Constructivism: The Learning Theory That Supports Competency Development of Engineers For Engineering Practice and Technology Leadership Through Graduate Education

A. L. McHenry, [1] D. R. Depew, [2] M. J. Dyrenfurth, [2] D. D. Dunlap, [3] D. A. Keating, [4] T. G. Stanford, [4] P. Lee, [5] G. Deloatch [6]

Arizona State University East[1]/ Purdue University [2]/ Western Carolina University [3] University of South Carolina [4] / California Polytechnic State University [5] / Morgan State University [6]

Abstract

This is the first of four papers prepared for a special panel session focusing on approaches and processes that represent the current insight into the way humans learn. It is particularly focused on how this knowledge is poised to guide professional graduate engineering education for creative engineering practice and leadership of technological innovation to enhance U.S. competitiveness. This panel session is a part of the evolutionary development effort being made to energize the members of the American Society of Engineering Education response to the urgency of engineering education reform, voiced by Wm. A. Wulf, president of the National Academy of Engineering in the American Society for Engineering Education (ASEE) 2002 Annual Conference's-Main Plenary Address[1]. As the panel leadoff paper of this session it introduces Constructivism as the learning theory and process that is most efficient in the development of professional competence. And that effectively guides the philosophical frameworks or curriculum approaches that prepares engineering and engineering technology students at all levels for the execution of integrative functions that are particular to the requirements of industrial practice and systems operations and management. Constructivist learning approach can be crucial in the enablement of sitting professionals making the jump to the leading edge of the practice-focused engineering that requires massive constructed intellectual fusion. This paper raises fundamental questions that must be answered to design a complementary applications competent engineering workforce through the higher education processes to significantly increase the size of the pool of such engineers who are needed to meet the leadership requirements of modern industry and government.

Introduction

In 2003 the ASEE copyrighted the following definition of engineers: "Engineers are problem solvers, people who search for quicker, better, less expensive ways to use the forces and materials of nature to meet tough challenges. Throughout the ages, from the building of the Egyptian pyramids to the landing on the moon, engineers have been the shapers of progress. The ever-increasing influence and rapid advance of technology demands a skilled and highly educated technically capable workforce. From defense, to global infrastructure such as telecommunications and right down to consumer gadgetry, the quality of graduate engineers affects the quality of all of our lives." [2]

Recently the National Academy of Engineering (NAE) has held a Technological Literacy conference and has issued a report that gives a new definition of technology for the 21st century that emerged. "In its broadest sense, technology is the process by which humans modify nature to meet their needs and wants. However, most people think of technology only in terms of its artifacts … but technology is more than its tangible products. An equally important aspect of technology is the knowledge and processes necessary to create and operate those products, such as engineering know-how and design, manufacturing expertise, various technical skills, and so on. Technology also includes all of the infrastructure necessary for the design, manufacture, operation, and repair of technological artifacts from corporate headquarters and engineering schools to manufacturing plants and maintenance facilities."[3]

The characteristics that differentiate professional engineering graduate education from that of graduate education for academic scientific research can be distinguished best by using modern definitions of engineering as follows:

> "Engineering has a mission, purpose, and method … as a creative profession; engineering is concerned with the combining of human, material, and economic resources to meet the needs of society for the advancement and betterment of human welfare.
>
> As creative professionals, engineers purposefully conceptualize, design, and lead the systematic development of new innovative technology in the form of new and improved products, processes, systems, operations, and breakthrough developments that are responsive to real-world needs. In this process, they use the integrative engineering method as a purposeful, deliberate and systematic practice for innovation and entrepreneurship, driven by an engineering ethic and responsible professional leadership for improvement and betterment, responsive to real-world needs." [4]

These new definitions of engineering and technology has cleared the way for specifying the differentiating characteristics that are needed in reshaping professional engineering education to better meet the needs of the U.S. engineering workforce across the spectrum, with particular focus on industry. Clear distinctions can now be made between the aims of research-based education for academic scientific research and those of professional education for creative engineering practice and leadership of technology innovation and industry competitiveness. A set of differentiating factors, that may be found in these definitions that are not generally common to the research paradigm are:

- Purposeful, deliberate and systematic practice
- Innovation based entrepreneurship
- Process development
- Industrial leadership
- Manufacturing planning and implementation
- Operation on and repair of technological artifacts

This partial list of common factors associated with professional engineers informs us of the characteristics that address the strong demand by industry and government as they seek employees to plan and execute their highest required activities and processes. The present engineering education teaching and learning approaches at the undergraduate level are focused on developing knowledge of specific fact that when intellectually fused enables the understanding of engineering principles, scientific laws and mathematics applications needed to conceptualize and execute solutions to problems with special focus on design. The learning theory that supports this approach is known as Cognitivism. Most of America's contemporary educated engineers are developed using cognitive theory based approaches as the primary engine of knowledge transmission.

Engineering education based on cognitive processes was adequate as the primary method of preparing engineering graduates so long as engineers applied their knowledge in a relatively stable technological environment. When in an environment where technology is advancing slowly and the demands of the industrial workplace are clustered at the low end of the technological spectrum, the level of competence that engineers and engineering technologist developed on-the-job is generally adequate for a long period of time. The "low-technology" use of these employees allows engineering education to minimize the development of technological competence and place emphasis on cognitive focused engineering education processes. As a result engineering education focused its evolutionary development efforts on fundamental research, driven by the desire for what was perceived as high value outcomes of it programs. The fifty-year pursuit of the research paradigm has moved undergraduate engineering programs of study to a research paradigm selection and support program. As a result the engineering laboratory courses have minimized skill development and therefore specifically focused competence development has been minimized as well. This move away from the development of technological competence lead to industry sought to fill the gap with its own efforts. Large resourceful companies created their own "ABC University" to fill the vacuum that existed. Instead of creating their own education specific process, there were new employee rotation programs formed to enable experience-based learning for new engineers and technologists while on-the-job. Thereby industry resorted to classical constructivism.

The constructionists' approach to teaching and learning is based on a combination of a subset of research within cognitive psychology and a subset of research within social psychology. Bruner pointed out the basic premise in 1990[5], when he indicated that an individual learner must actively "build" knowledge and skills and that information exists within the built constructs rather than in the external environment from which it was drawn. This was a controversial idea within the community who held the cognitive perspective of the time. However, all advocates of constructivism agree[6, 7] that it is the individual's processing of stimuli from the environment and the resulting cognitive structures that produce adaptive behavior, rather than the stimuli themselves. John Dewey[8] is often cited as the philosophical founder of this approach; however, Ausubel [9], Bruner[5], and Piaget[10], are considered the chief theorists among the cognitive constructionists. While Vygotsky[11], was the major theorist among the social constructionists[12].

Constructivism

Constructivism is a theory of learning founded on the premise that, by reflecting on our experiences, we construct our own understanding of the world. Each of us generates our own "rules" and "mental models," that we use to make sense of our experiences. Learning, therefore, is simply the process of adjusting (reconstruct) our mental models to accommodate new experiences.

There are several guiding principles of constructivism:

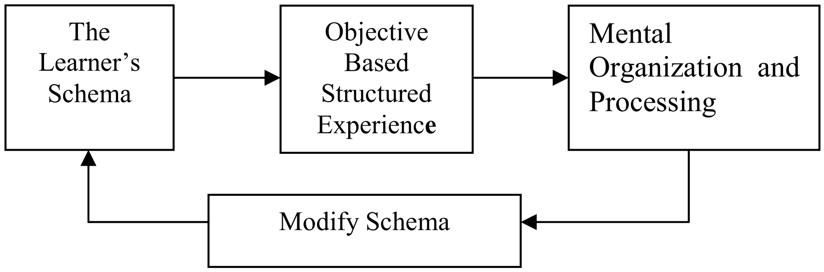
1. Learning is a search for meaning. Therefore, learning must start with the issues around which students are actively trying to construct meaning.
2. Meaning requires understanding **wholes** as well as parts. And parts must be understood in the context of wholes. Therefore, the learning process focuses on primary concepts, not isolated facts.
3. In order to teach well, we must understand the mental models that students use to perceive the world and the assumptions they make to support those models.
4. The purpose of learning is for an individual to construct his or her own meaning, not just memorize the "right" answers and regurgitate someone else's meaning.

Since high-tech engineering/engineering technology education is inherently interdisciplinary, with multiple career paths. One of the goals is to build actionable competence in a group of graduates. The primary focus of the education processes for this group is to create and evolve educational processes that enable the construction of knowledge with skill that is honed to levels that prepare graduates to directly assume career roles that employ professional competence with responsible leadership in the management of complex technological life spaces and systems. It helps its students build mental models through exposure to experience based feedback from an active environment with dynamic situations that enable intellectual model evolution. Since the purpose is to have each student develop competence in a defined spectrum of professional activities, assessment of a predetermined set of learning outcomes, ensures that students are provided with information on the quality of their learning through immediate highly personalized feedback.

The Pathway to Creative Competence

An intellectual approach to the creation of competence through constructivism has a definite structural character and can be modeled as a series of specific stepwise processes that consists of 1) Perceive, 2) Differentiate, 3) Generalize, 4) Re-conceive, and 5) Adaptively restructure. This learning process is very similar to that of a stored program computer process that consists of input, store, retrieve and reprocess. Figure 1, that follows is an illustration of such a process model.

Figure 1



Finally, Constructivism promotes the mental construction of the learner's reality (experiences). Experiences cause the learner to generate new understanding through mental processing of each new experience with respect to the existing understanding. D. H. Jonasson[13] puts it this way. "What someone knows is grounded in perception of the physical and social experiences which are comprehended by the mind."[12] Therefore, constructionists see learning as active, continuous and directly tied to the individual.

How Constructivism Impacts Learning

- *Curriculum*--Constructivism calls for the elimination of a standardized curriculum. Instead, it promotes using curricula customized to the students' prior knowledge. Also, it emphasizes hands-on problem solving.
- *Instruction*--Under the theory of constructivism, educators focus on making connections between facts and fostering new understanding in students. Instructors tailor their teaching strategies to student responses and encourage students to analyze, interpret, and predict information. Teachers also rely heavily on open-ended questions and promote extensive dialogue among students.
- *Assessment*--Constructivism calls for the elimination of grades and standardized testing. Instead, assessment becomes part of the learning process so that students play a larger role in judging their own progress.

Conclusion

There is a strong need for a large number of engineering graduates to be prepared through their formal education program whether they are in engineering or engineering technology programs, to be technologically competent on a broad scale. To achieve technological competence an engineer must have an effective combination of cognitive knowledge and skill that have been merged or built in an environment that enables the constructs created to have fidelity in the "real world" of their intended application. Hence as the industrial and other high-technology workplaces become more sophisticated and require greater competence to perform the engineering task the greater the need for constructivism as the primary learning motif in professional engineering education.

References

1. W. A. Wulf, President of the National Academy of Engineering, *Main Plenary Address,* ASEE 2002 Annual Conference, June 2002.
2. What is Engineering? American Society for Engineering Education Copyright © 2003
3. National Academy of Engineering, *Technically Speaking: Why All Americans Need to Know More About Technology,* 2002.
4. National Collaborative Task Force on Engineering Graduate Education Reform, *Strategic Plan*, 2004.
5. Bruner, J. (1990). *Acts of meaning*. Cambridge, MA: Harvard University Press
6. Ullman, S. (1980) Against direct perception. *Behavioral and Brain Sciences, 3*, 373 - 415.
7. Gibson, J. J. (1979). *An ecological approach to visual perception*. Boston: Houghton Mifflin
8. Dewey, J. (1933/1998) *How we think* (Rev. ed.). Boston, MA: Houghton Mifflin Company.
9. Ausubel, D. (1968). *Educational psychology: A cognitive view*. New York: Holt, Rinehart & Winston
10. Piaget, J. (1972). *The psychology of the child*. New York: Basic Books
11. Vygotsky, L. (1978). *Mind in society*. Cambridge, MA: Harvard University Press
12. Harnad, S. (1982) Neoconstructivism: A unifying theme for the cognitive sciences. In T.
13. Jonassen, D. H. (1991) Objectivism versus constructivism: do we need a new philosophical paradigm? *Educational Technology Research and Development,* 39 (3), 5-14.

.

.

.

.