AC 2010-1243: INNOVATIVE AND TRANSFORMATIVE LEARNING ENVIRONMENTS IN CONSTRUCTION ENGINEERING AND MANAGEMENT EDUCATION

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Innovative and Transformative Learning Environments in Construction Engineering and Management Education

Abstract

Most of today's students have grown up with technology including computers, the Internet, video games, digital recorders or players, and mobile phones. Consequently, it can be argued these students are fundamentally different from previous generations in how they learn. Today's students prefer instantly seeing, simultaneously interacting, and constantly communicating with learning environments. They learn actively, rather than passively, by taking advantage of technology.

Traditional construction engineering and management (CEM) education follows the Cartesian view of mind-matter dualism where the learner and the learning context are detached. Under this paradigm, concepts are presented as fixed, well-structured, and independent entities. Learning activities are divorced from their authentic context resulting in fragmentation and specialization of courses and educational experiences. This fragility can be observed in school when students neither retain nor are able to utilize knowledge allegedly acquired in previous courses. These problems are not exclusive to CEM education, but shared by most higher education models.

Traditional CEM education models, based on precisely well-defined problems and formal definitions, may not be satisfactorily fulfilling their mission of educating the leaders of tomorrow. Indeed, most students who use digital technology in daily life still come to class, sit in front of the lecturer, and memorize concepts without the proper context. Several efforts have been undertaken to develop learning environments to cope with the limitations in traditional learning paradigms which set up a dichotomy between the learner and the learning context. A variety of advanced educational tools such as games and simulations using innovative technology are examples of these efforts. This paper discusses the need and use of games and simulations as educational tools in construction engineering and management while proposing alternatives to the traditional educational paradigm so that students experience concepts embedded in their proper context promoting learning within the nexus of the activity.

Introduction

Over the last few decades, technology has been rapidly developed and disseminated. Most of today's students have grown up with technology including computers, the Internet, video games, digital recorders or players, and mobile phones. The current generation of students is often called digital natives since they use technology for social networking, blogging, communication, information, collaboration, or competition. From this point of view, today's students are acquainted with support of technology in their learning process.

Bransford et al.[9] state that different kinds of experiences condition the brain in different ways. It can be argued that today's students are different from previous generations in the way they absorb, interpret, and process new information. Ample experience with technology enables the current generation of students to change their expectations with respect to the way they acquire knowledge. This explains why today's students prefer instantly seeing, simultaneously interacting, and constantly communicating with learning environments.

By understanding the characteristics of today's students, educators may take advantage of new technologies to facilitate students' learning. Specifically, innovative technologies can be effectively employed to provide students with collaborative, interactive, adaptive, inquiry-based learning environments. Educators are expected to be willing and able to adopt technology's power to assist the students' learning process. Consequently, students can learn actively, rather than passively, with the support of technology in their learning.

Traditional Construction Education

Traditional construction education follows the Cartesian view of mind-matter dualism where the learner and the learning context are detached[7]. Under this paradigm, concepts are presented as fixed, well-structured, independent entities. Learning activities are divorced from their authentic context resulting in fragmentation and specialization of courses and educational experiences. This fragmentation of knowledge has been identified in the construction domain[12] and is partially responsible for the polarization of the learner and the learning context[17]. Decontextualized knowledge is intrinsically frail as demonstrated by students who are capable of recalling information on a test, but unable to apply the very same concepts in authentic practice[10]. These problems, of course, are not exclusive to construction education, but shared by most higher education models.

Traditional construction education models, based on precise, well-defined problems and formal definitions, may lessen the opportunities for today's students to explore real-world problems. McCabe et al.[25] argue that current CEM courses only teach the theories of construction engineering and management; thus, students may encounter difficulties in applying theoretical principles when exposed to real world situations. Furthermore, jobs in the construction industry often require context-specific knowledge and understanding of inter-dependencies among various elements. Traditional teaching methods are not fully capable of providing students with the necessary skills and knowledge to solve problems encountered in the real world [2].

For students to experience problems in realistic situations, case studies and site visits have been adopted by construction educators as a means to generate usable and robust knowledge with partial success. However, case studies can give the impression that there are easy-to-find and universally correct responses due to the necessary simplifications[32]. Also, site visits of large groups may be unpractical and involve risk[15]; hence, they may not be welcomed. Even though the construction jobsite is available for students' visit, it is not easy for educators to control the construction phase targeted for learning objectives and goals.

In the traditional classroom, students are considered as passive learners into whom knowledge can be transferred. Educators decide what students should know through the standard lecture. In addition, many conventional curriculums for CEM education rely on traditional teaching methods such as lecturing, seminars, and group project work. In this informational learning, it is a significant challenge for educators to get students engaged in learning.

Innovative and Transformative Learning

Construction can be defined as a highly complex system which has a wide spectrum of interrelated elements with multiple feedback loops and non-linear relationships. In addition, construction is a difficult environment to summarize due to differences of scale, nature, environment, society, etc. For these reasons, it has been a challenge for construction educators to provide learning environments in which students can experience such complexity in the classroom. By taking advantage of emerging technologies and their applications to the classroom, construction educators have been continuously seeking a seamless way to cope with these limitations.

Over the last decade, several efforts have been undertaken to develop learning environments in order to overcome the dichotomy between abstract knowledge and real-world context. Unlike traditional learning, innovative and transformative learning focuses on providing students with practical experiences to explore the problems they may encounter in the real world with the support of innovative technologies.

According to Mezirow[27], transformative learning may happen through transformative experience when learners can examine their own practice based on current experience, revise their own current view, and integrate this revised view into a new practice. Taylor[41] examines essential practices and conditions for fostering transformative learning, and states that "Effective instructional methods support a learner-centered approach and promote student autonomy, participation, and collaboration."[41] Today's students can be actively involved in learning through a wide range of technologies including blogging, podcasting, educational software, computer-based games and simulations, and so on. Marton et al.[24] describes that students, when being active learners, show a deep approach to learning by seeking a personal and meaningful understanding of that learning.

Learning through games and simulations itself emphasizes the learning process. Games and simulations offer interesting and engaging learning processes where students can actively participate, interact with others, and use their experience as the context. Thereby, students are able to critically reflect about the content. Games and simulations facilitate students' reflection on those experiences to empower them into altering their current perspectives.

In addition, through well-designed and developed games and simulations, supported by innovative technologies, students can inexpensively practice decision-making as well as problem solving in real-like contexts while having fun. The use of games and simulations may create immersive and highly motivated learning environments where learners interact with learning content and deeply learn the target knowledge for transformative learning. From this perspective, transformative learning is in conformity with a constructivism approach where learners construct knowledge through their own experience in the world[11, 14].

For innovative and transformative learning, educators should be prudent in using games and simulations. Considering the targeted learning objectives and goals, games and simulations should be implemented through proper strategies. It is a challenge for educators to use games and simulations in appropriate instructional settings as well as with the appropriate audience in the classroom.

Several efforts have shown the potential use of games and simulations to assist CEM education and facilitate students' learning. Particularly, computer-based games and simulations can be considered as effective tools and proposed for construction education [4, 37]. The concept of games and simulations in construction engineering and management is not a new idea in construction education. The earliest approach to games and simulations as educational and training tools in construction was the 'Construction Management Game'[5] which simulates the bidding process in the construction industry. This model has inspired a variety of research efforts in the area: CONSTRUCTO[21], AROUSAL[29], SuperBid[1], Parade of Trades[13], Simphony[20], STRATEGY[25], The Construction Marketing Game[8], VIRCON[22], ER[28], and the Virtual Coach[35]. These efforts provide stepping-stones towards creating interactive, participatory, and contextually rich learning environments in CEM education.

When new technology is involved in CEM education, changing instructional approaches may be more challenging. However, the availability of infrastructure for the use of technologies in instructional settings will enable educators to create innovative and transformative learning environments for today's students. Educators need to be aware of available technologies in the construction domain, which can be used to facilitate students' learning through games and simulations. The following section explores state-of-the-art technologies that have been proposed in the construction domain in order to understand what kinds of technologies lend themselves to games and simulations in CEM education.

State-of-the-Art Technologies for Games and Simulations in Construction

Virtual Reality (VR)/Three-Dimensional Computer Graphics (3D CG) have been used in the construction domain for worker training[42], safety training[39], site layout considering productivity and safety[40], and design evaluation[38]. It is obvious that advanced 3D CG/VR technology can be employed to improve CEM education through the use of games and simulations.

Many research efforts have explored and exploited sophisticated 3D CG/VR technology in construction. For example, Kamat and Martinez[23] developed 'VITASCOPE' which is used for 3D dynamic construction process simulations to effectively manage complex construction operation processes in 3D virtual environments. In addition, 3D computer models have been used to increase the speed and quality of design review. Simultaneously, 4D computer-aided design models as a construction tool have been developed to create more flexible and dynamic 4D simulation environments of construction progress. 4D modeling provides a mechanism to visualize elements of 3D computer-aided design models based on associated schedule intervals[34]. Through 4D simulation environments, project teams can virtually practice the construction of a unique artifact before building it in reality for the purpose of detailed work planning and coordination of multiple trades in a dynamic and uncertain project environment[16, 31].

Over the last five years, Building Information Modeling (BIM) technology has been highlighted. BIM is the product of a long evolution in computer modeling as a mainstream technology[19]. BIM technology enables us to model the form, function, and behavior of building systems and components[36]. Furthermore, BIM technology enables project participants to communicate and take advantage of project information such as job costs, construction schedules, and project quality without paper drawings or documents.

Since the first Head Mounted Display (HMD) in 1965, the rapid development of computer technology, information display technology, and human interface technology has made Virtual Reality (VR) a suitable technology for many different kinds of tasks. Aukstakalnis and Blatner[6] describe that VR is an effective way in which humans can interact with computers and directly manipulate objects in the virtual world. VR environments can be split into non-immersive VR (represented by ordinary desktop VR) and immersive VR. Ultimate VR environments completely immerse the user's personal view inside the virtual world through HMDs or Cave Automatic Virtual Environments (CAVEs), and interact with the environments.

These state-of-the-art technologies offer great potential for the development of games and simulations in CEM education. In such learning environments, students could physically interact with the virtual environment and their reactions to various real-like problems could be analyzed[26].

A Vision for Game- and Simulation-Based Learning

Technology has significantly changed the way information is created, accessed, sorted, and disseminated. However, over the last decade, learning environments in CEM education have seen little change as a result of these advances. Academic institutions of higher education have been conservative in responding to change, and many researchers have written about the slow rate at which academic institutions embrace innovation[18].

As stated before, the current generation of students is technology savvy. They take technology for granted as it has an important presence in their daily lives. However, technology's impact on today's student learning has been far from revolutionary. Most educators and even students may regard course-related innovations and technology adoptions in learning environments as separate domains. In the near future, this paradigm will be increasingly difficult to sustain, especially where academic institutions move toward innovative educational models.

Learning approaches based on games and simulations that use the latest state-of-the-art technologies can generate practical innovations in CEM education. As dynamic, interactive, and heuristic learning models, learners bring their prior skills and knowledge to the table and have to cope with certain challenges such as resource constraints in a dynamic context. Through games and simulations, learners are encouraged to construct multidimensional domain knowledge as well as develop several cognitive skills such as critical thinking, problem solving, and decision making, while understanding the consequences of their actions and decisions.

Successful learning opportunities can be created when following this constructivist theory[3]. Game and simulation learning is based on constructivist theory where "trial and error" is a primary source of knowledge acquisition. This approach holds the great possibility of providing today's students with innovative and transformative learning environments in CEM education. Unlike structured, instructor-driven learning, the learner-centered approach using games and simulations can assign more importance to external resources and learning communities to supplement their approaches to learning contents. Therefore, games and simulations for educational purposes can be used as powerful tools not only to increase the learner's active engagement and participation in learning, but also to enhance motivation and self-directed learning processes.

We argue that CEM education has to look beyond today's learning environments. Academic institutions must be committed to the continuous evaluation and adoption of innovative technologies and to the pursuit of opportunities for collaborations in an interdisciplinary environment that combines the strengths of subject matter experts, instructional designers, and others. Innovative and transformative learning environments in CEM education can usher in a new age of high-quality learning experiences, emphasizing the delivery of innovative courses.

Conclusions

Prensky[33] states that today's students who use digital technology in everyday life actually think differently, not just think about different things, since different kinds of experiences lead to different brain structures. Based on this fact, educators need to thoughtfully rethink today's learning environments, which are still based on traditional pedagogies. In addition, AbouRizk and Sawhney[2] point out that traditional teaching methods are not fully capable of providing CEM students with the necessary skills and knowledge to solve real world problems encountered in construction. This realization has moved several researchers to explore alternatives where learners can actively participate in the learning process. Students should practice problem solving in environments where concepts are embedded in their proper context.

To cope with these limitations in today's learning environments, we propose the use of games and simulations to provide today's students with adventure learning experiences in interactive and immersive 3D virtual environments. In such learning environments, students may be able to get deeply involved in participatory knowledge creation across networks of dispersed learners and learning communities[30]. By creating innovative and transformative learning environments, the following outcomes can be expected:

- Simulation of real-world processes
- Exploration of choice and consequence with complex variables
- Deep understanding of the targeted knowledge
- Self-directed learning
- Peer-to-peer teaching opportunities
- Highly motivated and engaged learning environment
- Autonomous thinking through meaningful perspectives

However, as promising as the use of games and simulations appears to be for learning environments, there are several major challenges researchers might face when developing games and simulations. One of the biggest challenges is likely to be the integration with traditional learning contents. Furthermore, developing a long-term strategy for game and simulation-based learning is one of the most important decisions construction educators and CEM programs can make as it will have a significant impact on the community for decades to come.

In conclusion, this paper explores the potential use of games and simulations for innovative and transformative learning with the goal of improving CEM education. Innovative technologies have been employed in various fields for worker training, safety training, design evaluation, and military training. Games and simulations can be incorporated into instructional settings to play a scaffolding role in new knowledge discovery and skill acquisition. The evolution of the game and simulation-based learning approach, in CEM education, can be an excellent example of the innovative and transformative pedagogy that most academic institutions aspire to.

Bibliography

1. AbouRizk, S. (1992). "A Stochastic Bidding Game for Construction Management." *Second Canadian Conference on Computing in Civil Engineering*, CSCE, Ottawa, Ontario, pp. 576-587.

2. AbouRizk, S. and Sawhney, A. (1994). "Simulation and Gaming in Construction Engineering Education." *ASEE/C2E2 /C2EI Conference*, Edmonton, Alberta, Canada, American Society for Engineering Education.

3. Aldrich, C. (2005). *Learning by Doing: A Comprehensive Guide to Simulations, Computer Games, and Pedagogy in E-Learning and Other Educational Experiences*. San Francisco: Pfeiffer.

4. Al-Jibouri, H. S. and Mawdesley, J. M. (2001). "Design and Experience with a Computer Games for Teaching Construction Project Planning and Control." *Engineering, Construction and Architectural Management,* 8, pp. 418-427.

5. Au, T., Bostleman, R. L., and Parti, E. (1969). "Construction Management Game – Deterministic Model." *ASCE Journal of Construction Division*, 95, pp. 25-38.

6. Aukstakalnis, S. and Blatner, D. (1992). *Silicon Mirage: The Art and Science of Virtual Reality*. Berkeley, CA: Peachpit Press

7. Barab, S. A., Hay, K. E., Barnett, M., and Squire, K. (2001). "Constructing Virtual Worlds: Tracing the Historical Development of Learner Practices." *Cognition and Instruction*, 19 (1), pp. 47-94.

8. Bichot, T. (2001). *The Construction Marketing Game*. Master's Thesis, Bradley University, Peoria, Illinois.

9. Bransford, J. D., Brown, A. L., and Cocking, R. R. (Eds.). (1999). *How People Learn: Brain, Mind, Experience, and School*. Washington, D.C.: National Academy Press.

10. Brown, J. S., Collins, A., and Duguid, P. (1989). "Situated Cognition and the Culture of Learning," *Educational Researcher*, 18 (1), pp. 32-42.

11. Candy, P. C. (1991). *Self-Direction for Lifelong Learning: A Comprehensive Guide to Theory and Practice.* San Francisco: Jossey-Bass.

12. Chinowsky, P. and Vanegas, J. (1996) "Combining Practice and Theory in Construction Education Curricula*," Proceedings of the 1996 ASEE Annual Conference*, American Society for Engineering Education, Washington, D.C., 1221, pp. 1-6.

13. Choo, H. J. and Tommelein, I. D. (1999). "Parade of Trades: A Computer Game for Understanding Variability and Dependence." *Technical Report 99-1*, Construction Engineering and Management Program, Civil and Environmental Engineering Department, University of California Berkeley.

14. Cranton, P. (1994). *Understanding and Promoting Transformative Learning: A Guide for*

Educators and Adults. San Francisco: Jossey-Bass.

15. Echeverry, D. (1996). "Multimedia-Based Instruction of Building Construction." *Proceedings of the Third Congress on Computing in Civil Engineering*, ASCE, Anaheim, California, pp. 972-977.

16. Fischer, M., and Kunz, J. (2004). "The Scope and Role of Information Technology in Construction." *CIFE Technical Report #156*, Stanford University.

17. Fruchter, R. (1997). "The A/E/C Virtual Atelier: Experience and Future Directions." *Proceedings of the Fourth Congress on Computing in Civil Engineering*, Philadelphia, pp. 395-402.

18. Getz, M., Siegfried, J. J., and Anderson, K. H. (1994). *Adoption of Innovations in Higher Education*. Nashville, TN: Vanderbilt University.

19. Gilligan, B. and Kunz, J. (2007). "VDC Use in 2007: Significant Value, Dramatic Growth, and Apparent Business Opportunity." *CIFE Technical Report #171*, Stanford University.

20. Hajjar, D. and AbouRizk, S. (1999). "Simphony: An Environment for Building Special Purpose Construction Simulation Tools." *Proceedings of the 1999 Winter Simulation Conference*, pp. 998-1006.

21. Halpin, D. W. and Woodhead, R. W. (1970). "CONSTRUCTO - A Computerized Construction Management Game." *Construction Research Series, No.14*, Department of Civil Engineering, University of Illinois.

22. Jaafari, A., Manivong, K., and Chaaya, M. (2001). "VIRCON: Interactive System for Teaching Construction Management." *Journal of Construction Engineering and Management*, 127(1), pp. 66–75.

23. Kamat, V. R., and Martinez, J. C. (2003). "Interactive Discrete-Event Simulation of Construction Processes in Dynamic Immersive 3D Virtual Worlds." *Proceedings of the CONVR2003 Conference on Construction Applications of Virtual Reality*, Virginia Tech, pp. 197-201.

24. Marton, F., Hounsell, D., and Entwistle, N. (Eds.) (1997). *The Experience of Learning* (2nd Edition). Edinburgh, Scotland: Scottish Academic Press.

25. McCabe, B. Y., Ching, K. S., and Savio, R. (2000). "STRATEGY: A Construction Simulation Environment." *Proceedings of the ASCE Construction Congress VI*, Orlando, FL, pp. 115-120.

26. Messner, J. I., Yerrapathruni, S. C. M., Baratta, A. J., and Whisker V. E. (2003). "Using Virtual Reality to Improve Construction Engineering Education." *Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition.*

27. Mezirow, J. (1997). "Transformative Learning: Theory to Practice." *New Directions for Adult and Continuing Education,* 74, pp. 5-12.

28. Nassar, K. (2002). "Simulation Gaming in Construction: ER, the Equipment Replacement Game." *Journal of Construction Education,* 7(1), pp. 16-30.

29. Ndekugri, I. and Lansley, P. (1992). "Role of Simulation in Construction Management." *Building Research and Information*. 20 (2), pp. 109-115.

30. New Media Consortium (2008). *The Horizon Report*. Austin, TX: New Media Consortium.

31. O'Brien, W. J. (2000). "Towards 5D CAD - Dynamic Cost and Resource Planning for Specialist Contractors." *Proceedings of the Sixth Construction Congress*, ASCE, 2000, pp. 1023-1028.

32. Pennell, R., Durham, M., Ozog, C., and Spark, A. (1997). "Writing in Context: Situated Learning on the Web." *Proceedings of the 14th Annual ASCILITE Conference*, Perth, Western Australia, The Australasian Society for Computers in Learning in Tertiary Education, pp. 463-469.

33. Prensky, M. (2001). *Digital Game-Based Learning.* New York: McGraw-Hill.

34. Riley D. (2003). "The Role of 4D Modeling in Trade Sequencing and Production Planning." In R. R. A. Issa, I. Flood, W. J. O'Brien (Eds.). *4D CAD and Visualization in Construction: Developments and Applications* (pp. 125-144), A.A. Balkema Publishers.

35. Rojas, E. and Mukherjee, A. (2005). "A General Purpose Situational Simulations Environment for Construction Education." *Journal of Construction Engineering and Management*, ASCE, 131 (3), pp. 319-329.

36. Sacks, R., Eastman, C. M., and Lee, G. (2004). "Parametric 3D Modeling in Building Construction with Examples from Precast Concrete." *Automation in Construction,* 13, pp. 291–312.

37. Sawhney, A., Mund, A., and Koczenas, J. (2001). Internet-Based Interactive Construction Management Learning System." *Journal of Construction Education,* 6 (3), pp. 124-138.

38. Shiratuddin, M. F and Thabet, W. (2003). "A Framework for a Collaborative Design Review System Utilizing the Unreal Tournament (UT) Game Development Tool." *Proceedings of the 20th CIB W78 Conference on Information Technology in Construction*, Waiheke Island, Auckland, New Zealand.

39. Soedarmono, D. R., Hadipriono, F. C. and Larew, R. E. (1996). "Using Virtual Reality to Avoid Construction Falls." *Proceedings of the 3rd Congress* Held in Conjunction with A/E/C Systems '96, Anaheim, CA, pp. 899-905.

40. Tawfik, H. and Fernando, T. (2002). "A Simulation Tool for Multi-Perspective Site Layout Analysis." *Proceeding of the European Conference on Product and Process Modeling*, Slovenia.

41. Taylor, E. W. (1997). "Building upon the Theoretical Debate: A Critical Review of the Empirical Studies of Mezirow's Transformative Learning Theory." *Adult Education Quarterly, 48*(1), pp. 34-59.

42. Wen, G., Xu, L., Chen, H., and Shang, H. (2009). "Horizontal Directional Drill Rig Operating Training System Based on Virtual Reality Technology." *Proceedings from ASCE 2009: The International Conference on Pipelines and Trenchless Technology*. Shanghai, China, 361(116), pp. 1093-1103.