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A CYBER-PHYSICAL LEARNING ENVIRONMENT FOR NETWORKED SCAFFOLDING IN ENGINEERING AND SCIENCE

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Abstract

This paper proposes the development of a technological framework and learning experiences grounded on theories of learning that foster authentic practice through cyber-physical systems. This framework is embodied in a technology-enhanced learning environment called "CyPhy-LENSES: Cyber-Physical Learning Environment for Networked Scaffolding in Engineering and Science." The design of this learning middleware is guided by advances in the learning sciences, scaffolding for inquiry-based learning and principles of technology-enhanced learning environments. CyPhy-LENSES will be available to the educational community through nees.org (Network for Earthquake Engineering Simulation). CyPhy-LENSES employs NEES cyberinfrastructure extensive array of open-source cyberinfrastructure tools developed for NEES research to enhance the learning process at the undergraduate level. Although this tool will be initially focused upon earthquake engineering education, ultimately, this middleware can be applicable to a broad range of science, engineering and technology education.

Keywords: cyber-physical systems; learning; scaffolding

Resumen

En este trabajo se propone el desarrollo de un marco tecnológico y experiencias de aprendizaje fundamentado en las teorías de aprendizaje que la práctica auténtica de acogida a través de sistemas ciber-físicos. Este marco está realizado en un ambiente de aprendizaje potenciado por la tecnología llamada " CyPhy-LENSES: Cyber-Physical Learning Environment for Networked Scaffolding in Engineering and Science." El diseño de este middleware aprendizaje está guiado por los avances en las ciencias del aprendizaje, andamios para la indagación aprendizaje basado en los principios y de los ambientes de aprendizaje potenciados por la tecnología. CyPhy Las lentes estarán a disposición de la comunidad educativa a través nees.org (Red de Simulación de Ingeniería Sísmica). CyPhy-LENSES emplea NEES ciberinfraestructura amplia gama de herramientas de ciber-infraestructura de código abierto desarrollado para la investigación NEES para mejorar el proceso de aprendizaje a nivel de pregrado. Aunque esta *herramienta se centrará inicialmente en la educación de ingeniería sísmica, en última instancia, este middleware puede ser aplicable a una amplia gama de la ciencia, la ingeniería y la tecnología de la educación.*

Palabras clave: *sistemas ciber-físicos; aprendizaje; andamiaje*

1. Introduction

In spite of the tremendous advances in information technology and the critical role of laboratory-based engineering education at all levels, the majority of research in the learning sciences and the design of effective technology-based learning environments examine learning within K-12 settings. Little has been done to date to understand the role of technological and digital tools in engineering education (Johri & Olds, 2011). Therefore, there is a critical need to investigate the role of cyber-physical inquiry systems that integrate signal processing, feedback control systems, computational modeling and simulation and data-communication technologies for learning purposes. In tandem, we must adequately prepare future engineers for the complex and rapidly evolving global challenges with knowledge and skills that go beyond mere theory — knowledge that is typically gained by generating, manipulating, analyzing, processing, simulating and visualizing materials, energy, processes and information.

To better prepare future engineers to effectively exploit the forthcoming data deluge, advances from the learning sciences in inquiry-based learning can help engineering educators and engineering curriculum designers to design authentic learning experiences. However, to engage learners in meaningful learning it is necessary to adopt a "practice perspective" (Roth & McGinn, 1997, p. 92). In a practice perspective the focus of learning (and research) is on participation in authentic experiences, where learning environments: (a) are personally meaningful to the learner, (b) relate to the real-world, and (c) provide an opportunity to think in the modes of a particular discipline (Shaffer & Resnick, 1999).

Through this position paper we present a technological framework and learning experiences grounded in theories of learning that can foster authentic practice through cyber-physical systems. Our framework is embodied in a technology-enhanced learning environment called "CyPhy-LENSES: Cyber-Physical Learning Environment for Networked Scaffolding in Engineering and Science."

2. Background

The growing challenges in sustaining the infrastructure of the Nation demands a new generation of engineers armed with multi-disciplinary skills and ability to find creative solutions. It is clear from the consequences of the recent string of destructive earthquakes in Haiti (January 2010), Chile (March 2010), New Zealand (February 2011), and Japan (March 2011), that the potential consequences of such events on our critical infrastructures are not as yet well understood. Clearly there is a strong need for the next generation of engineers to tackle these important problems with new skills at their disposal, but to train engineering in hazard mitigation cyber-physical systems are used.

Through cyber-physical systems engineers can learn to use information technology to utilize large data sets to make conclusions, implement informed decision making with sensor data, and work seamlessly in interdisciplinary teams. Experts are also taking this path forward when discussing the most promising directions for future research in infrastructure systems and in developing resilient communities (Dyke et al., 2010). Ubiquitous and low-cost sensing, monitoring of our built and natural environments, probabilistic modeling capabilities, diagnosis and prognosis using data and computational models, and feedback control systems are the toolset of the next generation of engineers leading the charge against these concerns. However, creating effective cyber-physical laboratory experiences requires an investment in curriculum design, experimental research, and infrastructure (Borgman et al., 2008). In addition, there is a constant debate over the educational value of the use of remote laboratories (Gomes & Bogosyan, 2009), but little has been written about evidence-based learning through laboratory instruction (Feisel & Rosa, 2005). Therefore, regardless of the modality (i.e., local or remote), there is a well-recognized need of well developed, researched, and tested curricular materials, lesson plans, and learning modules that can effectively guide and scaffold the integration of these technologies (Gomes & Bogosyan, 2009).

To address this gap, we propose the development of a learning middleware called CyPhy-LENSES. The design of this learning middleware will be guided by advances from the learning sciences and theories for the design of inquiry-based learning environments and technology-enhanced learning environments. The mechanism by which we will make CyPhy-LENSES available to the educational community will be through the premier cyberinfrastructure of the NEES (Network for Earthquake Engineering Simulation) project. NEES is a network of laboratories for earthquake engineering experiments focused on improving resilience to earthquakes in our society. We plan to employ this extensive array of cyberinfrastructure tools developed for NEES research to enhance the learning process at the undergraduate level.

3. Simulations and Cyber-Physical Laboratories in Science and Engineering Education

At a level unprecedented in human history, more and more graphical representations are being produced and exchanged through digital technology (Johri & Olds, 2011). Specifically, the role of simulations, remote laboratories and computation software has become the new form of literacy in engineering domains. For instance, researchers have identified that working with computational tools pose challenges such as task complexity, tool complexity and interface complexity, and that the integration of scaffolding can be provided to deal with complexities such as these to support inquiry processes (Quintana, Kasem, & Soloway, 1996).

In educational contexts, simulations, have been used for inquiry learning. In general, inquiry learning involves gathering, interpreting, and synthesizing different kinds of data to answer given questions (Quintana, Zhang, & Krajcik, 2005). Simulations in the context of inquiry learning provide unique educational benefits. They provide students with: (a) an opportunity to study abstract and complex physical phenomena involving many variables (Dede, Salzman, Loftin, & Sprague, 1999), (b) the ability to visualize and, in a certain way manipulate phenomena that is not possible with any other tools (Zacharia, 2007), (c) an environment that approximates, simplifies, or hypothetically creates reality (de Jong, 1991), and (d) the power to alter the time-scale of real processes (de Jong, 1991). However, researchers have emphasized that inquiry learning, in order to be successful, needs adequate but not intrusive scaffolding (de Jong & van Joolingen, 2007; Mayer, 2004; Njoo & de Jong, 1993; Reid, J, & Chen, 2003; van Joolingen, de Jong, & Dimitrakopoulout, 2007; Winn, 2002). Free exploration without any support has been shown not to benefit learners (van Joolingen, et al., 2007; Veermans, van Joolingen, & de Jong, 2006). Davies (2002) pointed out that simulations do not operate in isolation, but in conjunction with the learning environment as a whole.

Specifically in engineering education, laboratory-based courses play a critical role and the nature of this experiences have been changed and extended by remote laboratories (Ma & Nickerson, 2006). Connecting to labs remotely has several key advantages and promising aspects such as: flexibility, 24 hour access, supplement to traditional physical experiments, improved scheduling, better return on investment due to shared nature of resources, collaborative education, autonomous learning, access to disabled or under privileged locations, prevention of equipment damage, improved safety in many scenarios, and fulfillment of experimental needs without use of simulation. However, there is still a debate over the educational value of the use of remote laboratories (Gomes and Bogosyan 2009). Part of this debate is confounded by the kinds of educational objectives that are being used to evaluate the educational value of remote laboratories. While hands-on advocates focus on design skills, remote laboratories advocates focus on conceptual understanding (Ma & Nickerson, 2006). Regardless of the modality (i.e., local or remote), there is a well-recognized need of well developed, researched, and tested curricular materials, lesson plans, and learning modules that can effectively guide and scaffold the integration of these technologies (Gomes & Bogosyan, 2009). Thus, there is a critical need for the identification and implementation of design principles that can guide the development of curricular materials to scaffold the use of remote laboratories for learning and engagement.

Local and remote laboratories and simulations provide a unique opportunity for the development of learning experiences contextualized in authentic practice. Since practice consists of a process of action and reflection in context (Ehn, 1993), we argue that learning through practice requires involving learners in original "field" experiences where they participate in the process of collecting, transforming, and summarizing data and the representation of the relationship between the observed event and its re-representation (Roth & McGinn, 1997). The produced re-representations, transformations and summarization of field data, exhibit information on which students base their knowledge claims. This paper proposes a development framework for educational cyber-physical systems grounded in literature of science and engineering education purposefully designed to foster authentic practice in engineering education.

4. Theoretical Foundations for the Design

Constructivism is the theoretical perspective on which this project is based. Constructivism is appropriate to the design of CyPhy-LENSES because it assumes that knowledge is constructed in the individual's mind (Bodner, 1986). Constructivism holds certain assumptions that make it important for learning and instruction. One of these assumptions is that the construction of knowledge is a lifelong process requiring mental engagement by the learner (Mestre, 2005). It also assumes that learners come into a classroom with existing knowledge created by previous experiences (Mestre, 2005). However, an assumption held by learning scientists is that learning is not only located within the individual learner, but also "distributed across the knower, the environment in which knowing occurs, and the activity in which the learner participates" (Barab & Squire, 2004, p. 1).

In our own previous work we have investigated the affordances of modeling, simulation and computation as learning tools where efforts have concentrated on aspects of teaching and learning in engineering naturalistic learning environments (working classrooms). Preliminary studies that investigate student perceptions and experiences of computation and computational simulations (e.g., Brophy, Magana, & Strachan, 2013; Magana, 2009; Magana, Brophy, & Bodner, 2009, 2010, 2012a; Magana & Garcia, 2010) showed that, overall, graduate and undergraduate students reported positive experiences of these tools and their uses. However, differences were observed in the way undergraduate students reacted to the tools as compared with graduate students. Undergraduate students showed a moderately positive attitude toward their ability to interpret the outputs of the tools.

Two major themes emerged from the data related to students who encountered obstacles when using simulations as part of their learning experiences. One obstacle was related to student ability to do mappings between representations—i.e., conceptual, mathematical and computational representations— (Magana, Brophy, & Bodner, 2012b; Magana, Vasileska, & Ahmed, 2011); the other was the need for further instructional support (scaffolds) to be able to do mappings between the different representations. The implications of these findings lead to the need for learners to develop representational fluency between a qualitative understanding of the phenomenon, to mathematical and computational understandings (Magana, et al., 2012b), and the need to effectively integrate a learning middleware that will provide transparency and scaffolding embedded into some form of cyberinfrastructure.

Extensive literature has focused on the use of scaffolding to support inquiry learning. However, there is a need for evidence-based insights into the specific role of representations in the inquiry process, and more importantly, how student development of representational fluency can be fostered through technological scaffolding. In addition, there is a constant debate over the educational value of the use of remote laboratories (Gomes & Bogosyan, 2009), but little has been written about evidence-based learning through laboratory instruction (Feisel & Rosa, 2005). Therefore, regardless of the modality (i.e., local or remote), there is a well-recognized need of well developed, researched, and tested curricular materials, lesson plans, and learning modules that can effectively guide and scaffold the integration of these technologies (Gomes & Bogosyan, 2009). Specifically, to support students in their inquiry process, CyPhy-LENSES will embed Quintana's et al. (2004) scaffolding guidelines to support process management, articulation and reflection processes and sense making processes. Process management scaffolds are provided in the form of tabs to show specific steps to be followed (see Fig. 1). We also provide descriptions of expected outcomes in each of the steps, which will support learners by guiding them through the science inquiry process. Articulation scaffolds in the form of prompt questions will facilitate the ongoing articulation and reflection during the investigation; and Sense-making scaffolds provided in different forms, will allow learners to use representation and language that bridge their prior conceptions through the use of multiple representations intended to make explicit properties of underlying data.

5. Implementation through NEES Cyberinfrastructure

The mechanism by which we will propose to make CyPhy-LENSES available to the educational community is through the premier cyberinfrastructure portal for NEES (the Network for Earthquake Engineering Simulation). Tools have been developed recently for tele-operation and tele-observation of instructional shake tables, as well as for data streaming and analysis. Most of these tools are open source and are being continually updated and improved. We plan to employ this extensive array of cyberinfrastructure tools developed for NEES research to enhance the learning process at the undergraduate level.

The NSF-sponsored George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) provides an excellent opportunity to frame hazard mitigation in the very tangible context of earthquake engineering. While theoretical and analytical discussions are necessary, experiments are quite effective for demonstrating basic concepts in structural dynamics and earthquake engineering, supplementing the more traditional methods of delivery. Earthquake simulator tables, or shake tables, are typically used for experimental research in earthquake engineering. This equipment is capable of reproducing the motion of the ground during an earthquake, allowing for controlled testing of structures subjected to earthquakes. New concepts and techniques are often tested on scaled structures using shake tables before implementation on actual structures. Bench-scale shake tables offer an ideal mechanism to provide students access to such "hands-on" experiments (Kukreti & Wallace, 1996). At this scale, students can observe dynamic responses, design and build model structures, modify structures, measure responses, and reproduce earthquake records. Also, numerous student design competitions have been implemented at all levels to introduce and excite students about earthquake engineering and hazard mitigation.

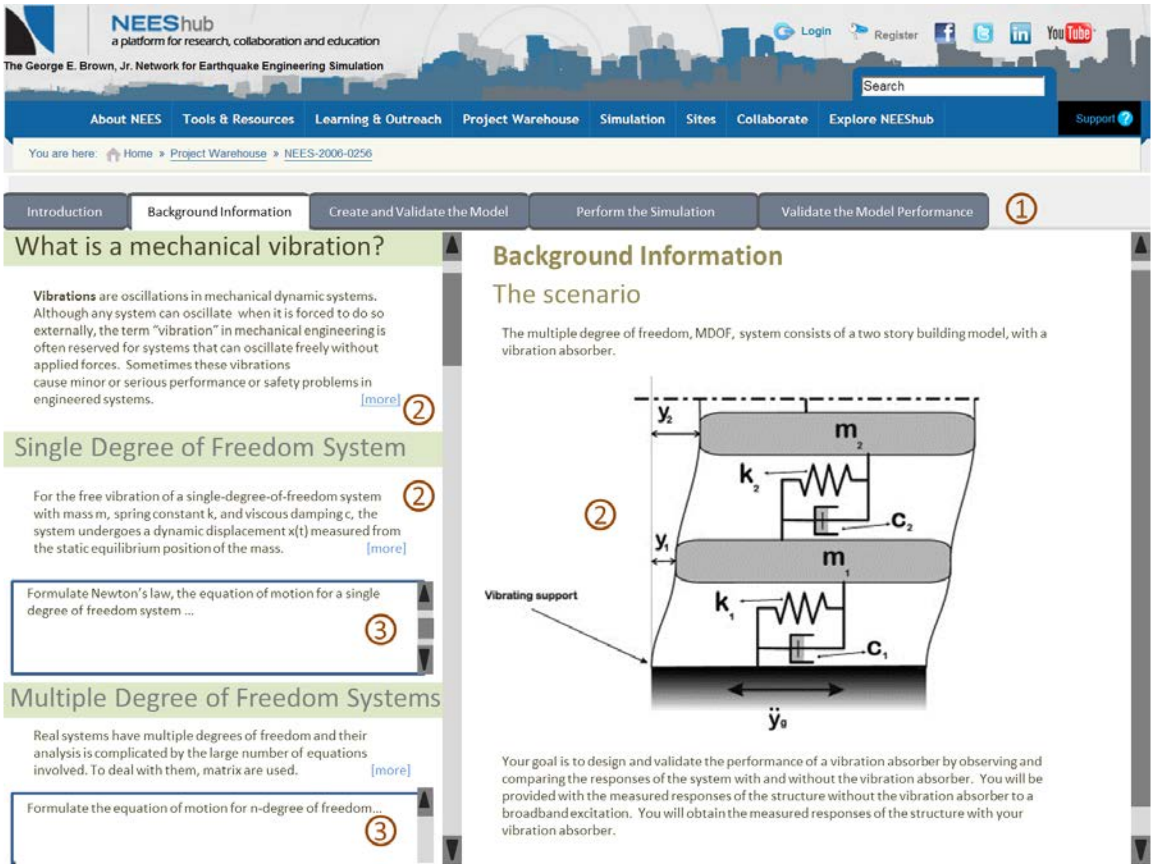

Fig. 1 Examples of embedded scaffolding. In 1, the tabs will guide the learner through a series of steps that need to be accomplished. In 2, learners will be provided with disciplinary information that will help them recall required prior knowledge. In 3, learners will be prompted to reflect on their prior knowledge necessary to accomplish the task successfully.

Tele-operation, remotely controlling the shake tables using the NEES cyberinfrastructure, was first accomplished in December 2004. More recently, an expansion of this effort has been undertaken involving tele-participation, streaming of data and video through NEES cyberinfrastructure tools. CyPhy-LENSES will make use of the instructional shake tables that are connected to the NEES cyberinfrastructure (see Fig. 2). Tele-operation using a java applet allows for remote control of the shake tables from any computer over the internet. Tele-participation through the NEES cyberinfrastructure allows for synchronized streaming video and data to be extracted from (and input into) the shake table operations through Open Source Data Turbine (OSDT). OSDT, also known as the Ring Buffer Network Bus (RBNB), is the data transfer tool used by NEES to synchronize and buffer video and data for tele-observation. The NEES Real-time Data Viewer (RDV) is then used to view the time synchronized streaming video and data from any computer over the Internet.

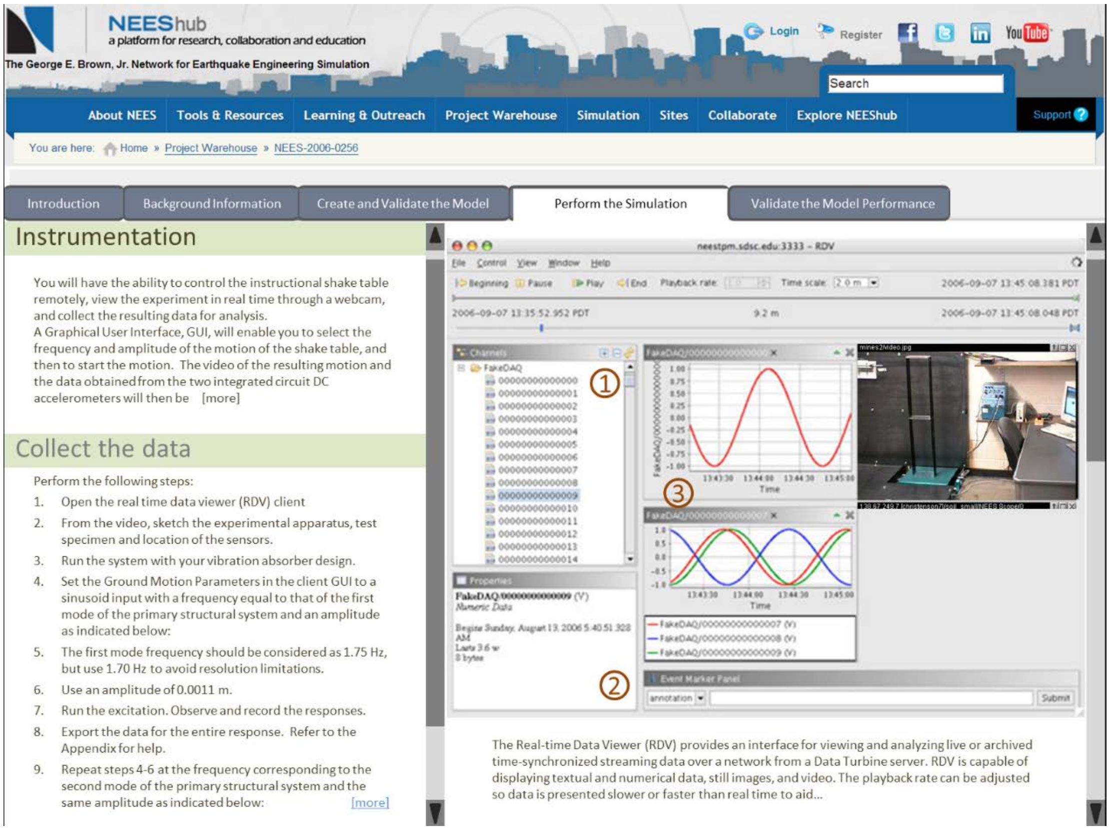

Fig. 2 Use of NEES.org remote instrumentation. In 1, learners will load existing experiments. In 2, learners are provided with visual and numerical data that they will analyze to verify computational models. In 3, learners may replay the experiment performed in order to better understand the behavior and dynamics of this system.

6. Learning Experiments in Earthquake Engineering

Hazard mitigation has been an important addition to the undergraduate civil engineering curriculum in recent years. Integration of the fundamental concepts of this multidisciplinary topic is not currently a component of traditional civil engineering education. Future civil engineers must have an understanding of the dynamic response of structures such as buildings, bridges, towers and dams to ground motions resulting from natural disasters such as earthquakes, and man-made disasters such as blast loads, and the implications of this behavior on the resulting structural designs. However, the worldwide importance of understanding and proper preparation for such topics is clearly needed.

The proposed CyPhy-LENSES provides the mechanism to engage a wide range of students in innovative laboratory experiences based within the framework of earthquake engineering, one readily demonstrated element of hazard mitigation, which will provide a combination of fundamental concepts and emerging technology in related topics (e.g. structural engineering, structural dynamics and structural control). The activities are based on the use of a bench scale shake table lab station.

Through the proposed learning experiments undergraduates will learn the fundamentals of structural dynamics (e.g. mode shapes and frequencies) while gaining experience with sensors and sensor technology, data acquisition, emerging technologies for seismic response modification, and established cyberinfrastructure tools. Specific instances of the learning experiments will embody the following specific learning goals:

- Operate the remote shake table to measure transient and forced vibrations in a simple, single degree of freedom system and determine the frequency and damping experimentally.
- Adapt a given numerical model of a lumped mass bench-scaled structure and compare the results of numerical simulation with experimental data.
- Design and validate the performance of a vibration absorber by observing and comparing the responses of the system with and without the vibration absorber.

7. Conclusion and Implications

Once completed, CyPhy-LENSES will be applicable to science, technology, engineering and math (STEM) education and, consequently, advance multiple fields, including: cyber-learning, engineering, information technology, and engineering education. Virtual or remote laboratories provide interactive simulations or instrumentation of laboratory equipment and experiments which, coupled with cyberinfrastructure, can be scalable to include easy experimentation through scaffolding, high level of interactivity, and the embedment of classroom activities. Consequently, STEM education could be intensely changed by placing far greater emphasis on learning that is based on learner interactions with complex data and systems.

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