

Cyber-environments as platforms for integrating engineering research and education

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1. CONTEXT

At the very outset, we define a cyber-environment as a collection of computational resources, data, and visualization resources made available through an online portal. Representative examples include the nanoHUB for computational nanotechnology, NEES for earthquake engineering, and LEAD for linked atmospheric environments. Every cyber-environment usually hosts a variety of simulation tools – called cyber-tools – that cater to specific scientific problems; for example, simulation of carbon nanotubes or studying behavior of earthquake wave propagation through faults. In addition to catering to the needs of a specific engineering community, cyber-environments - also popularly referred to as science gateways - provide a direct link between cutting-edge undertaken by the community and learners.

On February 5, 2007, the National Science Foundation released a document entitled “Cyber-enabled Discovery and Innovation” [1]. This document sets the NSF-wide strategy for how \$302 million dollars will be spent over the next 5 years for engineering and science research. The report states that “the National Science Foundation (NSF) will begin the Cyber-enabled Discovery and Innovation (CDI) initiative to explore radically new concepts, approaches and tools at the intersection of computational and physical or biological worlds.” This essentially means that the NSF strategy for the next generation of discovery and learning centers on the appropriate use of cyber-tools and cyber-environments. Furthermore, over the past few years, the National Science Foundation and indeed other funding agencies have invested significantly in cyber-tools and cyber-environments to advance engineering and other scientific domains. These engineering cyber-environments are starting to play a serious role in educating future engineers. Despite this critical role undertaken by cyber-environments, the literature in engineering education is deafeningly silent on the design and use of cyber-environments as engineering education platforms.

In this paper, we argue theoretically that cyber-environments provide learners with extremely authentic learning contexts. Furthermore, in discussing the core architecture of cyber-environments, we show how these environments move beyond the traditional bottlenecks in computation, data, and visualization resources that are trademarks of the conventional engineering classrooms. The core of this paper is a theoretical framework proposed to spawn a discussion about the role of cyberinfrastructure in engineering education. The purpose of this paper is not to explore a specific methodology, whereas to examine the larger problem space of cyber-learning and position it as a critical area of research within the field of engineering education. The paper explores the natural link that exists between advances in cyberinfrastructure and pedagogically sound approaches to using cyber-environments in engineering education.

2. THEORETICAL FRAMEWORK AND RESEARCH QUESTIONS

2.1. The Cyberinfrastructure Perspective

“The comprehensive infrastructure needed to capitalize on dramatic advances in information technology has been termed cyberinfrastructure (CI). Cyberinfrastructure integrates hardware for computing, data and networks, digitally-enabled sensors, observatories and experimental facilities, and an interoperable suite of software and middleware services and tools” [2]. Furthermore, the Atkins report [3], which is considered the genesis of the word cyberinfrastructure, elaborates on this definition further. It states, “The newer term *cyberinfrastructure* refers to infrastructure based upon distributed computer, information and communication technology. If *infrastructure* is required for an *industrial* economy, then we could say that *cyberinfrastructure* is required for a *knowledge* economy” (p. 5). Advances in cyberinfrastructure (CI) are starting to have a transformative effect on how research is conducted in science, engineering, and technology domains. The potential for next generation of cyber-enabled discoveries and innovations to have a profound broad stroke impact on human life is very high.

Cyberinfrastructure and resulting cyber-environments are critical for the engineering education community as this denotes a new way of conducting discovery and education at scales that were deemed impossible before – starting all the way from the nanoscale covering the entire spectrum up to the galactic scale and beyond. Theory and experimentation are the traditional methods of conducting engineering and science. However, with the maturing of cyberinfrastructure, use of simulations as one of the primary vehicles for conducting engineering and science is starting to gain increasing importance. Given the above definition of cyberinfrastructure, it would be easy to see it as being the domain of advanced engineering and science alone. It is critical to understand the impact of cyberinfrastructure on the larger socio-cultural context within which we function on a daily basis. The power of cyberinfrastructure lies in its ability to democratize science, engineering, and technology; “By making access to reports, raw data, and instruments much easier, a far wider audience can be served” [3, p. 29]. Most of us are direct consumers of cyberinfrastructure. From the weather forecasts on television to a simple search using a popular search engine online, cyberinfrastructure has revolutionized the average human’s lives. Cyberinfrastructure (CI) is tacitly present in our everyday lives.

While the importance of cyberinfrastructure as a critical field in enabling environments for engineering and science is steadily increasing, literature in the field of engineering education has remained largely silent and agnostic to this development. New theoretical frameworks that explore how engineering education research and indeed practice are affected by the significant impact of cyberinfrastructure need to be developed. The research question is: ***what type of theoretical frameworks will allow the seamless and high impact integration of cyber-environments within the engineering curriculum?*** This question highlights the critical need to advance the field of engineering education in such a way that the use of cutting-edge engineering cyber-environments can provide students at all levels with unprecedented level of access to learning resources, educational tools, and social support structures. This area of work is grounded firmly in what has been identified as a key issue for the discipline of engineering education – namely, the influence of learner and teacher characteristics on educational technologies used for educating future engineers [4, 5]. Therefore, the development of well-defined theoretical frameworks centered on the use and adoption of cyberinfrastructure has great potential to forge new directions in the field of engineering education. It must also be pointed out

that this work also advances scientific knowledge of cyber-tools, cyber-environments, and scientific workflows for engineering. It transforms cyber-environments such that they are more conducive for curricular use.

2.2. Connecting the Pedagogical Perspective

In this section, we demonstrate that the pedagogical problems in engineering education and the science of cyber-tools and cyber-environments are closely interlinked. However, these connections have not been leveraged in extant literature in the field of engineering education. While engineering curricula have evolved to include newer technologies, the actual process of teaching and learning continues to a great degree be highly constrained by resources available in the classroom environments. Much of the instruction is still constructed around what the faculty members can provide and mediate. Therefore, despite the infusion of modern instructional technology within engineering curricula, the fundamental instructional model in many situations still revolves around “information push”.

It is common knowledge that the field of engineering is moving towards more data intensive applications where moving from data to insights in an extremely short amount of time equates to competitiveness and scientific breakthroughs. Given this data rich world and the tools that engineers are required to use on a daily basis, the current state of the engineering curriculum is rather troubling. The basic skills needed in order to be successful as an engineer are fast expanding. One of the most important skills that students need, but the current engineering curricula do not provide, is the ability to harness cyber-tools that can look past traditional computational, network, and data bottlenecks. There is much research needed in order to build the kind of tools that can break the computational barriers of the traditional engineering classrooms. The fundamental question remains: *what types of cyber-tools and cyber-environments can provide a strong foundation for engineering students that prepare them for the knowledge economy?*

The impetus for using cyber-tools and cyber-environments for teaching and learning in engineering disciplines comes from the need to provide students with real-world, hands-on experiences that utilize a community of practice [6] as the basis for knowledge-creation activities. Lave and Wenger [7] argue that learners need to be placed within the larger context of practice in any domain so that they may learn from multiple experts not only the content, but also the culture of that discipline. In other words, according to situated learning theory [7, 8, 9], learners need to be placed within authentic contexts while simultaneously setting appropriate ability levels that can facilitate learning within these environments. The key theme to notice here is that of “real-world engineering experiences.” Other pedagogical theories – such as inquiry-based learning, problem-based learning, and cognitive apprenticeship [10, 11, 12, 13] – also emphasize that students need to be provided with authentic learning experiences in social settings.

Extant literature in the field of education has repeatedly pointed out that learning occurs best in environments that engage learners in dynamic environments that allows learners to engage in the process of “knowledge co-creation.” Such environments usually offer a high degree of realism, allow resources to be dynamically adapted to the needs of the learners, and promote significant social interaction. Furthermore, these environments offer highly personalized learning experiences, and are ubiquitous [14, 15].

Interestingly, work in the field of applied artificial intelligence show, in particular [15] and [16] shows clearly how the above learner requirements map onto the “semantic grid

problem” that computational scientists are trying to solve. In the words of [17], “flexible, secure, coordinated resource sharing among dynamic collections of individuals, institutions, and resources” is a major problem that the world of cyber-tools and cyber-environments is trying to solve. In the case that [17] is discussing, the focus is on how cyber-tools and cyber-environments can adapt themselves to individual scientists. This is fundamentally no different a question than what we are trying to solve in the field of engineering education through personalized learning systems. There is, however, one big difference. In the context of [17]’s discussion – the focus is still on content that scientists are using. Learner problems are not addressed adequately and there is a significant need to develop methodologies to address this problem. The semantic web techniques that are being used for creating future cyber-tools and cyber-environments are documented in [18], [19], and [20]. These very same techniques can be utilized to influence how cyber-tools and cyber-environments are used in engineering curricula. In the near future, this paper will be expanded to include demonstrations of how semantic grid techniques can be used in building future cyber-environments. It is, however, critical to emphasize the natural connection between the area of semantic grid and engineering education pedagogy. While this relationship has been documented in some of the works that we have cited here, it needs to be applied in meaningful ways to ensure appropriate learning outcomes in the engineering classroom.

3. CONCLUSIONS AND FUTURE DIRECTIONS

In this paper, we have attempted to highlight the natural synergies that exist between the field of engineering education and cyberinfrastructure. Our goal has been to identify a broad theoretical framework within which we can use cyber-environments for engineering education. Given the significant gap that exists in extant knowledge in the field of engineering education about cyber-environments, our goal is to begin a discussion about this critical area and simultaneously identify appropriate methodologies to address research problems in this area. Many of the actual methodologies that can be used to achieve a seamless integration of these fields are still being identified and refined. As a part of presenting and completing this paper, we will also discuss some of the technical details behind current generations of cyber-environments that demonstrate how cyber-environments by very virtue of their architecture allow significant realism and dynamic social interactions.

4. ACKNOWLEDGEMENT

This work is supported by NSF CAREER Award EEC-0747795.

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