophy, Magana, & Strachan, 2013). The underlying calculations that transform the parameters into the final output are usually hidden, and need to be inferred by the learner. This mechanism is called a black-box model and has been recognized to encourage the student to focus on the conceptual understanding, rather than to spend most of their time on manual calculations (de Jong & van Joolingen, 1998; Alessi, 2000). Furthermore, this exercise in which students are repeatedly formulating a hypothesis, revising the results, and drawing conclusions, stimulates students' learning through inquiry (de Jong, 2006).

From a practical point of view, the applicability of computer simulations in the educational practice relies on different characteristics. For example, the accessibility is given by the increased computer availability and the spread of internet, which has turned computer simulations into a popular learning tool (Marepalli et al, 2010). These tools allow students to be exposed to situations that otherwise would imply a high economic and logistic, or even dangerous, cost (Winn, 2002); it can replace specialized equipment or travel for data collection (Lindgren & Schwartz, 2009). Another characteristic is the interactivity of the student with the model, which is crucial in the user engagement and increased inquiry learning (Edelson, Gordin & Pea, 1999; Winn, 2002). The development of sophisticated interfaces with diversity of design features, gadgets, and graphics, make both input and output more realistic and attractive to the users (Adams et al., 2008b; de Jong & van Joolingen, 1998). The independence given to the student is another advantage of using simulations as instructional material; students are autonomous and allowed to follow their own pace and, also, to practice outside the classroom (Brophy et al., 2013).

The pertinence of using computer simulations in specific cases has also been claimed by some authors. They become pointedly useful when there is a need to provide an experimentation or complimentary practice to large groups of students or to distant learners (Ma and Nickerson, 2006). Likewise, in spite of the less documented use of computer simulations for nanotechnology education, Srivastava and Atluri (2002) stressed the importance of their development for the representation, demonstration, and analysis of nanomaterials and nanodevices. The difficulty that it brings to perform real experimentation in this field, where the nano-length dimension is prevalent, has led to view modeling and simulations as a crucial component in the field advancement (Srivastava & Atluri, 2002; Magana et al., 2012). In thermoelectricity, online simulations are a great option to simplify and represent complex energy systems to the student (Bahk et al., 2013). Undergraduate students are not overwhelmed with the complicated equations, and graduate students are exposed to an easy way to do research on thermoelectricity (Bahk et al., 2013).

Several research studies have been developed in order to probe the cited advantages and to encounter better implementation techniques in the classroom. These questions have led to a long research history on how computer simulations can be successfully implemented in education (de Jong & van Joolingen, 1998).

2.1 Evidence of learning with computer simulations

Within the development of computer learning environments, simulations have played an essential role (National Science Foundation, 2008). Certainly, they have been, and will continue to be, of great relevance with regards to science and engineering developments and, therefore, for major societal problems (National Science Foundation, 2006).

Perhaps the greatest concern regarding computer simulations in educational research has been the impact that their employment, as an instructional resource, has on the student learning process. Most of the experimental research studies developed to answer this question show a positive conclusion on the learning outcomes when simulations are implemented (Rutten et al., 2012; Smetana & Bell, 2012). Yet, it has also been claimed by experts that context and support structures play a major role in the success of these tools. The debate is open and further research is needed in order to discover how these relationships work (Njoo & de Jong, 1993; de Jong & van Joolingen, 1998; Trundle & Bell, 2010).

Two literature reviews were developed by Rutten et al. (2012) and Smetana and Bell (2012) with the purpose of identifying the effects of introducing computer simulations into science education and how this practice can be improved. In the first review, Rutten et al. (2012) performed a qualitative analysis and included the calculation of effect sizes and Cohen’s d for the analyzed papers. Seven research studies in the fields of biology, engineering and physics were placed in the category of concern for this research entitled “Enhancement of traditional instruction with computer simulations” (p. 138). Only two of the seven papers reported unfavorable results.

The research developed by Stern, Barnea and Shauli (2008) intended to assess the learning effects of introducing a computer simulation about kinetic molecular theory to a middle school physics course. This dynamic simulation allowed the students to visualize the particles in constant motion and under different conditions, such as changes in temperature and pressure. Although the results showed better performance in the group that was using the software, there was not meaningful learning gain in any of the groups. Moreover, the control group averaged better scores in the long-term learning assessment. The authors attributed this outcome to the instructors’ lack of preparation, which drove the students into a poorly guided practice with the computer simulations (Stern et al., 2008).

The other study that reported unfavorable results was developed by McKagan, Handley, Perkins and Wieman (2009) in the physics discipline. Its purpose was to improve teaching methodology for the photoelectric effect, which is an essential concept for the field of quantum mechanics and has been shown to be difficult for students to understand. In the context of the study, professors from a large course in physics for engineering students introduced *The Photoelectric Effect* interactive simulation as part of their instructional materials. Students demonstrated an increased ability to predict outcomes related to the photoelectric effect, but their capability to make connections between their multiple observations and to make inference from these connections was not pertinent. The authors explained these findings as a consequence of deficient reasoning skills among the students, which may be due to a lack of reinforcement of these competences in long-term physics education (McKagan et al., 2009).

Among the studies that encountered increased student understanding is the research of Jimoyiannis and Komis (2001). A computer simulation was successfully used to overcome the cognitive constraints of specific concepts in kinematics in secondary school students. The tool about Newtonian mechanics was called *Interactive Physics*. Students were able to change parameters, such as body masses and the gravity constant. They could make use of graphical representations to measure, understand and relate different physical properties, such as the velocity and acceleration. Based on their performance in four assessment tasks, the group of students who used the tool had a significantly better understanding of the topic than the students in the control group, who did not use the simulation. The first ones were also able to overcome their misconceptions of velocity and acceleration.

Baltzis and Koukias (2009) showed how the use of IT tools in an undergraduate course in analog electronics improved the academic results and the interest of the participants in the use of IT tools in the learning process. The courses in which the simulations were incorporated showed a ten percent increase in the number of students passing the midterm and final exams.

In the second review by Smetana and Bell (2012), 61 articles were found in which the effectiveness of computer simulations for teaching and learning was analyzed. These correspond to diverse disciplines of science and education levels from K-12 to college. An inductive qualitative methodology was implemented for the data analysis. According to the purpose of each study, the authors of the review classified the papers in four categories; 22 papers included in the category 'Promoting content knowledge', which was selected for its application to this research. Most of these papers found a positive effect regarding the implementation of computer simulations in the classroom, when either compared to traditional lectures or other instructional resources. Furthermore, the review authors argued that those papers that report unsatisfactory results have been criticized for methodological mistrust.

The SRI Education (D'Angelo et al., 2014) developed a study in order to provide a systematic review and meta-analysis of the literature about the effect of computer simulations on science, technology, engineering, and mathematics (STEM) education at the K-12 level. The 59 quantitative papers selected for the analysis lead to the conclusion that the use of computer simulations is beneficial for the achievement of positive learning outcomes. When factors, such as student group size, simulation flexibility, and curriculum design, are tested to describe the influence that these ones have on the simulations success on learning improvement, no significant effects have been found. On the other hand, design and instructional properties of the simulations can slightly increase the learning gains. Those characteristics include supporting scaffolding features and additional representations. No significant differences in the learning process were found between types of simulations or between the varied types of instructional attributes of the simulations (D’Angelo et al., 2014).

Other papers in the field of science that obtained positive results include a research study by Rivers and Vockell (1987), which showed how computerized simulations could help students increase their problem solving abilities. In the experiment, students exposed to the simulations performed as well as the control group; moreover, when a guided discovery was provided, the performance improved and surpassed the other participants. The results from an experiment developed by Finkelstein et al. (2005) showed that students using simulations in substitution of the real laboratory equipment had better performance in the conceptual assessment. They emphasized the advantage that simulations provide for improving students’ direct access to concepts.

2.2 Evidence of learning with computer simulations in engineering education

For approximately four decades, computer simulations have also been extensively used in engineering education (Magin & Reizes, 1990); they are regarded as an optimal way to replace physical laboratories, which have been proved to reinforce conceptual knowledge. Virtual experimentation is especially relevant when considering online engineering education (Striegel, 2001); virtual experimentation has become a practical mechanism to bring the advantages of laboratories to a numerous and geographically dispersed public (Balamuralithara & Woods, 2008; Ma & Nickerson, 2006).

Computer simulations allow learners to experiment with the application of numerical computer-based techniques that explain a system operation, when otherwise the explanation of these methods would be limited to lectures and tutorials (Smith & Pollard, 1986). This type of experimentation can also be regarded as a training of student design skills; they learn to make decisions, implement correct methods and interpret the results (Magin & Reizes, 1990). Additionally, computer simulations can help reduce the exhaustive work load when these numerical calculations need to be performed by students; the attention and time consumed in these tasks can be shifted to the analysis of the question under investigation (Smith & Pollard, 1986).

In spite of their expanded use for instructional purposes, less experimental research studies have been performed about simulations in engineering education when compared to scientific disciplines.

In 1971, De Vahl Davis and his colleagues lead the incorporation of simulation software of different engineering systems at the University of New South Wales. The simulation software was implemented as a supplement to traditional laboratories, with a greater emphasis on those systems that could not be physically manipulated. In 1973, they found that these tools had a positive effect on students' learning gains when compared to purely traditional instruction. They also raised concerns about the poor attention that students were giving to the error magnitude and the validity of the calculations, which were clearer in real experiments (Magin & Reizes, 1990).

Smith and Pollard (1986) addressed the positive results obtained by the Computer Assisted Teaching Unit (CATU), at the Queen Mary College, UK, when using different simulations in the areas of aeronautical, hydraulic, electrical, mechanical and nuclear engineering education (Smith and Pollard, 1986). Students from this college had the opportunity to participate in laboratory sessions using multiple simulations, where they were accompanied by a graduate student and a professor. The qualitative data obtained between 1973 and 1979 in this institution points out the positive perceptions of students (Smith & Pollard, 1986).

Using a "lesson study" methodology, Fraser, Pillay, Tjatindi and Case (2013) found a significant improved understanding of students regarding fluid mechanics. The simulations were used by sophomore engineering students and included a strong visualization component. The experimentation process with the simulations was guided with a worksheet. Additional results of the study concern the improvements to the simulations and the guidance sheet (Fraser et al., 2013).

Ma and Nickerson (2006) performed a revision of 39 studies with the goal to compare three different types of laboratories (hands-on, simulated and remote) engineering education. With the exception of one article, the authors found a general consensus, which states that there is no difference between the three kinds of laboratories in terms of their effectiveness in education. The negative conclusion at which Engum, Jeffreis and Fisher (2003) arrived can be explained by the nature of the topic treated and the intravenous catheter placement, which evidently demands a lot of physical skills training.

2.3 Disadvantages of using computer simulations in education

Some of the sources of the problems encountered for the incorporation of these tools in the teaching process are: (1) the difficulty of the exploratory learning process (Njoo & de Jong, 1993); (2) the lack of previous knowledge (Magana et al., 2009); (3)

the complexity of the modeling task (Clariana & Strobel, 2007, in Magana et al., 2009); (4) students' adoption of the innovative teaching materials; and (5) graphical design deficiencies (Adams et al., 2008b; Rieber, Tzeng, Tribble, 2004).

Perhaps one of the most recognized difficulties in computer simulation effectiveness in education is the lack of a defined instructional approach. In this way students are commonly confronted by the learning process without any guidance; a process that results in deficient knowledge acquisition (Njoo & de Jong, 1993; Davies, 2002; Trundle & Bell, 2010). It has been demonstrated that, given that students can be overwhelmed with extreme freedom and complexity, different strategies that guide the student through the use of simulations can enhance inquiry learning (van Berkum & de Jong, 1991; Edelson, Gordin & Pea, 1999).

In engineering, high criticism is given to the limitation that it represents in experimentation. As a result, not only students learning will be restricted to the software reliability, efficiency, and capability, but also their creativity may be discouraged (Magin & Kanapathipillai 2000; Balamuralithara & Woods, 2008). Some authors even claim that these tools cannot be regarded as a substitute for real laboratories due to the lack of reality in the results, the decreased practice with lab equipment management, the relevance of software control, and the constraint to imagination and curiosity (Magin & Kanapathipillai 2000; Balamuralithara & Woods 2008). However, the same authors, recognize the difference when working with mature students, which will not be affected by most of these limitations.

2.4 Instructional support for learning with simulations

Like other computer-based tools, computer simulations promote inquiry-based learning (Edelson, Gordin & Pea, 1999; de Jong, 2006). In this type of learning, the student is immersed in an experience closer to the way that science actually works; it starts with questions that lead the student through the search of a solution in an open-ended processs (Edelson, Gordin & Pea, 1999; Quintana et al., 2004). In this authentic and challenging process, the student is required to formulate, explain and apply conceptual knowledge (Edelson, Gordin & Pea, 1999; Quintana et al., 2004). The benefits of this type of learning include the gain of a deeper and intuitive conceptual understanding (de Jong, 2006). But, in spite of the student-centered condition of this type of learning, when guidance is absolutely absent, inquiry is not effective with regards to student learning improvement. In fact, the challenges and opportunities of implementing inquiry-based learning to obtain beneficial results has induced several research efforts (Quintana et al., 2004).

As for computer simulations, several researchers have addressed their concerns in relation to their implementation in education without any type of instructional support (Rutten et al. 2012; Smetana & Bell 2012; D'Angelo et al., 2014). Students need to have some type of directions while they operate the simulations (Smetana & Bell 2012). It is imperative to note the importance of improving both the simulation's design (Adams et al., 2008a,b) and the way they are introduced as an instructional resource in the classroom (de Jong, 2006). Both of these factors can influence the way inquiry learning is supported.

Major problems have been identified in the way students follow the inquiry procedures (de Jong & van Joolingen, 1998). The first problem confronted is the need of corresponding background knowledge (de Jong & van Joolingen, 1998). If that knowledge is unsufficient, the entire inquiry process is weakened (de Jong & van Joolingen, 1998). Other types of struggles that arise in the process are with the generation of a hypothesis, data collection, analysis, and interpretation (Edelson, Gordin & Pea, 1999); however, with the proper base of knowledge and the incorporation of some kind of support, the researchers have shown that these obstacles can be overcome and make way for positive outcomes from inquiry learning (de Jong, 2006; Smetana & Bell 2012).

Some of the support structures include 1) direct teacher direction (Smetana & Bell 2012), 2) permanent feedback (Smetana & Bell 2012), 3) reflection (Smetana & Bell 2012), 4) assignments (de Jong, 2006; Smetana & Bell 2012), 5) records of the experimentation history, 6) scaffolding (Quintana et al., 2004; de Jong, 2006), 7) explanations and further information (de Jong, 2006), 8) fading tools that provide specific information at specific moments of the simulation (de Jong, 2006), and 9) experimentation hints and prompts (Lin & Lehman 1999).

Assignments are a recommended way to allow the student to extract a large amount of knowledge from the computer simulations; in this sense, students will be prompted to ask better questions, identify relevant variables, and explain the results (Swaak, van Joolingen, & de Jong, 1998). According to the type of questions posed, solving the problem that has been posed can lead to finding relations among variables, predicting results, and/or explaining a phenomenon (de Jong & van Joolingen, 1998). The research provides evidence of the positive effect of accompanying simulations with assignments on learning (de Jong, 2006). For instance, Swaak et al. (1998) provided an assignment to support the computer simulations' incorporation. The students who had access to the assignment outperformed the ones who did not.

In the literature review created by the SRI Education (D'Angelo et al., 2014), no difference was found between multiple support strategies when tested on their effects on the benefits obtained from computer simulations. The purpose of applying any of those strategies should be to increase the higher-level thinking and help students guide their inquiry (Smetana & Bell, 2012). The methodology to provide students with convenient support should be further studied (de Jong & van Joolingen, 1998).

2.5 User Acceptance of Computer Simulations in Education

As mentioned above, there are several factors related to the effect that computer simulations have on the learning process; among these, the adoption of innovative tools by students is one of the most important. This user acceptance is highly relevant for the success of any technological tool implemented in different fields (Kay & Knaack, 2009). Multiple theories have arisen as an attempt to explain the factors that determine how a technological tool is perceived by the users; the final goal is to predict its future use. Besides, there has been a large amount of research concerning the acceptance of technology as a results of the importance of this problem (King & He, 2006).

In education, the engagement of the user is crucial as it compromises the effectiveness of the teaching material on students' understanding. Motivation is indispensable to increase the students' cognitive effort (Kay & Knaack, 2009). According to the last review of studies on this topic, students' perceptions about the advantage of using computational simulations are positive in all cases (Smetana & Bell, 2012). Students believe that the implementation of the tools has improved their performance; and moreover, they allude to multiple advantages (Smetana & Bell, 2012).

Similar positive results were observed in two studies developed by Magana, Brophy, and Bodner (2008, 2012). In the first study (2008), the objective was to study the experts' use of computer simulations from the nanoHUB infrastructure in education. The students' feedback to the way professors used the simulations in their courses was favorable. Some of the differences identified in their perceptions between instructors are hypothesized to be due to the academic field and the instructional support provided (Magana et al., 2008). In the second study (2012), the researchers analyzed the perceptions of science and engineering students regarding the simulations in nanoHUB. Students in different academic levels, undergraduate and graduate, reported positive opinions; however, the undergraduate students had a perception less favorable. Possible reasons for this result are the lack of required skills or knowledge (Magana et al., 2012).

An approach to students' perceptions leads to simulation design and support improvement, accomplishing the necessary engagement required from the user. And, as it was said before, student motivation is an essential pillar for the conceptual understanding acquisition.

2.6 Summary

The use of computer simulations has been shown to be beneficial to increase students learning gains in the different fields of science and engineering. However, there are multiple factors that can affect these positive outcomes. Among those conflicting factors, the instructional support provided to the students and the user adoption of the tools are some of the most studied.

Several research studies have addressed the effect of using instructional materials to support the inquiry-based learning during experimental practices of the students with the computer simulations. Experts and researchers claim the importance of offering students some type of guidance to guarantee the conceptual understanding improvement. Although there are several strategies that have been successfully used, further research is needed to identify consistent and sustained learning effects.

Students have demonstrated to have a positive attitude toward computer simulations. They think these tools do not only help them improve their learning, but they also highlight different advantages of computer simulations. Users' feedback is critical in order to ensure the tool success with educational purposes as well as to improve student engagement with the experimental tasks.

CHAPTER 3. THEORETICAL FRAMEWORK

Two frameworks guided the implementation of this study: inquiry-based learning and technology acceptance model. The first one supports the assumptions under which computer simulations are able to scaffold the learning process. The latter defines the specific constructs to assess student perceptions and adoption of the simulations.

3.1 Inquiry-based learning

Inquiry-based learning has been defined as the mechanism by which a person learns through the active exploration and interpretation of the natural or material world (Exploratorium Institute of Inquiry, 1996). Therefore, the learner is assumed to be in charge of their own learning process. This opposes to the direct instruction concept, where the educator embraces the responsibility of the transfer of the knowledge to the student (Swaak et al., 1998). The complete inquiry process comprises the following stages: (1) generating questions and hypotheses; (2) designing and executing experiments; (3) building conclusions; (4) evaluating, and (5) monitoring (Simsek, 2010; de Jong, 2006).

According to the amount of teaching influence, inquiry-based learning can be classified in three categories: in the open inquiry category, the student is responsible during the complete learning process, starting with the approach of the questions that will lead the exploration. In the second category, the structured or guided inquiry, the instructor provides a limited number of instructions that accompanies the student through the different stages. In the third category, when the inquiry is coupled, the guidance is stronger at the beginning, so the instructor starts the question generation; but later, the student is challenged to continue by following an opened inquiry methodology (Kong, 2008).

Experts in education have highlighted the advantage of inquiry-based learning for an improved conceptual understanding and the development of strong critical and logical thinking skills (Simsek, 2010). This learning theory advocates that the practice of prediction, observation, and explanation, is a convenient path for building a scientific based knowledge (van Joolingen et al., 2007). These statements have been restrained by educational research, which has uncovered some limitations of the inquiry learning mechanism. Specifically, researchers have argued the need of an active engagement from the student (Simsek, 2010). This motivation is imperative at the beginning, where the curiosity starts the questions generation, and during the rest of the process, where the passion supports the student through the failure and success of hypotheses testing (EII, 1996). De Jong (2006) found that students have difficulties with the practice of the inquiry learning steps; among others, we could mention the connection of data and hypotheses, or the experimental design as particular common mistakes. At the end, these problems may lead them to incorrect conclusions. Several researchers have addressed the importance of some support through the process in order to guarantee the effectiveness of the inquiry learning as the educational approach for student understanding (De Jong &

Van Joolingen, 1998). Also, the development and exploration of cognitive tools could become very useful in order to overcome the deficiencies identified in inquiry-based learning (de Jong, 2006).

Hands-on laboratories have been recognized as a valuable complement of the inquiry learning process. Consequently, in the current technological era, the virtual laboratories have gained a similar acknowledgment (de Jong et al., 2013). Computer simulations, specifically, comprise an attractive tool to develop experimentation on a particular domain (Njoo & de Jong, 1993: Bravo et al., 2006). Using computer simulations allows students to extract a large amount of information and infer the knowledge related to the topic under study (Swaak et al., 1998). These tools represent an advantage over physical experimentation; they can simplify the experiments, and promote students' concentration on a limited number of concepts (de Jong et al., 2013).

3.2 Technology Acceptance Model

The adoption of technological tools has been one of the greatest concerns given their constant and rapid development. The user acceptance models attempt to predict the actual system use of a technological tool by measuring a specified number of key variables in the users' reactions to operating it (Davis, 1989; Venkatesh, Morris, Davis, & Davis, 2003). In 1989, Davis first proposed the Technology Acceptance Model (TAM), which has been one of the most used theories in technology diffusion research (Bagozzi, 2007). This model uses two constructs as the main concepts that affect the future intention to use: the Perceived Usefulness (PU) and the Perceived Ease of Use (PEU).

The first one was defined by Davis (1989) as "the degree to which a person believes that using a particular system would enhance his or her job performance." (p. 320); and the second one as "the degree to which a person believes that using a particular system would be free of effort." (p. 320). In short, the users' adoption of the technological tool is determined by the need and the ease of usage.

After the presentation of TAM, multiple models have been proposed in order to expand the number of constructs that help to explain the individuals' decisions. However, the TAM is still the most common model used in research. The simplicity in the number of measures is the greatest advantage of TAM; a characteristic that has not compromised its effectiveness (Bagozzi, 2007; King & He, 2006).

Although originally it was not developed with this purpose, TAM has been used successfully for several research studies in education (Persico, Manca, & Pozzi, 2014). Selim (2003) demonstrated the effectiveness of TAM to explain users' intention to use an e-learning environment (Park, 2009). Landry, Griffeth, and Hartman (2006) obtained similar results in a research study where the goal was to understand users' perceptions about a learning tool (Park, 2009). Arguing the insufficiency of the model for academic purposes, some other researchers have also tried to extend the original model with specific constructs (Teo, 2009; Buchanan, Sainter, & Saunders, 2013). Effectiveness, perceived access to technical support, compatibility, computer self-efficacy, and perceived affective quality, are some of the variables that have been stated as possible contributors to explain the system use (Persico et al., 2014; Cheung & Vogel, 2013).

3.3 Summary

Computer simulations have been said to promote inquiry-based learning. This learning theory proposes that students learn through the active exploration, and therefore, it is the base for the use of experimental practices in education. In this process, students generate questions, hypotheses, results and conclusions. Although the student is expected to be autonomous, the amount and type of guidance provided in the process can determine the learning outcomes.

The technology acceptance model (TAM) is perhaps the most used theory to assess users' adoption of a technological tool. Its purpose is to determine if the users will continue to use a specific technology, in this case, computer simulations. The evaluation is based in two constructs; the perceived ease of use and the perceived usefulness.

These theories supported the development of the study. The inquiry-based learning theory supports the assumption of the learning effects of computer simulations, and the TAM guided the assessment of students' perceptions.

CHAPTER 4. COURSE DESIGN

The study was developed along with the implementation of an online course called “Thermoelectricity: From atoms to systems”. Within the course, three computer simulations were incorporated with the objective of providing the students with an engaging and experimental activity that could reinforce the information presented in the traditional video-lectures. In this chapter, the learning environment and the computer simulations are described.

4.1 The course “Thermoeletricity: From atoms to systems”

The course is hosted in the nanoHUB-U platform and is opened to students around the world with different academic backgrounds. nanoHUB-U is an initiative that aims to provide graduate students, as well as professional engineers and researchers, with the latest advances in research and technology of nanoscience (Datta & Lundstrom, 2013). This purpose is materialized through the offer of online courses. One of the distinctive characteristics of this nanoHUB-U courses, when compared to other distant courses, is the incorporation of nanoHUB.org simulations as part of the curriculum (Datta & Lundstrom, 2013).

nanoHUB.org is a nanotechnology user facility created and supported by the Network for Computational Nanotechnology (NCN) (Farnsworth et a., 2013). Its goal is to make simulations and modeling accessible to the advancement and research in the fields of nanoscience and nanotechnology (Farnsworth et a., 2013).

The courses in nanoHUB-U can be approached either as a (1) self-paced experience, where no certification is received, or (2) instructor led, where the student needs to work harder in order to receive a completion certificate. Courses are free for the students enrolling in the self-paced section, but a nominal fee of $30.00 is charged to students in the instructor led section (“About”, 2014).

This specific course is recommended for undergraduate seniors, graduate students, and researchers in engineering and physics, who are interested on learning about the basic concepts of thermoelectricity and its application to thermoelectric devices. The course attempts to integrate computer simulations that encourage students to apply modeling techniques in the context of thermoelectric devices. For this purpose, three simulation tools were introduced as part of the teaching material.

4.1.1 Learning Objectives

The general objective of the course was to “develop a unified framework for understanding essential physics of thermoelectricity, their important applications, and trends and directions” (Shakouri, Datta, & Lundstrom, 2013). The main topics treated throughout five weeks are (1) basic concepts of energy conversion in thermoelectricity, (2) thermoelectric transport parameters, (3) nanoscale and macroscale characterization,

(4) thermoelectric systems, and (5) recent advances in thermoelectric materials and physics.

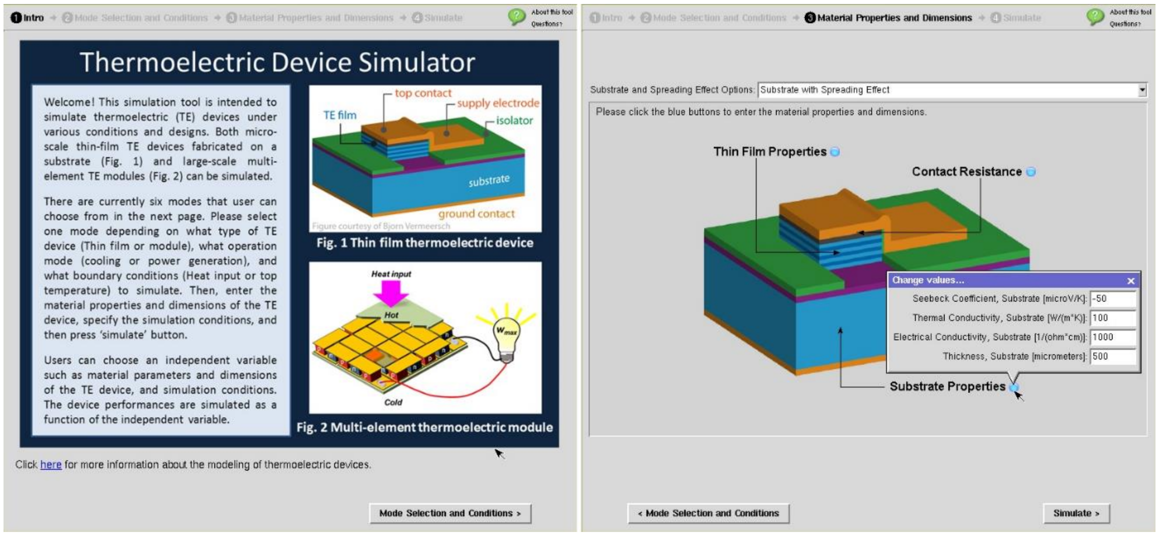
4.1.2 Course Format and Learning Materials

The online course was developed to be five weeks-long using a bottom-up approach. Each week a specific topic related to thermoelectric systems was developed. The teaching materials consisted of (1) video lectures; (2) quizzes related to each video lecture; (3) weekly homework assignments; (4) supplemental material such as related scientific articles; (5) weekly exams; and (6) three simulation tools implemented only during the last two weeks of the course. The quizzes, homework assignments, and exams were all multiple choice questionnaires and were answered online. Only the results of the exams accounted for the final grade of the course; quizzes and homework assignments were scored, but not graded. Also, students could make use of the discussion board to communicate with the instructors or the course managers.

4.2 Computer Simulations

Three computer simulations were introduced during the last two weeks of the course. The three of them are hosted on nanoHUB.org and are available for free to any registered user.

(a) The 'Thin-Film and Multi-Element Thermoelectric Devices Simulator' (TE Device) (Fig. 4.1) was developed by a team of Purdue University students, professors, and post-doctoral researchers at Birck Nanotechnology Center. It simulates micro-scale thermoelectric devices and large-scale multi-element thermoelectric modules (Bahk, Youngs, Shaffter, Yazawa, & Shakouri, 2013).



Welcome! This simulation tool is intended to simulate thermoelectric (TE) devices under various conditions and designs. Both micro-scale thin-film TE devices fabricated on a substrate (Fig. 1) and large-scale multi-element TE modules (Fig. 2) can be simulated.

There are currently six modes that user can choose from in the next page. Please select one mode depending on what type of TE device (Thin film or module), what operation mode (cooling or power generation), and what boundary conditions (Heat input or top temperature) to simulate. Then, enter the material properties and dimensions of the TE device, specify the simulation conditions, and then press 'simulate' button.

Users can choose an independent variable such as material parameters and dimensions of the TE device, and simulation conditions. The device performances are simulated as a function of the independent variable.

Figure courtesy of Bjorn Vermeersch

Fig. 1 Thin film thermoelectric device

Fig. 2 Multi-element thermoelectric module

Click here for more information about the modeling of thermoelectric devices.

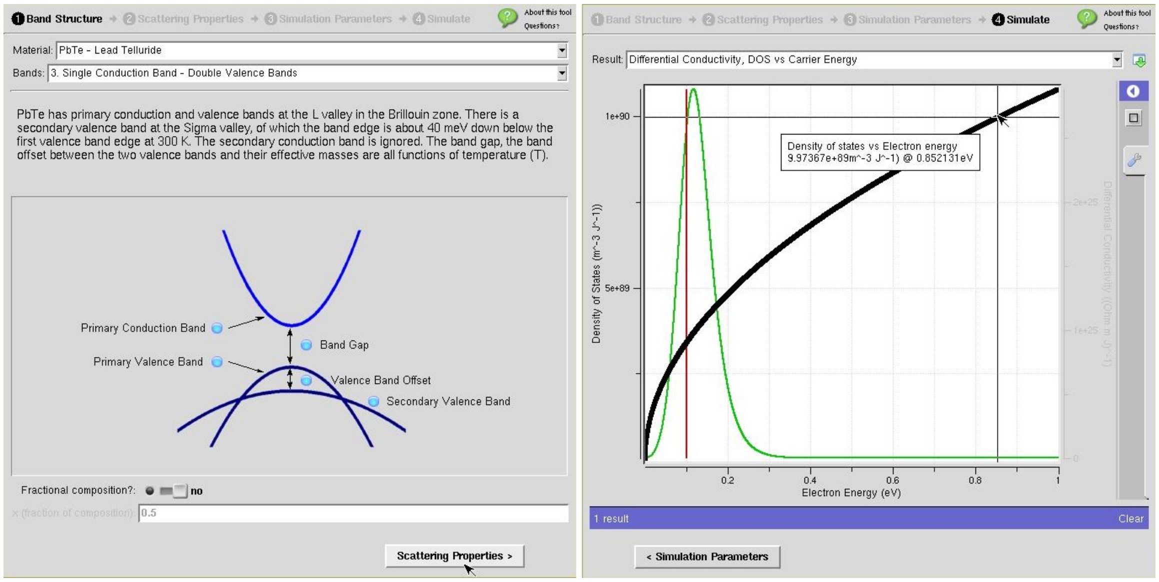
Substrate and Spreading Effect Options: Substrate with Spreading Effect

Please click the blue buttons to enter the material properties and dimensions.

Seebeck Coefficient, Substrate [microV/K]: -50
Thermal Conductivity, Substrate [W/(m*K)]: 100
Electrical Conductivity, Substrate [1/(ohm*cm)]: 1000
Thickness, Substrate [micrometers]: 500

Figure 4.1 Introduction interface of the 'TE Device' simulation and Parameter input interface in the 'TE Device' simulation

(b) The 'Linearized Boltzmann transport calculator for thermoelectric materials' (TE Material Properties) (Fig. 4.2) was developed by a team conformed by experts from Purdue University and University of Texas at El Paso. It uses the linearized Boltzmann transport equation to simulate various thermoelectric properties for any semiconductor material based on the non-parabolic band structure information (Bahk, Post, Margatan, Bian, & Shakouri, 2013).



Material: PbTe - Lead Telluride

Bands: 3. Single Conduction Band - Double Valence Bands

PbTe has primary conduction and valence bands at the L valley in the Brillouin zone. There is a secondary valence band at the Sigma valley, of which the band edge is about 40 meV down below the first valence band edge at 300 K. The secondary conduction band is ignored. The band gap, the band offset between the two valence bands and their effective masses are all functions of temperature (T).

Fractional composition?: no

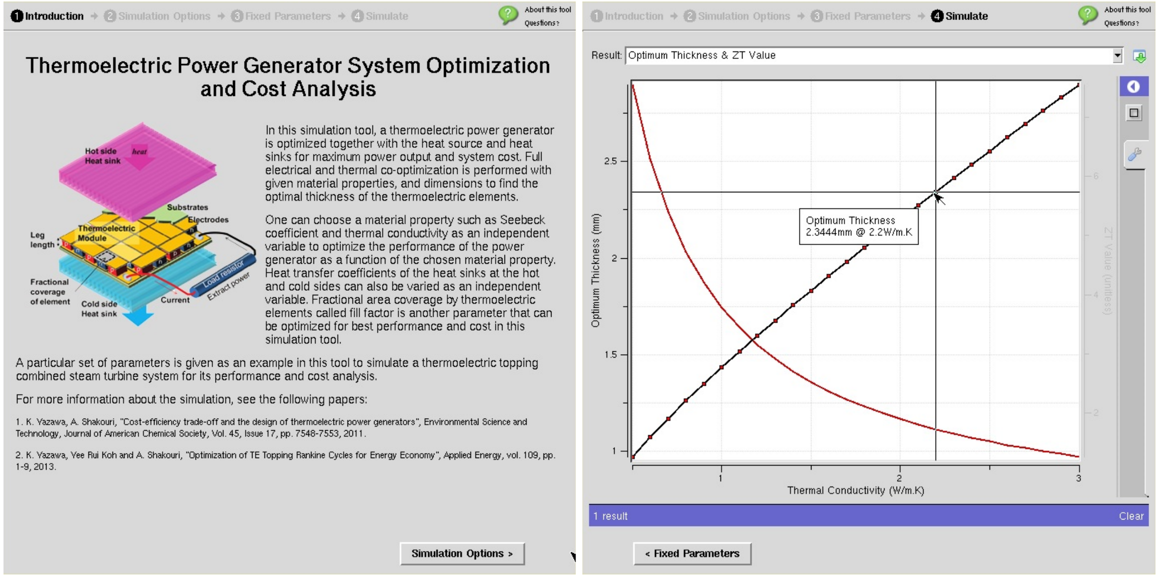
x (fraction of composition): 0.5

Result: Differential Conductivity, DOS vs Carrier Energy

Density of states vs Electron energy
9.97367e+89m^-3 J^-1) @ 0.852131eV

Figure 4.2 Introduction interface of the 'TE Material Properties' simulation and Parameter input interface in the 'TE Material Properties' simulation

(c) The 'Thermoelectric Power Generator System Optimization and Cost Analysis' (TE System Optimization) (Fig. 4.3) was also developed by a Purdue University team at Birck Nanotechnology Center. This simulation calculates cost and efficiency of thermoelectric devices given particular materials features and heat transfer coefficients. The final goal is to learn how a thermoelectric power generator could be optimized in order to achieve the maximum power output and the lowest system cost (Yazawa, Margatan, Bahk, & Shakouri, 2013).



Thermoelectric Power Generator System Optimization and Cost Analysis

In this simulation tool, a thermoelectric power generator is optimized together with the heat source and heat sinks for maximum power output and system cost. Full electrical and thermal co-optimization is performed with given material properties, and dimensions to find the optimal thickness of the thermoelectric elements.

One can choose a material property such as Seebeck coefficient and thermal conductivity as an independent variable to optimize the performance of the power generator as a function of the chosen material property. Heat transfer coefficients of the heat sinks at the hot and cold sides can also be varied as an independent variable. Fractional area coverage by thermoelectric elements called fill factor is another parameter that can be optimized for best performance and cost in this simulation tool.

A particular set of parameters is given as an example in this tool to simulate a thermoelectric topping combined steam turbine system for its performance and cost analysis.

For more information about the simulation, see the following papers:

1. K. Yazawa, A. Shakouri, "Cost-efficiency trade-off and the design of thermoelectric power generators", Environmental Science and Technology, Journal of American Chemical Society, Vol. 45, Issue 17, pp. 7548-7553, 2011.

2. K. Yazawa, Yee Rui Koh and A. Shakouri, "Optimization of TE Topping Rankine Cycles for Energy Economy", Applied Energy, vol. 109, pp. 1-9, 2013.

Result: Optimum Thickness & ZT Value

Optimum Thickness
2.3444mm @ 2.2W/m.K

Figure 4.3 Introduction interface of the 'TE System Optimization' simulation and Parameter input interface in the 'TE System Optimization' simulation

In any of the three simulations, the user goes through four steps. First, an introductory information about the simulation is given. In some cases, basic information to start the simulation is requested to the user. In the next two steps, the parameters are set by the user, sometimes using basic guidance and information provided in the simulation interface. The fourth section shows the output in the form of graphs. The user is able to decide which output to see and they can move the cursor over the lines in order to identify specific values. The operator can go back to reset the parameters as many times as desired.

4.3 Summary

This study was developed in the context of an online course entitled "Thermoelectricity: From atoms to systems". The course uses a bottom-up approach to teach basic and advanced concepts related to thermoelectricity. The course had a duration of five weeks. During the course, three computer simulations were incorporated with the purpose of providing students with an experimentation practice. Students are expected to increase their conceptual understanding after using the simulations.

CHAPTER 5. METHODS

Computer simulations have been widely used to support inquiry learning process. They represent a potential complement or even replacement of hands-on experimentation or laboratories, when the implementation of those ones is not feasible. In the current study, the incorporation of a set simulation tools in a distance learning course were expected to increase student conceptual understanding of thermoelectric devices. Also, user perceptions about the simulations were analyzed using the constructs established in the Technology Acceptance Model (TAM); the perceived usefulness and the perceived ease of use.

The research questions that guided the methods design are 1) Can the use of computer simulations in an online course improve student understanding of thermoelectric devices? 2) What are student perceptions about the incorporation of computer simulations in an online thermoelectricity course?

5.1 Research Design

In order to answer the proposed research questions, the researcher decided to develop a case study research design. According to Yin (2002), case studies are commonly used (a) when answering “how” or “why” type of questions, and (b) when studying a contemporary phenomenon in a real-life context where we cannot manipulate events. Moreover, this type of design is used for doing an exhaustive analysis of a phenomenon focusing on a single unit. The purpose of this case study is to investigate how computer simulations that were originally created for research purposes can be used to improve student understanding of difficult concepts in a course, when implemented in a distance learning format.

5.2 Participants

Participants in this study were students in the “instructor led” section of the 5-week long online course entitled “Thermoelectricity: From atoms to systems”. This section of the course was offered by nanoHUB-U between the months of October and December, 2013. 175 students were enrolled in the section.

Participants comprised 65% males (114) and 15% females (26); 20% of the students (35) refused to reveal their gender. Most of them were graduate students (46.3%), followed by university faculty (8%), staff (6.2%), national lab affiliates (4.5%), industry affiliates (4%), undergraduate students (2.3%), government affiliates (1%) and unemployed (1%); 8.6% are university affiliate but refused to specify their position and 18% did not reveal their affiliation, nor their position. Given the distant nature of the course, students reside in several countries around the world. The largest number of students are in the US (40%), followed by India (4%), Canada (2.9%) and Australia (2.9%); 30.3% are distributed into 30 different countries and 20% refused to reveal the country of residence.

Although there were 175 students enrolled in the course, just 67 of them were active participants throughout the five weeks. The number of students that completed each of the assessment questionnaires is depicted in Table 5.1. For the present study, the analysis will be based on the results from students who answered more than one of the learning assessments. The 32 observations for the completed surveys will be analyzed to gather student perceptions about the course and the computer simulations.

Table 5.1 Number of participants that completed each of the assessment questionnaires

Questionnaire	Number of students
Pre-test	46
Homework	19
Instructional assessment	67
Post-test	30
Survey	32

5.3 Procedures

The study took place during the fourth week of the course. As part of this week, there was one homework assignment and one instructional assessment where the students had the opportunity to operate two simulation tools, the TE Device and the TE System Optimization simulations.

During this week students (1) watched the video-lectures and took the quizzes, (2) answered the pretest questionnaire, (3) were exposed to two computer simulations while answering the homework and the instructional assessment questions, and (4) answered the post-test questionnaire. The time elapsed between the various activities could vary from hours to a couple of days (Fig. 5.1).

At the end of the course students completed a survey related to their perceptions about the course. Questions about their satisfaction with the course and their experience with the simulation tools were also included.

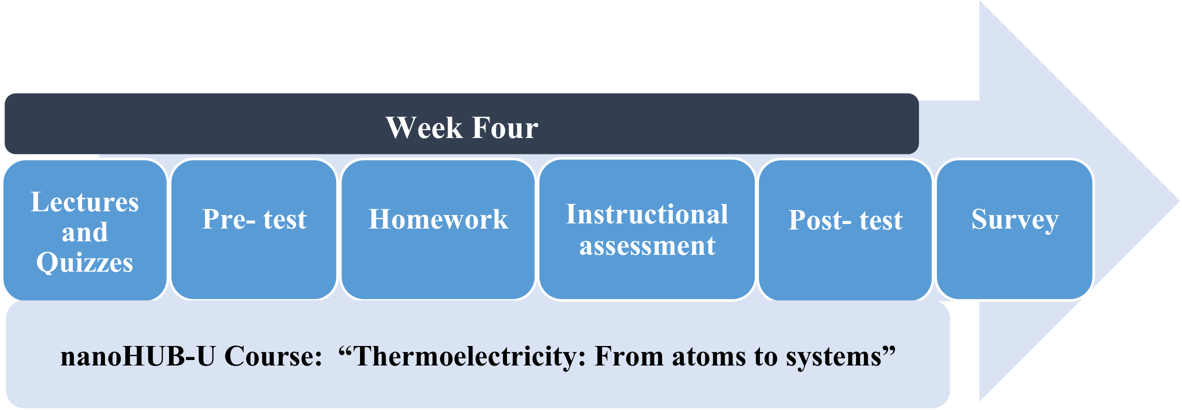


Figure 5.1 Procedures and Data collection.

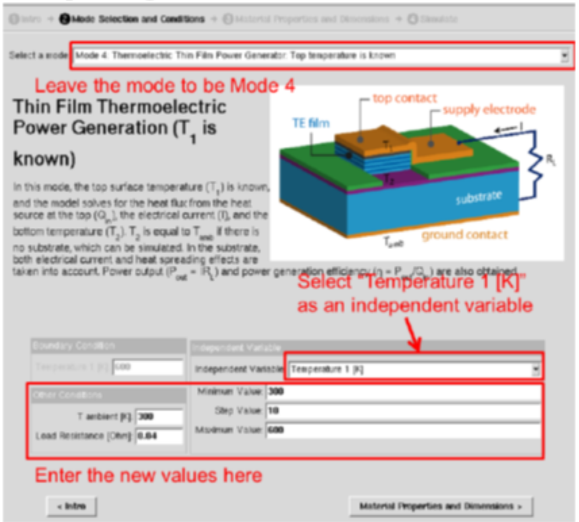
5.4 Data Collection Method

The data was collected during the week four of the course offered during the fall semester of 2013. All the data collection materials were posted online on the course website (nanoHUB-U).

5.4.1 Instructional Materials

One homework assignment was provided (Fig. 5.2). It consisted of 21 multiple choice questions related to the topic discussed on the week four. Students needed to make use of the computer simulations in order to find the correct answer. Each question had a thorough set of instructions that guided the students on how to operate the simulations. The guidance included information about the parameters that needed to be changed and some screenshots of the simulation interface where the related sections were displayed. The final score for the homework assignment was recorded, although it was not taken into account for the course grade.

(Simulation on Power Output as a function of temperature difference) Now, simulate the power output as a function of the temperature difference ΔT. Click "clear" at the down right corner at the output page to clear the previous simulation results. Go back to the second phase "Mode Selection and Conditions", and leave the mode to be "Mode 4: Thermoelectric Thin Film Power Generator." Change the independent variable to "Temperature 1 [K]." Set the minimum, step, and maximum values of the temperature 1 to be "300", "10", and "600" K, respectively. Leave the ambient temperature to be "300" K. enter "0.04" Ω for the load resistance. Note that this load resistance value matches the internal resistance of the power generator.



Select a mode: Mode 4: Thermoelectric Thin Film Power Generator: Top temperature is known

Leave the mode to be Mode 4

Thin Film Thermoelectric Power Generation (T_1 is known)

In this mode, the top surface temperature (T_1) is known, and the model solves for the heat flux from the heat source at the top (Q_{in}), the electrical current (I), and the bottom temperature (T_2). T_2 is equal to T_{amb} if there is no substrate, which can be simulated. In the substrate, both electrical current and heat spreading effects are taken into account. Power output ($P_{out} = I^2R_L$) and power generation efficiency ($\eta = P_{out}/Q_{in}$) are also obtained.

Select "Temperature 1 [K]" as an independent variable

Temperature 1 [K]: 500

Independent Variable: Temperature 1 [K]

Minimum Value: 300

Step Value: 10

Maximum Value: 600

T ambient [K]: 300

Load Resistance [Ohm]: 0.04

Enter the new values here

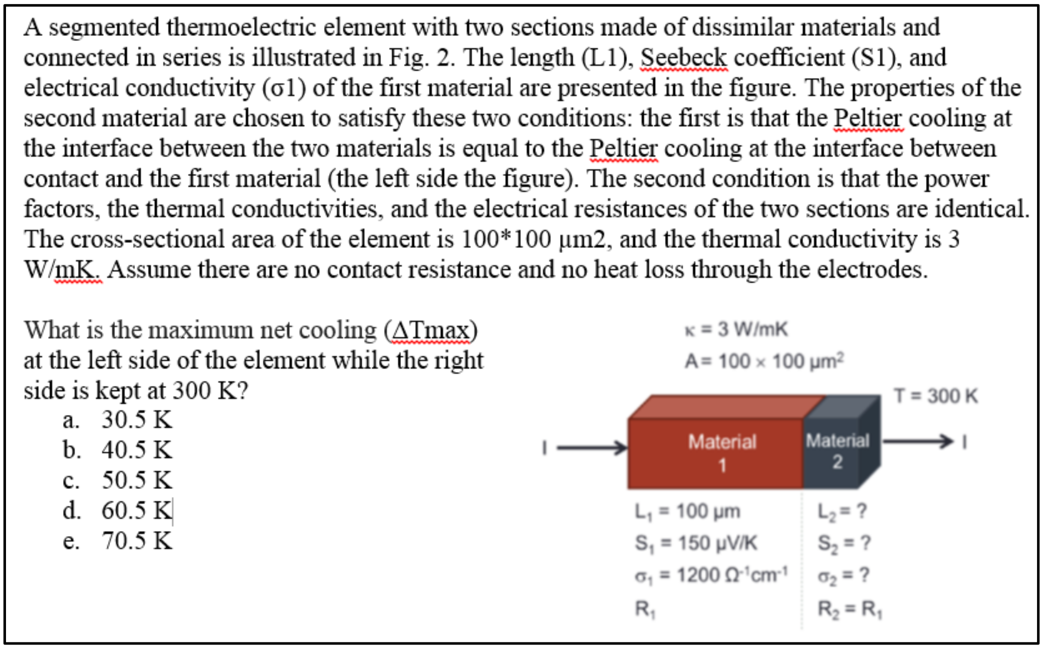
Keep the previous material property and dimension values as used in the previous simulation in the third phase. Click "Simulate" to start the simulation.
After the simulation is done, check the power output graph as a function of the top surface temperature (T_1). What are the power outputs at $T_1 = 400$ K, 500 K, and 600 K, respectively? See if the power output increases in proportion to $(\Delta T)^2$ as predicted in Prob. 5-2.

a. $P_{out} = 1.2$, 4.8, and 10.8 mW
b. $P_{out} = 2.3$, 9.2, and 20.7 mW
c. $P_{out} = 3.9$, 15.6, and 35.2 mW
d. $P_{out} = 4.5$, 18.0, and 40.5 mW
e. $P_{out} = 5.2$, 20.8, and 46.8 mW

Figure 5.2 Assignment question example

At the end of the week four, an instructional assessment was provided. In this assessment each student was required to make use of the computer simulations and allowed to make three attempts to get the best score (Fig. 5.3). Given the relevance of the instructional assessment as an additional opportunity to operate the computer simulations for several times, for the purpose of this study, it was regarded as an instructional assessment. Using this denomination, it is expected to clarify the assumption that this questionnaire required the students to practice with the simulations based on specific questions, and, therefore, it is expected to boost inquiry with guidance.

The instructional assessment comprised eight multiple choice. The questions were mainly related to the experimental practice with the simulations, rather than about conceptual understanding. In like manner, in order to have the correct answer, the use of the computer simulations was mandatory. With respect to the homework assignments, although the type of questions was similar, less guidance was given on how to proceed with the simulations in this instructional assessment. The final score was recorded and accounted for a high percentage of the course grade.



A segmented thermoelectric element with two sections made of dissimilar materials and connected in series is illustrated in Fig. 2. The length (L1), Seebeck coefficient (S1), and electrical conductivity (σ1) of the first material are presented in the figure. The properties of the second material are chosen to satisfy these two conditions: the first is that the Peltier cooling at the interface between the two materials is equal to the Peltier cooling at the interface between contact and the first material (the left side the figure). The second condition is that the power factors, the thermal conductivities, and the electrical resistances of the two sections are identical. The cross-sectional area of the element is 100*100 μm2, and the thermal conductivity is 3 W/mK. Assume there are no contact resistance and no heat loss through the electrodes.

What is the maximum net cooling (ΔTmax) at the left side of the element while the right side is kept at 300 K?

a. 30.5 K
b. 40.5 K
c. 50.5 K
d. 60.5 K
e. 70.5 K

Figure 5.3 Instructional assessment question example

5.4.2 Learning Assessments Materials

The pretest and the posttest questionnaires were intended to measure student learning gains that can be attributed to their exposure to the computer simulations (Appendix A). Both questionnaires contained the same set of 10 multiple choice questions arranged in a different order. Rather than operational skills, all the questions in these questionnaires were related to conceptual understanding of the major topic; accordingly, students did not need to use the computer simulations. The pretest and the posttest were provided right before and after being exposed to the computer simulations, correspondingly. During this time between the two tests the students completed the homework assignment (optional) and the instructional assessment (mandatory) as instructional support for the simulations. The specific topics related to the concepts assessed are depicted in table 5.2.

Table 5.2 Topics evaluated in the week four of the thermoelectricity course

Simulation	Topic	Instructional materials and assessment materials
TE Device	Operation principles of TE devices Design optimization of TE devices	Homework assignment, Instructional assessment, Pre-test, post-test
TE Device and TE System Optimization	Effect of parasitics in a TE device	
TE System Optimization	Cost-efficiency trade-off in TE power generation	

5.4.3 Perceptions Survey

The survey consisted on 20 questions classified in three sections (Appendix B). The first section collected demographic information of the participants. The second asked about the satisfaction of the students with the course in general. The last section inquired about the perceptions that they had, specifically, about the computer simulations. Ten questions were included in the last section, six of those questions were grouped on three categories using the definitions from the TAM: Usefulness, Ease of Use, and Intention to Use (Table 5.3). Question from this section were formulated using a five-level Likert-type scale from 1 (strongly disagree) to 5 (strongly agree). Perceptions were interpreted as (1) negative, when scores ranged from 1 to 2.3, (2) undecided, when scores were between 2.4 and 3.6, and (3) positive, when between 3.7 and 5.0. Each of the questions in the mentioned categories were answered for each of the simulation tools. The four last questions from this section were open ended questions; three particularly about the simulation tools and one about the course in general.

Table 5.3 Survey questions categorization

Category	Question
Usefulness	Using this simulation tool enabled me to accomplish the assignment successfully
	I think using this simulation tool fits well with the way I learn
Ease of use	I find this simulation easy to use
	I had a positive and pleasant experience with the simulation tool when working on the assignments
	The user interface of this simulation tool helped me avoid making errors
Intention to use	I am interested in receiving training or additional information about additional functionality and features of this simulation tool
Open- ended	How did the simulation tools help you the most during your learning process?
	What can we do to make the simulation tools more useful for your learning in this course?
	Did you encounter any problems while working with the simulation tools (i.e., TE device tool, TE system tool or Boltzmann transport tool)? Please indicate the problems you encountered and which...
	Please indicate any other additional comments as related to nanoHUB-U, this course, any module or the simulation tools.

5.5 Validity and Reliability of the Instrument

All the learning assessment materials, including the pretest and posttest questionnaires, were built and reviewed by three thermoelectricity experts (the instructor, a postdoctoral student and a research scientist) involved in the course design. The instructors agreed on the appropriateness of each of the questions according to the topics developed in the course.

The survey was designed and reviewed by educational researchers aiming to meet specific objectives of interest. The questions corresponded to the three constructs developed in TAM. In order to assess the reliability, a factor analysis for the survey questions from similar constructs was performed. Values for the Cronbach's alpha coefficient superior to 0.7 are considered to guarantee internal consistency for each group of questions (Table 5.4).

Table 5.4 Reliability table with Cronbach's alpha coefficients

		TE Device		TE System		Boltzmann Transport	
	No. of Questions	Mean	Cronbach's alpha	Mean	Cronbach's alpha	Mean	Cronbach's alpha
Usefulness	6	4.1	0.901	4.0	0.926	4.1	0.905
Ease of use	9	4.1	0.951	4.0	0.951	4.0	0.941
Intention to use	3	4.1	-	4.1	-	4.1	-

5.6 Ethic Conduct of Research

The current study received an approval from the Institutional Review Board "IRB" to develop research with human subjects. The confidentiality of the participants' identities will be guaranteed. Only the authorized researchers will have access to the original dataset; for the analysis purposes, each user ID will be replaced with a code defined internally.

The participation of the students will not compromise their final grade. The responses obtained in the research questionnaires will not be revealed to the course instructor as individual results. The final results from the data analysis will not contain any information about personal individual information of the participants.

5.7 Data Analysis

The data analysis was developed using quantitative and qualitative techniques. The approaches are explained for each of the research questions.

5.7.1 Can the use of computer simulations in an online course improve student understanding of thermoelectric devices?

The homework assignment, the instructional assessment, and the pretest and posttest questionnaires were analyzed in order to identify the learning gains of the students with the implementation of the simulation tools. The data was analyzed using descriptive and inferential statistics to identify tendencies in the students' performance along the week four. Given that the assignment represented an opportunity to for the students to receive guidance and gain experience with the simulations, the difference of the posttest and pretest results were compared between the group of students that answered the corresponding homework and the ones who did not answer it. The instructional assessment was also regarded as a possible predictor of student conceptual improvement, because while solving it, students were required to operate the computational tools.

The students were classified into two groups: the *low performers* (LP) and the *high performers* (HP). Students with a pretest score below the group average belong to the first group, and the ones with a pretest score above the group average are in the second group. The same analyses mentioned above were performed for both groups separately.

The statistical analyses consist of:

a. Learning gains were analyzed in a paired t-test between the pretest and the posttest scores. This was based on the 29 students that answered both questionnaires.

    - $H_{0\text{-}1}$: there is no conceptual understanding change from the pretest to the posttest.
    - $H_{0\text{-}1}$: $\mu_{diff} = 0$, $H_{\alpha\text{-}1}$: $\mu_{diff} \neq 0$

    As the sample size is not too large, a permutation test was done in order to support the reliability on the paired t-test results.

b. The pretest and the posttest scores were compared in a paired t-test, in order to evaluate learning gains separately for low and high performers. These two samples were selected from the 29 students that answered both tests. Again, given the small size of the sample, a permutation test was done in order to support the reliability on the paired t-test results.

- $H_{0\text{-}2}$: in the specific group of LP, the average of the difference (posttest-pretest) is equal to zero, meaning no conceptual understanding change from the pretest to the posttest.
- $H_{0\text{-}2}$: $\mu_{\text{diffLP}} = 0$, $H_{\alpha\text{-}2}$: $\mu_{\text{diffLP}} \neq 0$
- $H_{0\text{-}3}$: in the specific group of HP, the average of the difference (posttest-pretest) is equal to zero, meaning no conceptual understanding change from the pretest to the posttest.
- $H_{0\text{-}3}$: $\mu_{\text{diffHP}} = 0$, $H_{\alpha\text{-}3}$: $\mu_{\text{diffHP}} \neq 0$

A two sample t-test defines if the learning improvement in any of the groups is significantly different.

- $H_{0\text{-}4}$: The conceptual understanding improvement from one of the groups was not higher or lower score than the score of the other group.
- $H_{0\text{-}4}$: $\mu_{\text{diffLP}} = \mu_{\text{diffHP}}$, $H_{\alpha\text{-}4}$: $\mu_{\text{diffLP}} \neq \mu_{\text{diffHP}}$

c. The homework completion influence on student conceptual understanding was investigated through a two sample t-test. It compared the average of the difference between pretest and posttest for the students that completed and for the ones that did not complete the assignment. The sample were the 29 students that answered both questionnaires. The same model was performed separately for the groups of low and high performance.

  - $H_{0\text{-}5}$: There is not a homework effect on the conceptual understanding improvement.

- $H_{0\text{-}5}$: $\mu_{hw} = \mu_{nohw}$, $H_{\alpha\text{-}5}$: $\mu_{hw} \neq \mu_{nohw}$
- $H_{0\text{-}6}$: There is not a homework effect on the conceptual understanding improvement for the group of LP.
- $H_{0\text{-}6}$: $\mu_{hwLP} = \mu_{nohwLP}$, $H_{\alpha\text{-}6}$: $\mu_{hwLP} \neq \mu_{nohwLP}$
- $H_{0\text{-}7}$: There is not a homework effect on the conceptual understanding improvement for the group of HP.
- $H_{0\text{-}7}$: $\mu_{hwHP} = \mu_{nohwHP}$, $H_{\alpha\text{-}7}$: $\mu_{hwHP} \neq \mu_{nohwHP}$

d. Due to the relevance of the instructional assessment as an opportunity for students to experiment with the computer simulations, a regression model was developed to study the instructional assessment effect on conceptual learning. The posttest score was regressed against the pretest and the instructional assessment scores; for this model the results of 29 students that answered the three questionnaires (i.e., the pretest, the posttest and the instructional assessment) were used. A similar model was performed separately for the groups of low and high performance.

- $H_{0\text{-}8}$: the instructional assessment score, when pretest score is taken into account, does not have an effect on the posttest score.
- $H_{0\text{-}8}$: $\beta_{pretest} = \beta_{\text{instructional assessment\_score}} = 0$, $H_{\alpha\text{-}8}$: Some $\beta_i \neq 0$
- $H_{0\text{-}9}$: the instructional assessment score, when pretest score is taken into account, does not have an effect on the posttest score for the group of LP.
- $H_{0\text{-}9}$: $\beta_{pretestLP} = \beta_{\text{instructional assessment\_score LP}} = 0$, $H_{\alpha\text{-}9}$: Some $\beta_{iLP} \neq 0$
- $H_{0\text{-}10}$: the instructional assessment score, when pretest score is taken into account, does not have an effect on the posttest score for the group of HP.

- $H_{0\text{-}10}$: $\beta_{pretestHP} = \beta_{\text{instructional assessment\_score HP}} = 0$, $H_{\alpha\text{-}10}$: Some $\beta_{iHP} \neq 0$

e. The combined effects of homework completion and instructional assessment score were tested in a multiple regression. The sample used was the 29 students that completed all the assessment materials. Again, the groups of low and high performance were analyzed separately using a similar model.

- $H_{0\text{-}14}$: the instructional assessment score and the homework completion, when pretest score is taken into account, do not have an effect on the posttest score.
- $H_{0\text{-}14}$: $\beta_{pretest} = \beta_{\text{instructional assessment\_score}} = \beta_{hw\_completion} = 0$, $H_{\alpha\text{-}14}$: Some $\beta_i \neq 0$
- $H_{0\text{-}15}$: the instructional assessment score and the homework completion, when pretest score is taken into account, do not have an effect on the posttest score for the group of LP.
- $H_{0\text{-}15}$: $\beta_{\text{instructional assessment\_score LP}} = \beta_{hwLP} = 0$, $H_{\alpha\text{-}15}$: Some $\beta_{iLP} \neq 0$
- $H_{0\text{-}16:}$ the instructional assessment score and the homework completion, when pretest score is taken into account, do not have an effect on the posttest score for the group of HP.
- $H_{0\text{-}16}$: $\beta_{\text{instructional assessment\_score HP}} = \beta_{hwHP} = 0$, $H_{\alpha\text{-}16}$: Some $\beta_{iHP} \neq 0$

Variable added last t tests as well as the All-Possible-Regressions selection procedure helped to evaluate the relevance of specific variables in the model.

5.7.2 What are student perceptions about the incorporation of computer simulations in an online thermoelectricity course?

5.7.2.1 Perceptions about the course

Responses to the first two sections of the 33 observations reported in the survey were analyzed. The analysis consists on descriptive statistics that help identify trends in participant satisfaction, perceived self-performance, and perceived usefulness. The average scores were considered negative when between 1.0 and 2.3, neutral when between 2.4 and 3.6, and positive when between 3.7 and 5.0. Additionally, one of the open-ended questions, which is related to the course in general, was analyzed using open coding.

5.7.2.2 Perceptions about the computer simulations

The six questions corresponding to the third section of the survey, which is specifically related to the computer simulations, were analyzed using descriptive statistics. Mean scores were also calculated for each category from the adapted TAM. The average scores were considered negative when between 1.0 and 2.3, neutral when between 2.4 and 3.6, and positive when between 3.7 and 5.0.

Also, each construct average score was correlated to the difference between the posttest and the pretest scores, the homework completion, and the instructional assessment results, separately. This correlation assesses the relation between the student satisfaction with the computer simulations and their performance in week four. This analysis was based on the group of students that completed the pre, post-test, and survey, and the instructional assessment and the survey.

The four open-ended questions were analyzed using open coding. This allowed defining categories that represent student perceptions about the computational simulations.

5.8 Summary

This case study was attempted to evaluate the incorporation of a set of computer simulations in an online course. The study was conducted during the week four of the course “Thermoelectricity: From atoms to systems”. In this week, students were required to use two computer simulations about thermoelectric devices. A pretest-posttest design was implemented to assess the learning gains. Statistical tests were performed in order to assess the effects of the computer simulations. Further tests helped to uncover the effect of the instructional materials as support for the computer simulations operations on the learning improvement.

Students’ perceptions were investigated using a survey, which was provided at the end of the course. Likert type scale and open-ended questions were included for quantitative and qualitative data collection. The data analysis about perceptions was based on descriptive statistics and open coding.

CHAPTER 6. RESULTS

In this chapter, the results of the study developed according to the methodology proposed are presented. The first section contains the statistical analyses of the learning gains describing the level of attainment of the stated learning outcomes of the online course. In the second section, the outcomes of both the quantitative and qualitative data from student perceptions are summarized. At the end of the chapter, a summary of the main findings is provided.

6.1 Can the use of computer simulations in an online course improve student understanding of thermoelectric devices?

A survey of students' performance on the instructional materials and the learning assessments is shown through descriptive statistics (Table 6.1). The number of students that completed each of the questionnaires was different. As a result, the sample size for some of the statistical analyses varied. The majority of the students answered the instructional assessment, and a smaller number of them responded the pretest and the posttest assessments.

Regarding the learning outcomes, the highest average scores were achieved on the homework and on the instructional assessment. Lower average scores were encountered in the pretest and posttest. However, the mean score in the posttest was higher than the ones in the pretest. The average scores in both of these assessments suggests a limited level of achievement of the learning objectives.

Table 6.1 Descriptive statistics of instructional materials and learning assessments

Learning assessment	N	Mean	Standard deviation (SD)	Min	Max
Pretest	46	46.5	16.1	10	80
Instructional assessment (first attempt)	67	66.8	15.8	37.5	100
Instructional assessment (final attempt)	67	80.1	16.9	37.5	100
Posttest	30	56	17.7	30	90

6.1.1 Learning gains

The learning gains were measured through a pretest and posttest design. The pretest assessed student understanding of specific topics related to thermoelectric devices; its purpose was to measure the knowledge right after the student had seen the traditional video-lectures, but before they used the simulations. The posttest estimated the knowledge acquired after the students had the opportunity to learn by using the computer simulations.

$H_{0\text{-}1}$: the average of the difference posttest-pretest is equal to zero, meaning there is no conceptual understanding change from the pretest to the posttest ($H_{0\text{-}1}$: $\mu_{diff} = 0$, $H_{\alpha\text{-}1}$: $\mu_{diff} \neq 0$)

The statistical analysis was performed through a paired t-test in order to identify if the performance in the posttest was significantly better than in the pretest; it consisted on the comparison of the average of the difference between each pair of scores from each student. The sample size of this test corresponded to 29 students who completed both questionnaires.

Participants' scores were significantly better in the posttest than in the pretest (M ± SD: 10.0 ± 13.63, t(28)= 3.95, p= 0.0005, d=0.7335) (Fig. 6.1). Considering the small sample size, the results of this analysis were validated through a permutation test (p=0.0006). This result indicates that the learning gain was significant, and that the experience with the computer simulations assisted the students to improve the conceptual understanding.

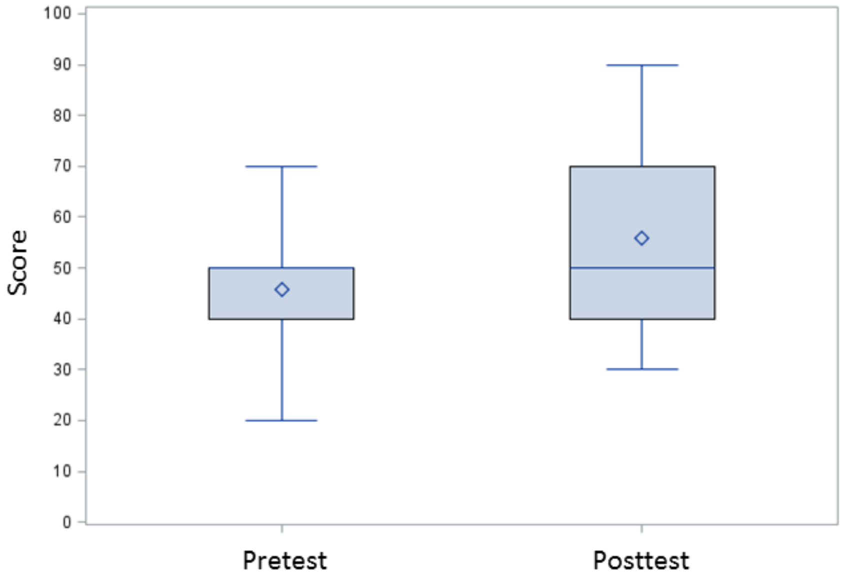


Figure 6.1 Students' pretest and posttest scores boxplot

$H_{0\text{-}2}$: *in the specific group of LP, the average of the difference (posttest-pretest) is equal to zero, meaning no conceptual understanding change from the pretest to the posttest* ($H_{0\text{-}2}$: $\mu_{diffLP} = 0$, $H_{\alpha\text{-}2}$: $\mu_{diffLP} \neq 0$)

$H_{0\text{-}3}$: *in the specific group of HP, the average of the difference (posttest-pretest) is equal to zero, meaning no conceptual understanding change from the pretest to the posttest* ($H_{0\text{-}3}$: $\mu_{diffHP} = 0$, $H_{\alpha\text{-}3}$: $\mu_{diffHP} \neq 0$).

According to the results on the pretest, participant responses were classified into two groups; low performers (LP) and high performers (HP); thus, students with a pretest score below the group average (Mean >= 46.5) were included in the low performing group and the ones above the group average were included in the high performing group. The learning gains were tested separately in order to identify how the computer simulations could benefit students with a different conceptual understanding level before using the simulations. It is hypothesized that the level of knowledge demonstrated in the pretest could influence that pattern.

The objective of this test was to identify if on average, the low and high performing groups, improved their conceptual understanding. A similar paired t-test was developed separately for the 13 students included in the low performing group and for 16 in the high performing group. As it was expected, the HP group's average score was better than the LP group, both in the pretest and the posttest scores (Table 6.2); moreover, the LP group's posttest average score was still lower than the HP posttest's average score. Yet, both of the groups demonstrated a significant improvement in their conceptual understanding in the posttest, with a higher average improvement shown by the HP group. The results of this test were also confirmed with a permutation test (p=0.0396 for LP and p=0.0082 for HP).

$H_{0\text{-}4}$: The conceptual understanding improvement from one of the groups was not higher or lower score than the score of the other group ($H_{0\text{-}4}$: $\mu_{diffLP} = \mu_{diffHP}$, $H_{\alpha\text{-}4}$: $\mu_{diffLP} \neq \mu_{diffHP}$)

A two sample t-test was performed in order to unveil if the difference between low and high performers change from pretest to posttest was significant. The difference in the average improvement was not statistically significant between low and high performers (M ± SD: -1.39± -11.83, t(26.9)= -0.27, p= 0.786).

Table 6.2 Pretest and posttest for low and high performers

	Low Performers		High Performers	
	Pretest	Posttest	Pretest	Posttest
Mean	34.62	43.85	55	65.63
SD	6.6	14.46	6.32	14.59
Mean difference	9.23		10.63	
SD of the difference	12.56		14.82	
T statistic	t(12)=2.65		t(15)=2.87	
p- value	0.0212		0.0117	

6.1.2 Instructional support effect

The contribution of instructional materials related to the operation of the computer simulations also was analyzed. Therefore, statistical tests were developed to study the effect of the students' participation on the homework and on the instructional assessment on their learning gains from the pretest to the posttest.

6.1.2.1 Homework assignment effect

$H_{0\text{-}5}$: There is not assignment effect on the conceptual understanding improvement ($H_{0\text{-}5}$: $\mu_{hw} = \mu_{nohw}$, $H_{\alpha\text{-}5}$: $\mu_{hw} \neq \mu_{nohw}$)

Conceptual improvements among the students who did or did not do the homework assignment was tested with a two sample t test. The two groups correspond to 15 students that did not complete the homework, and 14 students that did complete the assignment. Although the students that did complete the homework had a higher average score difference (M ± SD: 11.43 ± 14.6), than the ones that did not do it (M ± SD: 8.67 ± 13.02), the difference between the two groups was not significant (t(26.1)= -0.54, p= 0.596) (Fig. 6.2).

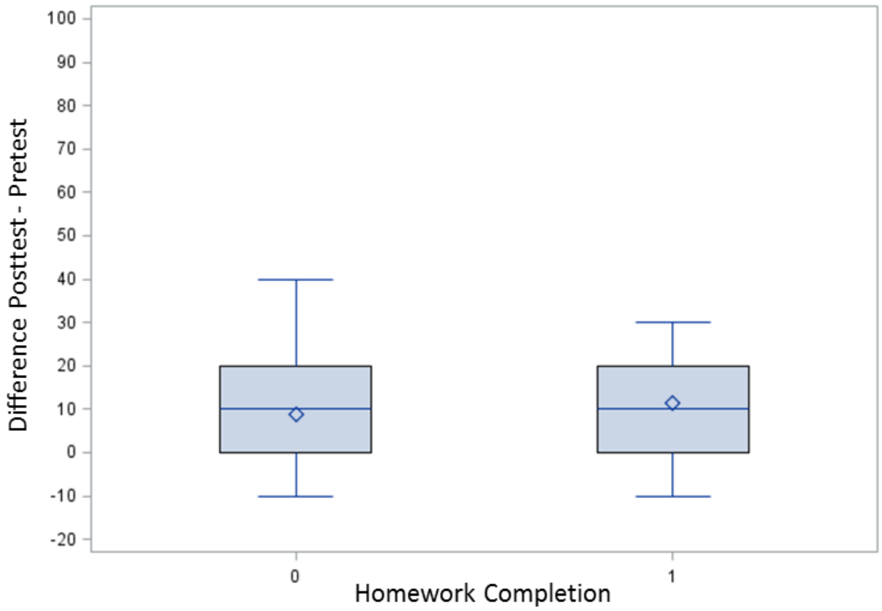


Figure 6.2 Learning improvement by homework assignment completion

$H_{0\text{-}6}$: There is not an assignment effect on the conceptual understanding improvement for the group of LP ($H_{0\text{-}6}$: $\mu_{hwLP} = \mu_{nohwLP}$, $H_{\alpha\text{-}6}$: $\mu_{hwLP} \neq \mu_{nohwLP}$)

A similar test was developed for the groups of high and low performers, separately. The sample for the low scorers was of 13 students, from which 6 did the homework, and 7 did not do it. The two mean samples were found not to be significantly different (M ± SD: 8.33 ± 7.52, for the no-homework group, and M ± SD: 10.0 ± 16.33, for the homework group, t(8.7)=-0.24, p=0.8146) (Fig. 6.3).

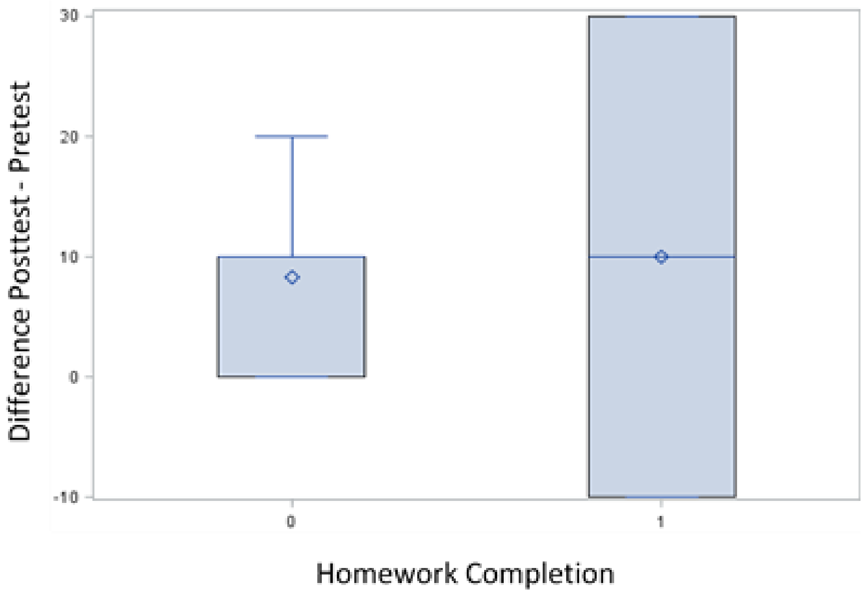


Figure 6.3 Learning improvement by homework assignment completion for low performers

H_{0-7}: There is not a homework effect on the conceptual understanding improvement for the group of high performers (H_{0-7}: $\mu_{hwHP} = \mu_{nohwhHP}$, $H_{\alpha-7}$: $\mu_{hwHP} \neq \mu_{nohwHP}$)

The high scorers were 16 students; 7 did the homework, and 9 did not do it. In spite of the higher average score from the students that did the homework (M ± SD: 12.85 ± 13.8, for the homework group and M ± SD: 8.88 ± 16.16, for the no-homework group) (Fig. 6.4), the difference in the means is not statistically significant (t(13.8)=-0.53, p=0.605).

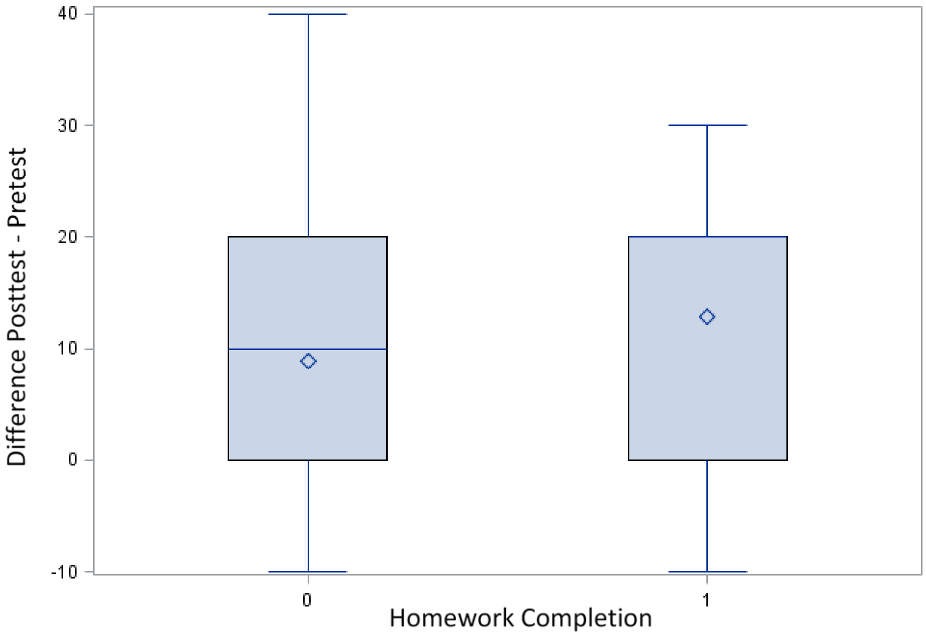


Figure 6.4 Learning improvement by homework assignment completion for high performers

6.1.2.2 Instructional assessment effect

$H_{0\text{-}8}$: the instructional assessment score, when pretest score is taken into account, does not have an effect on the posttest score ($H_{0\text{-}8}$: $\beta_{pretest} = \beta_{instructional\ assessment\_score} = 0$, $H_{\alpha\text{-}8}$: Some $\beta_i \neq 0$)

The instructional assessment was another opportunity for the students to interact with the computer simulations, and it was regarded as a training for the students to master the computer simulations and develop the operational skills. In order to identify the relationship between these operational skills mastery with the conceptual understanding improvement, a multiple linear regression was developed between the instructional assessment score and the pretest and posttest improvement. The sample corresponds to the 29 students who completed the pretest, the posttest and the instructional assessment.

Most of the students did more than one attempt to answer the exam. Four students did one attempt only, 11 students did two attempts, and 14 did three attempts.

The model was found significant for explaining the posttest scores (F=10.33, p=0.0005, r^2= 0.4427, adjr^2= 0.3998). This result suggest that the pretest and instructional assessment scores, as a group, can predict a student performance in the posttest. The variable added last t-test, for which the null hypothesis states that a specific variable is not related to the response, we can conclude that the instructional assessment score is not a significant predictor of the posttest scores (t=0.80, p=0.4322). This result is confirmed using the All-Possible-Regressions selection procedure. The pretest variable by itself explains most of the variation in the posttest (r^2= 0.4291, adjr^2=0.4079).

$H_{0\text{-}9}$: The instructional assessment score, when pretest score is taken into account, does not have an effect on the posttest score for the group of LP ($H_{0\text{-}9}$: $\beta_{pretestLP} = \beta_{instructional\ assessment\_scoreLP} = 0$, $H_{\alpha\text{-}9}$: Some $\beta_{iLP} \neq 0$)

The effect of the instructional assessment score on the improvement of low performers and high performers was also assessed with a similar multiple regression model for the 13 and 16 students in the categories, correspondingly. For the low performers, the pretest and the instructional assessment scores as a group of predictors did not explain the posttest score (F=2.58, p=0.1248).

$H_{0\text{-}10}$: The instructional assessment score, when pretest score is taken into account, does not have an effect on the posttest score for the group of HP ($H_{0\text{-}10}$: $\beta_{pretestHP} = \beta_{instructional\ assessment\_scoreHP} = 0$, $H_{\alpha\text{-}10}$: Some $\beta_{iHP} \neq 0$)

In the high performers' case, the model was significant in the posttest scores explanation (F=4.29, p=0.0393). However, according to the results of the variables added last t test, the instructional assessment score was found to be a good predictor of the variation in the posttest (t(1)=2.83, p=0.0151), while the prestest score was not (t(1)=0.92, p=0.3779). The best model would only include the instructional assessment score.

6.1.2.3 Homework assignment and instructional assessment score effect

$H_{0\text{-}11}$*: the instructional assessment score and the homework completion, when pretest score is taken into account, do not have an effect on the posttest score (*$H_{0\text{-}11}: \beta_{pretest} = \beta_{instructional\ assessment\_score} = \beta_{hw\_completion} = 0$, $H_{\alpha\text{-}11}$: *Some* $\beta_i \neq 0$*)*

The relationship among the posttest with the pretest, the homework completion, and the instructional assessment score was tested in a multiple regression. Although the model was found to be significant (F=6.86, p=0.0016), the only predictor that suggests a significant effect on the posttest is, again, the pretest score (t(1)=4.11, p=0.0004). The homework completion and the pretest instructional assessment were not found to be good predictors (t(1)=0.87, p=0.3934, for the instructional assessment score, and t(1)=0.63, p=0.5317, for the homework completion). Using the All-Possible-Regressions selection procedure, the best prediction model contains only the pretest variable.

$H_{0\text{-}12}$: the instructional assessment score and the homework completion, when pretest score is taken into account, do not have an effect on the posttest score for the group of high performers ($H_{0\text{-}12}$: $\beta_{\text{instructional assessment \_scoreLP}} = \beta_{hwLP} = 0$, $H_{\alpha\text{-}12}$: Some $\beta_{iLP} \neq 0$),

$H_{0\text{-}12:}$ the instructional assessment score and the homework completion, when pretest score is taken into account, do not have an effect on the posttest score for the group of low performers ($H_{0\text{-}12}$: $\beta_{\text{instructional assessment\_scoreHP}} = \beta_{hwHP} = 0$, $H_{\alpha\text{-}12}$: Some $\beta_{iHP} \neq 0$)

Using the same group of variables, the pretest, the homework completion and the instructional assessment score, a multiple regression model was developed to assess its prediction on the posttest variation for the low performers. The model was not significant for the low performers (F=1.59, p=0.259), nor for the high performers (F=2.75, p=0.0932). These three predictors, as a group, do not explain the variation in the posttest outcomes.

6.2 What are student perceptions about the incorporation of computer simulations in an online thermoelectricity course?

Perceptions about the course and the simulations were analyzed using the 32 student responses to the course survey. The analysis is divided in four subsections: survey demographics, perceptions about the course, perceptions about the computer simulations and the relationship between perceptions and learning performance.

6.2.1 Survey demographics

The first section of the course survey attempted to identify student demographic information. This information provided a general profile of the participants that took the course. The participants that answered the survey were 27 males (82%) and 6 females (18%) from several countries in the world; where India and the United States had the largest representation (18% e.a.). Most of them were in the range of 26-40 years old (70% approx.), and less were less than 25 (18%), older than 56 (9%) or between 41-55 years old (3%). 39% are physics students, and other common majors are electrical engineering (21%), mechanical engineering (6%), and physics engineering (6%), among others (18%). Their level education varied from master (42%), bachelor (33%) and doctoral degree (24%). Lastly, most of them (94%) completed the course. In fact, one of the students that did not complete the course was excluded from the following analyses, given that his survey was incomplete. Students' perceptions about the course

6.2.1.1 Quantitative analysis

In order to gather relevant information about the course in general, students were inquired about the usability, ease of use and intention to use some of the materials in the future. Students claimed that the course is useful and relevant for their interests and that they will continue to use some of the contents that were provided (Fig. 6.5). They are undecided in the way they perceived the ease of use of nanoHUB-U. In average they think their performance in the course was rather good than excellent.

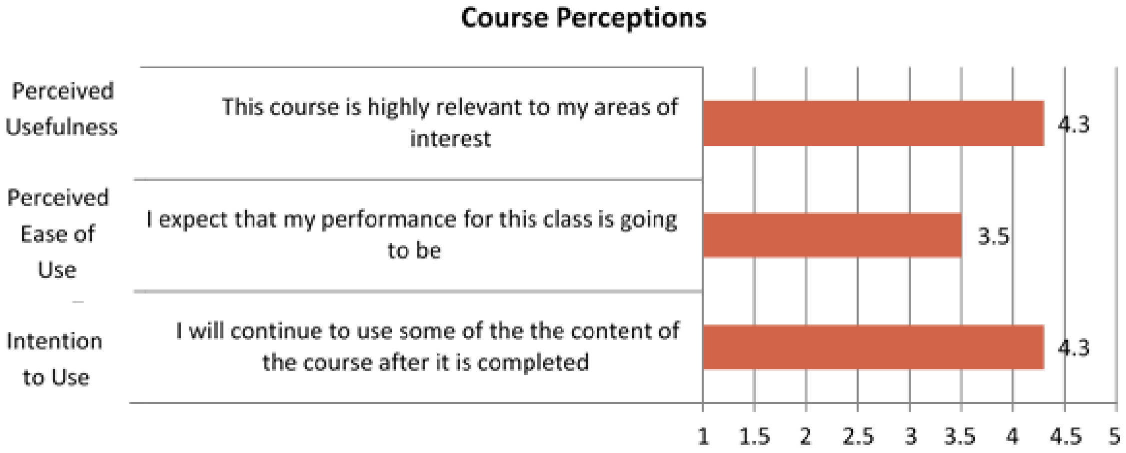


Figure 6.5 Students' Perceptions about the Course

6.2.1.2 Qualitative analysis

At the end of the survey students were asked to indicate any other additional comments as related to nanoHUB-U, the course, any of the modules, or the simulation tools. From 33 students who answered the survey, 13 of them answered this question (39.4%). The 61.5% described the course as a good experience. Illustrative comments include "*This course was very helpful for my research and understanding. Thank you very much for making it affordable and easy to access.*", "*Very nice to see so much of the chemistry training in thermoelectrics as applied to engineering (and nano-applications)*", and "*The course content was extremely good and helped in getting aware of the recent advances in the field of Thermoelectricity. I enjoyed the learning a lot.*"

Additional feedback was given by five individuals. They addressed difficulties such as the fast pace of the course, the lack of recognition for the students that completed all the materials, the inconvenience of some of the assessment materials, and some technical problems. Some recommendations are the balance in the information given in different weeks and to incorporate new computer simulations about other topics on thermoelectricity.

6.2.2 Students' perceptions about the simulations

6.2.2.1 Quantitative analysis

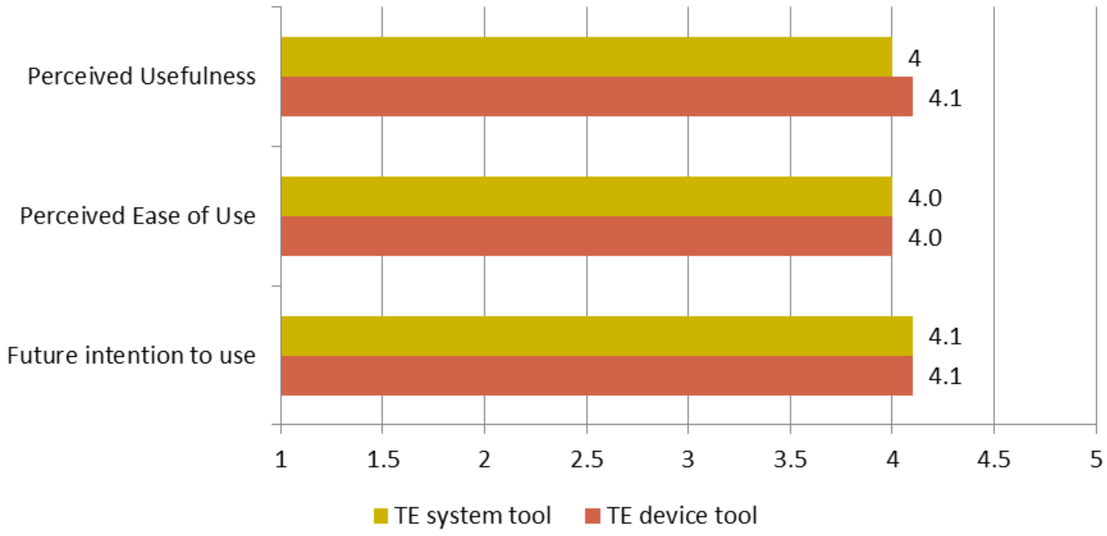


Figure 6.6 Students' Perceptions about the Computer simulations

The average attitude of the students towards the two computer simulations implemented on week four of the course can be described as positive. Both, the 'Thin-Film and Multi-Element Thermoelectric Devices Simulator' (TE Device) and the 'Thermoelectric Power Generator System Optimization and Cost Analysis' (TE System) were rated as useful ($\bar{x}_{TEDevice}$= 4.1 and $\bar{x}_{TESystem}$= 4.0) and easy to use ($\bar{x}$= 4.0, in both cases). Moreover the students demonstrated a high intention to use them in the future for their own areas of interest ($\bar{x}$= 4.1, in both cases) (Fig. 6.6).

In terms of perceived usefulness, participants agreed that the simulations fit with the way they learn ($\bar{x}_{TEDevice}$= 4.0 and $\bar{x}_{TESystem}$=3.9) and they helped them to complete the assignments ($\bar{x}_{TEDevice}$= 4.2 and $\bar{x}_{TESystem}$=4.1) (Fig. 6.7). As for the perceived ease of use (Fig. 6.8), they thought the user interface helped them to avoid mistakes ($\bar{x}$= 4.0, in both cases), that it was a good experience using the simulations for the assignments ($\bar{x}$= 4.0, in both cases), and that it was easy to use them ($\bar{x}$= 4.0, in both cases) .

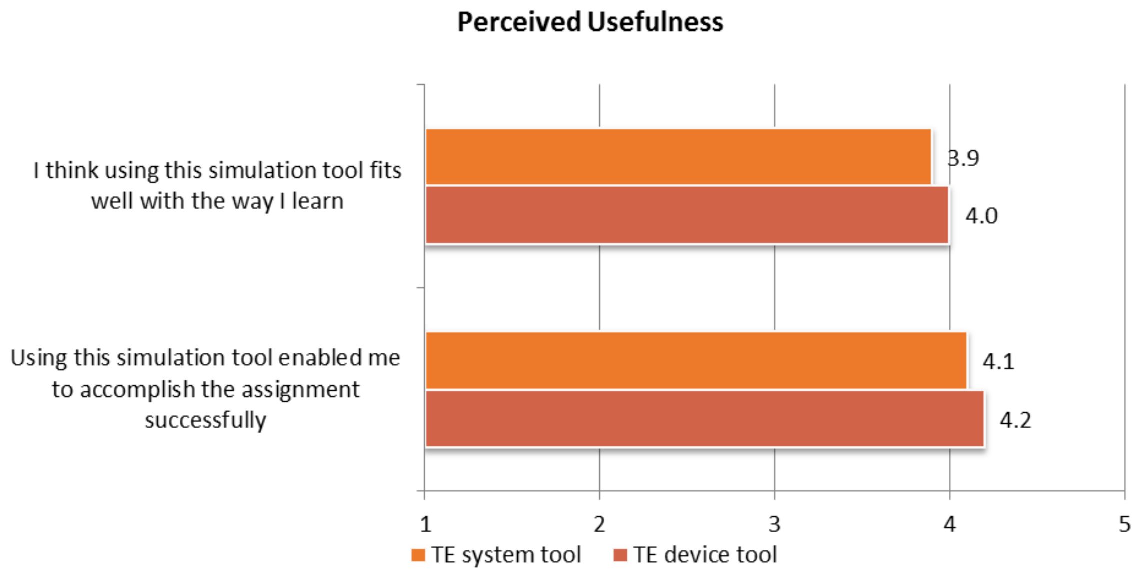


Figure 6.7 Students' Perceived Usefulness about the Computer Simulations

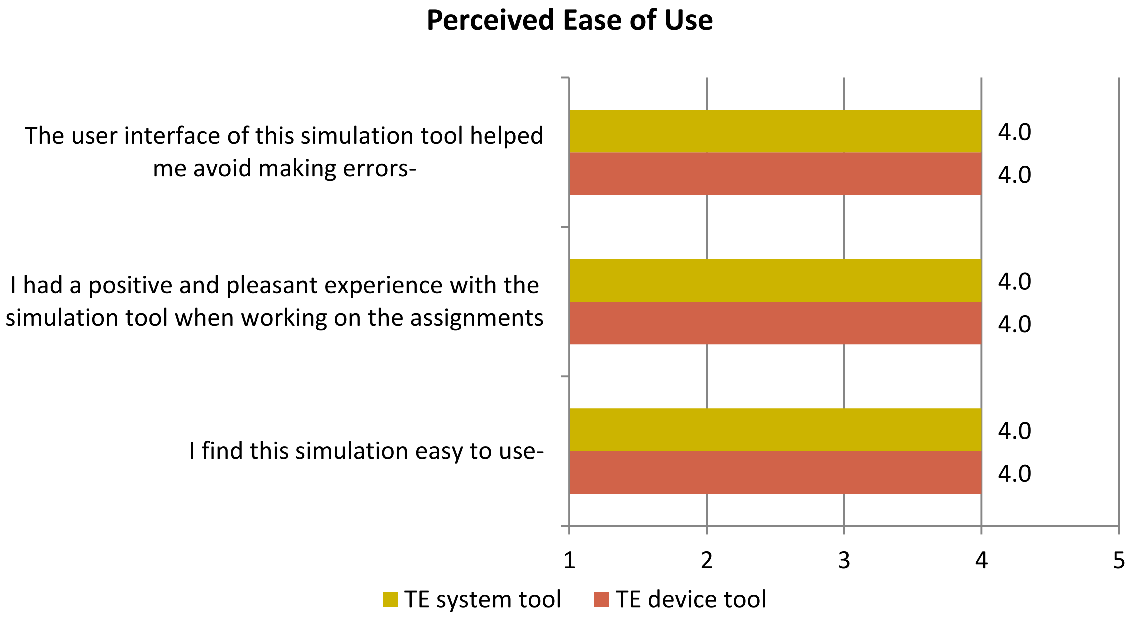


Figure 6.8 Students' Perceived Ease of Use about the Computer Simulations

Moreover, the students claimed that they were interested on receiving additional training and more information on how to use the computer simulations (x̄= 4.1, in both cases). This demonstrates a high interest on the future use of these tools (Fig. 6.9).

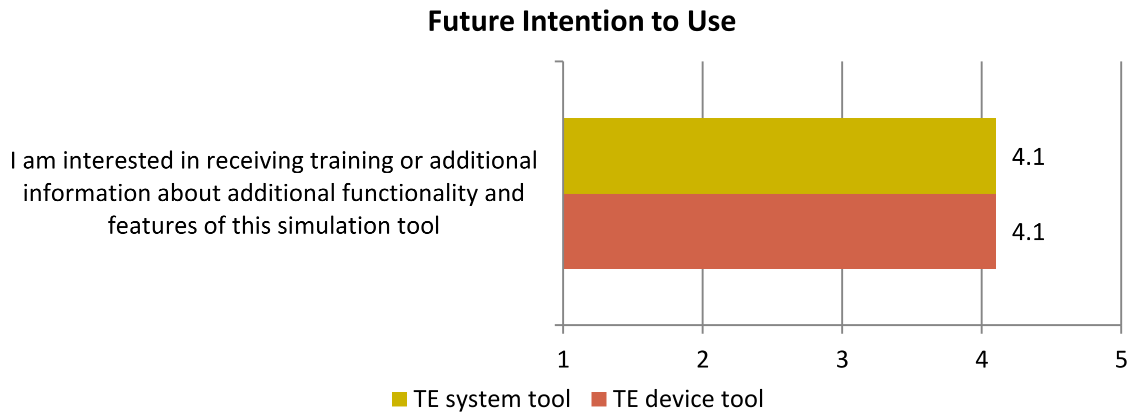


Figure 6.9 Students' Future Intention to Use the Computer Simulations

6.2.2.2 Qualitative analysis

Three open-ended questions were asked to the students at the end of the survey in order to gather their opinions about specific characteristics of the computer simulations. Their answers were analyzed by question.

Question 1: How did the simulation tools help you the most during your learning process?

Three open-ended questions were asked to the participants. The first question was about how the simulations helped them in their learning process. It was answered by 15 out of the 33 students (45.5%) who responded the survey. Most of the responses were positive (93.3%). They highlighted the opportunity to experiment and test different scenarios (53.3%) as an advantage of this approach. Examples of this comments are "*Was much closer to hands-on than simply performing mathematical simplifications or integrations*", "*The simulation tools, apart from the faculty, were important part of the course as it gave me the opportunity to test different scenarios and understand the theory more effectively*", and "*Gave hands-on experience in seeing how changes in input parameters effects the performance*".

The realistic experience offered with the computer simulations was also expressed by 33.3% of the students who provided claims such as "*The ability to plot results as a function of some particular parameter (e.g. ZT versus Temperature) gave a better feel for how materials properties played out in practice, something that is not always intuitively obvious*" and "*They helped me to visualize the equations of the problem*".

The advantageous ease of use of the tools was pointed out by 20% of the respondents: "*I think the user friendly interface helped a lot. It was easy to use and for most of the assignment I did NOT even need to completely read the structure multiple times to perform a simulation*" and "*It's easy to understand and can use easily*".

The only student that did not show satisfaction claimed that he/she limited its usage only when it was required by the homework or the instructional assessment.

Question 2: What can we do to make the simulation tools more useful for your learning in this course?

This question was filled in by 14 students, after excluding one of them who did not use the computer simulations. Two participants did not find any comment to add, and expressed that they were very friendly.

In relation to the educational component of the simulations, a common request (28.6%) was to provide some experimental data in order to allow them to test more realistic scenarios and to relate it to practical applications. One of them claimed "*I feel most comfortable when the simulation sits with experimental data, thus allowing for comparison as well as practical applications*." Another 28.6% mentioned some scaffolding techniques that could be provided in order to improve the usage of the tools. This strategies include (1) more detailed information on the parameters, (2) additional videos or texts specifically related to the simulations, and (3) information about the equations and how the simulations work.

Other comments included the enhancement of the interactivity, some design details on the user interface, the server performance, and the flexibility to perform several calculations and to increase the availability of materials for the thermoelectric devices.

Question 3: Did you encounter any problems while working with the simulation tools (i.e., TE device tool, TE system tool or Boltzmann transport tool)? Please indicate the problems you encountered.

The question about difficulties with the computer simulations was answered by 15 students. Most of them reported not having any problem with the simulations (60%). Observations related to obstacles in their learning process (21%) included the lack of information on the governing equations implemented in the simulations, the overload imposed by the lack of mastery with the technological tools, and the inconsistency they may find between the analytical and the simulated solution. Technical problems, such as the difficulties with the browser used or the mouse errors, were noted by 21% of the respondents.

6.2.3 Perceptions correlation with student performance

The average score for the three TAM constructs were correlated to the different learning materials and assessments. The sample size used for each correlation varied according to the number of students that answered both the survey and the corresponding learning resource. The Pearson Correlation Coefficients for each pair of variables are displayed in table 6.3. A significant correlation was found between the student Perceived Ease of Use and the homework score. The success in the homework response may have influenced how the students regard the easiness to operate the computer simulations. Conversely, a student with a high ability to use the tools will both perform better on this assignment and rate the simulation as easy to use.

None of the other correlation coefficients was found to be significant. This results suggest that other learning materials and assessments were not related to the way the students perceived the computer simulations. The distinctive case of the homework assignment score may be explained as this was the questionnaire in which students were required to spend more time using the computer simulations. Also, the amount of instruction and guidance given was greater than in any other resource.

Additional graphical scatterplots were developed in order to identify other possible non-linear relationships. However, no interesting patterns were observed. The small amount of data points is a limitation on this analyses.

Table 6.3 Students' performance and perceptions corrrelations

		Pretest	Posttest	Instructional assessment (first attempt)	Instructional assessment (final attempt)	HW score	Diff
Sample size (N)		15	12	20	20	8	11
Usefulness	r	0.178	-0.254	-0.111	-0.224	0.598	-0.249
	p-value	0.525	0.426	0.642	0.343	0.118	0.461
Ease of use	r	0.0645	-0.1758	-0.164	-0.174	0.71	-0.211
	p-value	0.819	0.585	0.49	0.462	0.049*	0.534
Intention to use	r	0.1254	0.0841	-0.234	-0.354	0.682	-0.167
	p-value	0.656	0.795	0.322	0.126	0.063	0.623

Notes: Pearson Correlation Coefficients, Prob > |r| under H0: Rho=0
*Statistical significant correlation

6.3 Summary

Students significantly improved their conceptual understanding of thermoelectric devices (M ± SD: 10.0 ± 13.63, t(28)= 3.95, p= 0.0005, d=0.7335). A similar pattern was observed for both LP (M ± SD: 9.23 ± 12.56, t(12)= 2.65, p= 0.0212) and HP (M ± SD: 10.63 ± 14.82, t(15)= 2.87, p= 0.0117).

No significant differences were found between the students who completed and the ones who did not complete the homework assignment (t(26.1)= -0.54, p= 0.596). The same conclusion was made for the LP group (t(8.7)=-0.24, p=0.8146) and for the HP group (t(13.8)=-0.53, p=0.605). The multiple regression model used to assess the effect of both pretest and instructional assessment on the posttest score was found to be significant (F=10.33, p=0.0005, r^2= 0.4427, adjr^2= 0.3998). However, further analysis reveals that the instructional assessment was not found to be significantly related to the learning improvement (t=0.80, p=0.4322). The same model was shown not significant for the LP (F=2.58, p=0.1248). For the HP, this model was significant (F=4.29, p=0.0393); the instructional assessment specifically was found to be a good predictor of the posttest results (t(1)=2.83, p=0.0151).

The outcome of the regression model performed to assess the coupled effect of the homework and the instructional assessment were congruent with the other results. For the complete group, the model was significant (F=6.86, p=0.0016), but the only variable that was an appropriate predictor was the pretest score (t(1)=4.11, p=0.0004). For the LP the model was not significant (F=1.59, p=0.259). Neither it was for the HP (F=2.75, p=0.0932).

Students' perceptions about the course were mainly positive. Still, they declared undecided in terms of the perceived ease of use of the course. The average scores for the three constructs when evaluated for the computer simulations were all in the positive range. Students perceived the simulations to be useful, easy to use, and they are interested on using them in the future.

The feedback obtained from the open-ended questions ratify the satisfaction of the students with the course and the computer simulations. Students recognized the importance of the simulations on the promotion of inquiry-based learning and, moreover, they highlighted how these tools can be an opportunity for experimental practices. They also suggested other strategies for the improvement of the computer simulations as learning materials. Some of the most repetitive comments were related to additional instructional support materials that can boost the inquiry process.

The learning performance was expected to be related to the users' perceptions about the tools. Most of the three constructs and the learning materials scores were not found to be significantly correlated. A unique significant correlation was found between the homework assignment and the perceived ease of use. Still, the small sample size of these tests is a limitation for these results and conclusions.

CHAPTER 7. DISCUSSION

Throughout this chapter, relevant findings of this research and its implications for the field are discussed. The limitations of the study, the conclusions and possibility for future work are presented as well.

7.1 Discussion

The purpose of this case study was to evaluate how a set of computer simulations could be implemented in order to improve student conceptual understanding of thermoelectric devices as part of an online course. The research was developed in a learning context with a very specific set of characteristics; (1) the format consisted of a distance learning environment, (2) the course was offered to students with an advanced academic degree, (3) the topics taught are considered to be of a high level of conceptual difficulty, (4) the hands-on experimentation with the system under consideration (i.e., the thermoelectric devices) is not easily affordable, even in the context of a traditional classroom, and (5) the simulations used were originally designed to be used for research purposes.

This study hypothesized that the computer simulations incorporated in the course would help the students to increase their conceptual understanding of thermoelectric devices. This learning process was expected to be enhanced by the use of instructional support. Student engagement and satisfaction with the tools was also predicted to be positive; and this attitude toward the simulations is believed to have an effect on the student performance concerning the learning tasks. The discussion is presented in accordance with the proposed research questions and the corresponding findings obtained.

7.1.1 Can the use of computer simulations in an online course improve student understanding of thermoelectric devices?

The first research question of this case study attempted to contribute to the debate on how to successfully use computer simulations in education. According to the statistical analysis, participants' performance was found to be significantly better in the posttest than in the pretest (M ± SD: 10.0 ± 13.63, t (28) = 3.95, p=0.0005, d=0.7335). The use of computer simulations helped them to increase their conceptual understanding of thermoelectric devices. This outcome further supports findings from previous research studies on the implementation of computer simulations with educational purposes. In most of the cases, these computational tools have been found to support student conceptual understanding (Rutten et al., 2012; Smetana & Bell, 2012). This finding also helps to support the statement that virtual experimentation can be considered a successful replacement for learning contexts in which experiences with real laboratories are not feasible (Finkelstein et al., 2005; Ma and Nickerson, 2006; and de Jong et al., 2013). For this online course, this was the case in that it was not feasible to have students perform experiments in real laboratories.

The same pattern was observed for those students with a lower performance (LP) and those with a higher performance (HP) in the pretest when analyzed independently; in fact, both groups showed a similar magnitude of improvement, suggesting that the use of computer simulations was equally effective regardless of how students performed on the pretest. This result is comparable to the outcome of the research study developed by Brophy, Magana and Strachan (2013). They encountered a situation in which students who used a molecular dynamics simulation equally benefited from it in their learning, regardless of the students' attendance in the lecture and/or the pre-lab session, where concepts related to the simulation tool were taught.

Even though the students' conceptual understanding was found to improve significantly, their scores on the learning assessments were limited, as observed in their posttest score (M ± SD: 56 ± 17.7). This limited result can be attributed to the advanced level of complexity of the topic. Thermoelectricity is subject matter where experts in the field, who were also instructors of this course, are still making new discoveries in this area.

Stern, Barnea and Shauli (2008) found that, although there was a significant improvement in molecular kinetic understanding in the students using the computer simulations, the learning objectives were not achieved. The authors associated the results with a possible effect of instructors' lack of ability in the operation of the technological tool; then, the guidance that the students received was defficient (Stern, Barnea and Shauli, 2008). However, the learning context of this aforementioned study had multiple dissimilarities with the present study. Previous studies have discussed other explanations to the moderate learning objectives achievement; some of the remarks that may be related to this study are the strength of the student background knowledge and other competences (McKagan et al., 2009), the complexity of the simulation task (Clariana and Strobel, 2007, in Magana, Brophy, & Bodner, 2009), and the conceptual overload caused by the exploratory process (Njoo & de Jong, 1993).

In opposition to the expected results of this study, neither the completion of the assignment nor the instructional assessment scores had a positive effect on the students' learning improvement. When assessed separately for the LP and HP groups, the results are divergent. The assignment guidance through the simulations did not have an impact on students' learning gains for either of the two mentioned groups. On the other hand, the instructional assessment score was a significant predictor of student improvement only for the group of HP. This suggests that, in this group, the instructional assessment performance is a predictor of their conceptual understanding. Combined effects of homework completion and instructional assessment scores were analyzed in a single multiple regression model. This model was not significant; the homework completion and the instructional assessment score, together, are not good predictors of the posttest grade variation.

The results obtained regarding the support provided by instructional materials to the process of learning with simulations are incongruent with the existing literature. Experts in the use of computer simulations in education have claimed the importance of guidance to the student through the operation of the computer simulations (Njoo & de Jong, 1993; Davies, 2002; de Jong, 2006; Trundle & Bell, 2010). According to these authors, the accomplishment of the expected learning gains is subjected to the correct instructional support. Particularly, assignments have been proved to be a useful strategy to guide learning (Swaak et al, 1998; de Jong, 2006). Moreover, no differences have been found between the types of instructional support; therefore, it would be expected that having assignments as part of the learning materials would have a positive effect on students' improvement.

The conflicting findings of this study could be explained by the differences in the learning context with the ones that have been used for most of the research in the field (Smetana & Bell, 2012; Rutten et al., 2012; D'Angelo et al., 2014). As it was noted by Balamuralithara and Woods (2008), the maturity of the participants and the level of education is directly related to the benefits of using computer simulations. In this case, the amount and type of instruction may differ with regard to the needs of K-12 and college students.

7.1.2 What are student perceptions about the incorporation of computer simulations in an online thermoelectricity course?

The second part of the case study focuses on discovering the perceptions of the users concerning computer simulations and identifying how those opinions may relate to student learning performance. Students' perceptions about the course were found to be predominantly positive. The students' perceptions regarding the usefulness of the computer simulations paired with the students' future intentions to use computer simulations to aid learning had high ratings; students thought that the course was relevant for their interests, and they also indicated that they intended to use some of the content in the future. In terms of the perceived ease of use, students declared that they were undecided; they rated their expected performance on the course as "Good" rather than

"Very Good" or "Excellent". The difficulty associated with the topics delivered through the course could explain this reaction. In the open-ended questions, "helpful," "nice" and "extremely good" were some of the adjectives used by the students to describe the course. Also, some meaningful feedback was given about the pace, learning materials and content distribution throughout the course. Addressing some of these issues could help improve students' performance in the course.

The participants demonstrated that they were satisfied, specifically, with the computer simulations. The student-perceived usefulness score was positive; students thought the use of the simulations was appropriate to the way they learn and that it allowed them to complete their homework successfully. They perceived the simulations as easy to use; they believed the interface was helpful, and they had a pleasant experience when working with the simulations. Lastly, they acknowledged their interest in continuing using the simulations in the future. These responses agree with what has been addressed in other studies; the attitude of the students toward the use of computer simulations is almost always satisfactory (Smetana & Bell, 2012). Magana, Brophy and Bodner (2008, 2012) also concluded that the students are usually satisfied with the computer simulations from the nanoHUB.org initiative. Particularly, participants in their study reported greater enjoyment than that demonstrated by the graduate over the undergraduate students with the nanoHUB.org tools (Magana, Brophy and Bodner, 2012).

Students not only claim satisfaction with the simulations, but they recognize the multiple advantages of accessing these tools (Smetana & Bell, 2012). In this case study, the open-ended responses provided an insight into those impressions. One of the most relevant conclusions from the students' comments to these questions was acknowledging that these tools served as an approach to real experimentation. Samples of those assertions include students' comments that they enjoyed the opportunity of having an approach to hands-on experience, being able to see the effect of changing parameters, testing multiple scenarios, and helping to visualize the equations. These claims allow us to identify that the simulations drove the students to follow an inquiry-based process. They perceived that the simulations were providing them with the same benefits of hands-on experimentation, with all the steps and advantages that these practices imply for inquiry-based learning.

A repetitive observation was made about how helpful it would be to use real and/or experimental data when operating the simulations. Also, some ideas to improve the course included the increase of scaffolding given by the simulations- user interface, and new instructional support strategies such as information on the parameters and the equations.

The feedback recorded by the students is highly relevant to the inquiry-based learning discussion, and how the computer simulations, coupled with instruction, can prompt inquiry. The students' comments suggest that, for more advanced levels of education, other types of instructional support could be used in order to obtain better learning outcomes. As mentioned above, although existing research claims that there is no difference between support techniques (D'Angelo et al., 2014), this conclusion may change if different types of audience are studied.

All the strategies mentioned by the students have been recognized to be effective in terms of increased learning (de Jong, 2006). The Meaningful Problem approach with realistic data, the scaffolding strategies, and the transparency, may provide an opportunity to enhance student practice with the simulations (Edelson, Gordin and Pea, 1999; Quintana et al., 2004). Meaningful problems is a task of real interest to the student, and can, therefore, increase engagement (Edelson, Gordin and Pea, 1999). This approach could also make better use of students' background knowledge and experience on the topic. In scaffolding, the instructors give further assistance to the students, which is particularly useful when students are solving difficult tasks or completing difficult exercises (Quintana et al, 2004). Making the simulations more transparent to the students is a way to let them have access to more information about the variables and the relationships being illustrated in the simulation. This can be done by revealing the governing equations and calculations of the simulation. The need for transparency in the simulations was also reported by Magana, Brophy and Bodner (2012). In that research study, students also expressed their desire to have this type of information. The researchers of the aforementioned study proposed a framework to integrate scaffolding and transparency.

Student performance and the students' perception about the simulations were found to be unrelated. Most of the students rated the simulations positively, and from these positive ratings, it can be concluded that students were satisfied with the simulations regardless of whether or not the simulations actually helped the students; progress with regard to their learning of the material. Homework was the only material found to be positively correlated to the students' perceptions. It can be hypothesized that the greater the operation of the simulation, the higher the students ranked satisfaction with the simulation; however, the small sample size used for this correlational analysis is a limitation of these results as well as a limitation of the conclusion about these relationships.

7.2 Limitations of the Study

Student commitment to completing the course from the beginning to the end was very low. From the 176 students who enrolled in this course, only 67 completed the materials for the five weeks. Moreover, the instructors and researchers control over the participation of those active students was limited. The data obtained depended on the voluntary cooperation of the students. This phenomenon resulted in a small sample size available for the statistical analyses of this study.

The restricted control over the data collection process leads us to assume and rely on the voluntariness and honesty of the students on the responses to the learning assessments. Additional strategies for similar future studies to increase the participation rate, the control over the sample size and participant commitment are recommended. Such strategies may include student participation compensation, the use of a very strict timeline for the completion of the assignments and online tracking of student activity while answering the tests.

The conclusions of the study are limited by the lack of a group for comparison. Having a control group would allow the confirmation of any differences between the simulations and using other traditional instructional materials, such as using hand calculations to solve the problems (Smetana & Bell, 2012).

Additionally, the online nature of this learning environment represented an opportunity to have students from multiple nationalities and educational backgrounds, which in this case study were not regarded as predictor variables of students learning improvement using simulations. The influence of these factors should be considered for future research on the impact of computer simulations in education.

7.3 Implications for teaching and learning

This case study provides an insight on the value of using computer simulations as educational resources in certain conditions that have not been broadly studied; these conditions include mature students, with a high level of education, using computer simulations in a distance-learning course. The simulations provided the students with a meaningful learning experience, which was demonstrated both in the increase of learning gains and in the students' perceptions of the computer simulation.

The failure to demonstrate the relevance of instructional supported operation of the simulations on the students' conceptual understanding improvement is a controversial finding; however, the lack of research on similar conditions to those assessed in this study can explain this divergence. Therefore, the need for further investigation with regard to this phenomenon in comparable conditions is imperative; the effect of other instructional strategies for similar contexts should be explored. This knowledge would help successfully implement computer simulations and obtain the desired learning outcomes in the future.

The analysis of the student perceptions confirm that the computer simulations prompt inquiry-based learning. In the same sense, the information provided by the participants when asked about ways to enhance the simulations endorse the need to explore the use of different support strategies for inquiry-based learning.

These coupled findings of (1) the limited effect of the provided learning materials on conceptual performance and (2) the students' requests for further instructional support, can be considered for future improvements on the instructional design for this specific course "Thermoelectricity: From atoms to systems". According to previous research and the students' feedback obtained from this study, it would be recommended to use different types of support for the use of the computer simulations in the course. Identified successful strategies that can both increase inquiry-based learning and student engagement with the simulations include the meaningful problems approach (Edelson et al., 1999), increased support from the user-interface (Quintana et al., 2004), and increased transparency in the model explanation (Magana et al., 2012).

In the meaningful problems task, students are guided to solve a problem that matters to them (Edelson et al., 1999). For such an advanced level of education, students are used to base their practices on solving real problems and using experimental data; this approach could take advantage of the students experience with real research practices. Scaffolding opportunities in the user interface helps the student to have assistance throughout the experimentation process (Edelson et al., 1999; Quintana et al., 2004). This technique is particularly important to support the student while developing difficult tasks (Quintana et al., 2004, Magana et al., 2010). Finally, increasing the simulations transparency has been shown to be a necessary technique for computer simulations used in engineering education (Magana et al., 2010). Engineering students could benefit from further visibility on how the model works and the governing equations that explain the simulation process and results (Magana et al., 2010). Specifically, for the level of education treated on this study, increased transparency should not represent a source of conceptual overload.

7.4 Conclusion and Future Work

This case study attempted to analyze how computer simulations can increase student conceptual understanding of thermoelectric devices. The effect of instructional support and student perceptions were also investigated. The results obtained from a pretest-posttest design are consistent with previous research on the positive effect of computer simulations for increased conceptual understanding in different academic fields. The tools benefited the students who performed better in the pretest as well as the ones who did not perform well in the pretest; however, the learning objectives were, in average, not successfully achieved.

The instructional support for the use of the computer simulations provided in the homework assignment and the instructional assessment did not have an effect on learning improvement. These findings conflict with previous research. This divergence can be explained by the lack of research in learning contexts with conditions similar to those of the ones in this study. Further research on instructional support for computer simulations when implemented 1) for the education of mature students, 2) to teach concepts of advanced level of difficulty and 3) in a distance-learning environment should be developed.

Participants' perceptions were found to be positive, both in the quantitative and the qualitative analysis. The answers to the open-ended questions demonstrate student satisfaction with several properties of the simulations. This feedback also confirms how the computer simulations boost inquiry-based learning. The suggestions offered by the respondents to improve the practice with the simulations also confirms the need to explore other support resources. The relationship between students' perceptions and performance, which was hardly studied in this study, also needs to be investigated.

Computer simulations are an appropriate tool to complement or even replace experimentation, when the traditional practices are not possible. For online courses this is an opportunity to provide hands-on learning experiences to students. Using the appropriate instructional support and taking into account students perceptions helps to improve both the inquiry-based learning and the student engagement; these two factors result in student an increased and a deeper conceptual understanding.

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APPENDICES

Appendix A Pretest and Posttest Questions

Answer the ten questions below by choosing the best answer (one).

1. Thin film thermoelectric devices are used for cooling electronic micro-chips. What is the main reason of using thin-films instead of bulk materials for thermoelectric cooling?
a. Sometimes does not require a heat sink for low heat flux applications
b. Can be easily integrated with micro-chips
c. Precise control of thickness that is necessary for cooling small devices is possible
d. Can easily fit micro-scale heat sources.
e. All of the above

2. If it is required for a hot side temperature to be cooled down to the temperature of the cold reservoir at the other side, what is the most energy efficient cooling method with a thermoelectric device?
a. Control the drive current to get the maximum temperature difference between the two sides.
b. It is not desired to use a thermoelectric device.
c. Temporally set the drive current for maximum cooling and then gradually lower the current until the temperature reaches the target temperature.

d. Put the drive current for maximum cooling performance of the thermoelectric device.

3. When you have a properly working thermoelectric device placed between a heat sink and a cooling target, what will occur if you significantly increase the drive current to the device?
a. Nothing changes
b. Improve the cooling performance
c. Increase the temperature of the target device
d. Decrease the heat sink temperature

4. Thermoelectric generators can be used for waste heat recovery from automotive exhaust gas. If the temperature of exhaust gas is 500 °C with cooling water is near 100 °C. Which is the better design for the thermoelectric generator?
a. Use 100 °C to 350 °C across the thermoelectric device
b. Use 200 °C to 400 °C across the thermoelectric device
c. Use 100 °C to 500 °C across the thermoelectric device
d. Use 150 °C to 450 °C across the thermoelectric device

5. If one successfully extracted a 500 Watts of electrical power from a 4,000 Watts of exhaust gas heat using a thermoelectric generator. What is the energy conversion efficiency?
a. 14.3%
b. 12.5%
c. 8.0%
d. 5.0%

6. What is the effect of a substrate underneath a thin film thermoelectric cooler?
a. Reduce the effective thermal resistance of the device
b. Increase the effective thickness of thin film
c. Increase the coefficient of performance
d. Minimize current spreading through the device
e. Generate Peltier heating at the interference with thin film

7. What is the effect of contact resistance at the cold side of a thin film thermoelectric cooler?
a. Decrease thermal resistance
b. Decrease Peltier cooling
c. Increase Peltier cooling
d. Increase thermal response time
e. Increase Joule heating

8. How is the optimal power output Pout of a thermoelectric power generator related to the temperature difference ΔT across the device?
a. Pout is proportional to ΔT.
b. Pout is a function of ΔT, but can increase or decrease with ΔT, depending on the material properties.
c. Pout is proportional to 1/ΔT.
d. Pout is proportional to (ΔT)2
e. Pout is proportional to eΔT

9. How is the cost of a thermoelectric device at optimal design affected by ZT of the material used?
a. In general, cost does not depend on ZT.
b. Cost will change if ZT changes, but can increase or decrease, depending on the operating condition.
c. Cost is only related to the maximum power output of the device.
d. Cost decreases if ZT is higher.

e. Cost increases if ZT is higher.

10. How does the heat transfer coefficient between a heat sink and a thermoelectric module in a thermoelectric system affect the power output?
a. Power output does not depend on heat transfer coefficient.
b. Power output can increase or decrease depending on which side (hot or cold) the heat sink is used at.
c. Power output increases if heat transfer coefficient is higher.
d. Power output is maximized if heat transfer coefficient is at the optimal value.

Appendix B Perceptions' Survey

Dear student,
The purpose of this survey is to obtain information about your views and perceptions about the course and the learning materials provided to you. Your participation is voluntary. The information is confidential and will NOT be identified.

Please enter your nanoHUB ID

Section 1: Background information

1. What is your gender?
   - ○ Male
   - ○ Female

2. What is your age?___________

3. What is your major? (Please write the complete name)______________

4. What is the highest level of education you have completed?________________

5. In which country did you complete your highest level of education?

____

6. Did you complete the "Thermoelectricity: From atoms to systems" course?
   - ○ Yes
   - ○ No

Section 2: Perceptions about the modules

7. This course is highly relevant to my areas of interest
   - ○ Strongly Agree
   - ○ Agree
   - ○ Neither Agree nor Disagree
   - ○ Disagree
   - ○ Strongly Disagree

8. I expect that my performance for this class is going to be:
   - ○ Excellent
   - ○ Very Good
   - ○ Good
   - ○ Fair
   - ○ Poor

9. I will continue to use some of the the content of the course after it is completed
   - ○ Strongly Agree
   - ○ Agree

-
- Neither Agree nor Disagree
- Disagree
- Strongly Disagree

10. Overall, I would rate the design of this module as
Nanoscale and microscale characterization:

- Excellent
- Very Good
- Good
- Fair
- Poor

Thermoelectronic systems:

- Excellent
- Very Good
- Good
- Fair
- Poor

Selected recent advances:

- Excellent
- Very Good
- Good
- Fair
- Poor

Section 3: Perceptions about the simulation tools
Please note: We will be using abbreviated names for the simulation tools in the following questions. Find here the complete name and the link to each one of them in case you need to remember to which one we are referring to. "TE device tool": "Thin film and multi-element thermoelectric devices simulator" (nanohub.org/tools/thermo)
"TE system tool": "Thermoelectric power generator system optimization and cost analysis" tool (nanohub.org/tools/tedev) "Boltzmann transport tool": "Linearized Boltzmann transport calculator for thermoelectric materials" tool (nanohub.org/tools/btesolver)

11. Using this simulation tool enabled me to accomplish the assignment successfully (for each: TE device tool, TE system tool, Boltzmann transport tool)

- Strongly Agree

- Agree
- Neither Agree nor Disagree
- Disagree
- Strongly Disagree

12. I think using this simulation tool fits well with the way I learn (for each: TE device tool, TE system tool, Boltzmann transport tool)

- Strongly Agree
- Agree
- Neither Agree nor Disagree
- Disagree
- Strongly Disagree

13. I find this simulation easy to use (for each: TE device tool, TE system tool, Boltzmann transport tool)

- Strongly Agree
- Agree
- Neither Agree nor Disagree
- Disagree
- Strongly Disagree

14. I had a positive and pleasant experience with the simulation tool when working on the assignments (for each: TE device tool, TE system tool, Boltzmann transport tool)

- Strongly Agree
- Agree
- Neither Agree nor Disagree
- Disagree
- Strongly Disagree

15. The user interface of this simulation tool helped me avoid making errors (for each: TE device tool, TE system tool, Boltzmann transport tool)

- Strongly Agree
- Agree
- Neither Agree nor Disagree
- Disagree
- Strongly Disagree

16. I am interested in receiving training or additional information about additional functionality and features of this simulation tool (for each: TE device tool, TE system tool, Boltzmann transport tool)

- ○ Strongly Agree
- ○ Agree
- ○ Neither Agree nor Disagree
- ○ Disagree
- ○ Strongly Disagree

17. How did the simulation tools help you the most during your learning process?
18. What can we do to make the simulation tools more useful for your learning in this course?
19. Did you encounter any problems while working with the simulation tools (i.e., TE device tool, TE system tool or Boltzmann transport tool)? Please indicate the problems you encountered and which tool you are referring to.
20. Please indicate any other additional comments as related to nanoHUB-U, this course, any module or the simulation tools.

Thank you for your time in responding these questions. We really appreciate your help!

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