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Using Architecture Pedagogy to Enhance Engineering Education

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Using architecture pedagogy to enhance engineering education

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Abstract

Based on evidence, numerous advisory boards and scholars insist engineering education must change (NSB, 2007; McKenna, Froyd, King, Litzinger, & Seymour, 2011) and that hands-on, inquiry-driven, project-based learning pedagogies can enhance STEM education (Boyer & Mitgang, 1996). These pedagogies have formed the core of architectural education since the Renaissance and have been in continuous use since that time. As such, engineering educators can benefit from observing how architecture students learn and understanding how they are taught. Likewise, architecture can benefit from applying the group-based learning strategies employed by engineering teachers who use student-centered, project-based pedagogies. Trans-disciplinary approaches hold particular merit.

Keywords: Project-based learning, experiential learning, studio, cognitive development, intellectual development, architecture

1. Introduction

In its mandate to enhance science and engineering education, the National Science Board (henceforth NSB, 2007) asserted, "*Engineering education must change in light of changing workforce and demographic needs"* (p. 1). The NSB has been quite specific in how it expects these changes to occur. To improve engineering education, the NSB advocates hands-on activities, collaborative work, and real-life applications that have social relevance. Additionally, the NSB recommends that educators integrate systems content as well as "component-level content" (p. 4) in the courses they teach. These are essential aspects of problem-based learning and of its more extensive cousin, project-based learning. Both of these are referred to as PBL, but the later better reflects the type of experiential learning defined by Kolb (1984). They have been used to teach architecture for centuries (see Figure 1).

Figure 1. At Hampton University, students in the second year architecture studio work in groups to create designs that reflect site, program, and construction consideration and synthesize them into the design of complex objects.
Figure 2. Engineering labs at the Escola Superior de Tecnologia e Gestão de Águeda (Universidade de Aveiro) are set up for group learning. Past projects, created by teams of students, line the walls of many labs.

Engineers "need to be adaptive leaders, grounded in a broad understanding of the practice and concepts of engineering" (NSB, 2007, p. 2). The NSB identified this as a current deficit in engineering. The NSB described shortfalls in engineering graduates' ability to navigate "complex interrelationships [that] encompass human and environmental factors." These attributes are also required of architects and there is ample evidence of how they are developed within architectural students. Because the pedagogy employed in architectural education has been successful in instilling these abilities in students, the approach holds considerable significance for educators in engineering (Arens, Hanus, & Saliklis, 2009; Boyer & Mitgang, 1996; Boyer Commission, 1998; Eastman, McCracken, & Newstetter, 2001).

Universities across the United States, and indeed across the world, are attempting to achieve the NSB's goals. In fact, an increasing number of institutions are now using studio-based courses to teach STEM subjects (science, technology, engineering, and mathematics). In similar fashion, others now assign design projects to engineering, biomedical, and interdisciplinary groups

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of students (Boyer Commission, 1998; Eastman, McCracken, & Newstetter, 2001). Some engineering programs are beginning to structure their curricula around projects. Engineering programs at the Escola Superior de Tecnologia e Gestão de Águeda (Universidade de Aveiro) are much like architecture in the US, with content-based course supporting high-credit design-based activities (see Figure 2).

Such programs put student assignments in context so that they are less abstract. This helps students become more flexible engineers who are able to see relationships in the broader context, think iteratively, direct their own learning, adapt to the changing context and requirements of professional practice (Arens, Hanus, & Saliklis, 2002; Boyer & Mitgang, 1996). The NSB noted that such pedagogical techniques also help (1) make engineering more relevant to a broader group of students and (2) attract and retain a more diverse group of students—two critical outcomes the NSB seeks to achieve. In response to such needs, PBL formats are being implemented in more and more engineering classrooms. However, there is much room for research, improvement, and expansion in the use of PBL (McKenna, Froyd, King, Litzinger, & Seymour, 2011).

Figure 3. Engineering and architecture students work side by side to generate new designs, apply emerging technologies, build houses, educate the public about them, and compete in the US Solar Decathlon, held every second year (US Department of Energy, 2009).
Figure 4. At the University of Michigan, students enrolled in the *SmartSurfaces* (an elective design studio) work on trans-disciplinary group-based design problems. Here, students are presenting designs for "biomenetic" SmartSurfaces (SmartSurfaces, 2010).

For instance, this type of cross- or trans-disciplinary learning is evident in the project-based design studios conducted at the University of Michigan under the title *SmartSurfaces* (Marshall**,** Shtein, & Daubmann, 2011) and in Solar Decathlon studios conducted around the country and around the world (see Figure 3). In *SmartSurfaces*, trans-disciplinary teams (of students majoring in architecture, art and design, and materials engineering) work together to design "smart" surfaces that have specific, yet ill-defined, properties. In past years, students have designed biomimetic surfaces (see Figure 4), heliotropic surfaces, and solar-powered surfaces for a "Power House" located in Detroit. The blogs written by students in these courses document and illustrate learning that occurs due to cross-pollination of disciplinary knowledge and skills. Students in all these disciplines need to learn creative, contextual, and critical thinking. Their blogs indicate that are better prepared to work with people from other professions after completing this course.

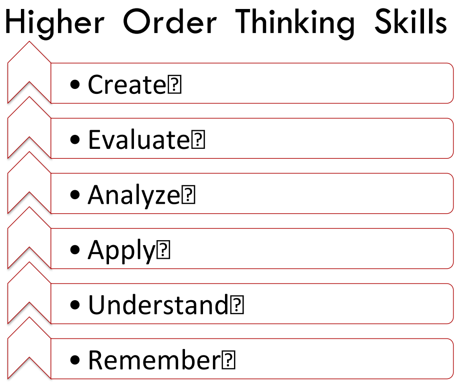
Despite inspiring examples like these, the use of projects in engineering education is typically much more reserved than it is in architecture. This paper argues for more extensive use of context-dependent, ill-structured, project-based pedagogies in engineering. It explains how this is accomplished in architecture and explains potential benefits related to cognitive and intellectual development.

2. Architecture pedagogy

Architecture education is well known for employing studio pedagogy and other active learning techniques to teach students to "think outside the box" and apply knowledge with regard for and sensitivity to context. A three-year study conducted by Ernest Boyer and Lee Mitgang (1996) led these education experts to assert that "architectural education is really about fostering the learning habits needed for the discovery, integration, application, and sharing of knowledge over a lifetime" (p. xvi). Architecture's studio-based pedagogy involves hands-on, problem-based learning in a workshop setting. Architectural design projects are vehicles that help students develop concepts and apply critical thinking to an increasingly complex range of issues over time. This approach is used worldwide to teach architecture and is sometimes also employed in the training of urban planners, engineers, and scientists as well (Boyer Commission, 1998; Newstetter, Behravesh, Neressian, & Fasse, 2010). In addition, medicine and art use similar techniques.

"The study of architecture is among the most demanding and stressful on campus," Boyer and Mitgang (1996) asserted, "but properly pursued it continues to offer unparalleled ways to combine creativity, practicality, and idealism" (p. 5). These two scholars are "convinced that architecture education, at its best, is a model that holds valuable insights and lessons for all of higher education." In fact, they found it to be "one of the best systems of learning and professional development that has been conceived."

Arens, Hanus, and Saliklis (2009) argued that the studio-based model "is particularly well-suited for the education of engineers because of its attempt to blend both art and science in the 'learn-by-doing' experience" (p. 5). Although architecture students learn to make decisions in context, such is often not the case for engineering students. Arens and his colleagues explained that engineering programs tend to emphasize the lowest-order thinking skills on Bloom's six-level Taxonomy (see Figure 5). In the past, they say, accreditation standards stressed lower-order skills and left the highest skills to students to master in graduate school or in the field. Like assert that typical engineering assignments lack adequate context.



(Bloom's Taxonomy as revised by Anderson & Krathwhol, 2001)

Figure 5. Bloom's Taxonomy (1956) as revised by Anderson and Krathwhol (2001).

Arens, Hanus, and Saliklis (2009) note that in contrast, architecture education focuses on honing students' higher-order abilities, such as analysis, evaluation, synthesis, and creation. These values are built into architectural accrediting standards (The National Architectural Accrediting Board, 2009) and are upheld in practice (Boyer & Mitgang, 1996). Arens *et al*. urge comparing the way engineers learn in lectures and labs "to a studio environment in an undergraduate Architecture curriculum, where the faculty often begin with the highest levels, such as Evaluation in applying value judgments about the adequacy of the design and Synthesis, by putting disparate pieces of information together, and Analysis in solving large complex problems by reducing them to smaller pieces" (p. 1).

On the other hand, architecture educators are prone to leave the acquisition of specific bits of knowledge (such as specific building codes, zoning regulations, and cost factors) for students to learn during professional internships. As such, they sometimes sacrifice delivery of technical content in favor of helping students master "design thinking" skills. In doing so, they aim to empower students to be capable of self-directed learning.

Oberall, it appears that format known as the *design studio* or *atelier*—used by architects for centuries—might be of value to engineers. The studio format provides a collaborative way of working that fosters creativity and ingenuity. This format emphasizes collective learning over hierarchy. As explained previously by Chance (2008), the word *atelier* is common among western languages, and is often used interchangeably with the English word *studio*. Both terms refer to an artist's workshop, a place where art or architecture is taught, or a location where skilled workers produce art or other finely crafted objects. The design studio is also commonly conceptualized as an experimental design laboratory or workshop. In reality, Chance notes, the studio functions much like a conventional newsroom, where people work in a wide-open space to actively refine a product that involves some sort of communication. The studio format that is commonly employed in design fields promotes quick, creative action. Workers in the design studio endeavor to envision and/or create meaningful products. In many cases, they develop an overarching concept or vision that helps define and unify their creations. Using the studio metaphor might also provide a way to re-conceptualize how engineering is practiced, to more effectively harness the creative potential of individuals and of the collective staff.

3. Engineering pedagogy

In engineering, these pedagogies are often described as Project-Based or Problem-Based and Student-Centered. The unifying theme of PBL and other SCL approaches is that they are inductive, the problem or project is presented first and this drives the learning so that students develop questions before seeking answers. We argue that these methods—particularly the ones that use group-based learning pedagogies—are highly suited to engineering education. When learning in a group-based, project-driven format, students are required to concurrently develop technical and non-technical knowledge and skills. As such, learning, teaching and assessment must be aligned with the delivery of technical *and* nontechnical outcomes. In a study by Moesby (2005), employers rated graduates from a student-centered institute much higher on a range of non-technical skills than their counter parts from a traditional institute.

3.1. Student-Centered Learning

Student-Centered Learning (SCL) pedagogies focuse attention on the learner's needs and abilities. They aim to help students achieve levels of engagement and thinking (Biggs & Tang 2007) higher than required in more traditional formants (where the teacher and the teacher's knowledge take center stage). SCL approaches include problem-based learning (PBL) as well as enquiry learning, project-based learning, discovery learning, case-based teaching and just-in-time teaching. Prince and Felder (2006) conducted a review of these learning and teaching methods and concluded that they: (1) encourage deep learning, (2) improve critical thinking and self-directed learning, and (3) are based on theories of learning and an established understanding of how the brain functions.

3.2. Project-Based Learning

As discussed previous by Duffy and Bowe (2010), the group-based project or problem driven approach typically requires students to work in groups of three to six. Groups explore a problem or project that is aligned with their prior knowledge but that requires them to stretch beyond it. Each group follows an iterative process of brainstorming, self-directed learning, and reporting. In the brainstorming phase of the cycle, each group discusses the problem and suggests possible paths and alternative solutions for investigating it. Group members query each other for current understanding.

Duffy and Bowe (2010) suggest roles for various members of the group. They note that a chairperson can manage the group meetings and a scribe can record any tasks or learning goals that must be addressed. However, the entire group should be able to view the notes being generated (this can be compiled on a large pad, whiteboard, or common sheet of paper) so that there is a central point of focus and agreement. The group should delegate tasks to each member before the meeting finishes. Each member must then follow up on that task during the "self-directed phase." This provides opportunity for each individual to develop information literacy skills and learn to manage and direct his/her own learning. This is the rough equivalent of "homework" in other contexts. In this case, the students write their own "homework assignments." Each student develops his or her own strategy for completing the assignment. When the group reassembles, each member brings new findings and information to share with the group. At this point, each group member should explain in her/his own words what s/he has discovered. This provides opportunity for members to teach and question each other.

The process enhances learning and requires students to build skills in communication, negotiation and conflict resolution—as evident in the *SmartSurfaces* blogs. Having addressed some or all of the issues from the last meeting, the group then starts the cycle again by identifying to do next, delegating new tasks, and so on.

A tutor should be present for most, if not all, meetings—to gently guide the process and observe each student's progress. In addition to conducting formal assessment, the tutor will need to monitor learning and group process. In the realm of learning, the tutor should: ask "directing" questions, check understanding, ascertain if tasks have been completed, and help summarize learning. In the realm of group process, the tutor should: openly question the group's decisions, encourage equal participation, include everyone in discussion, help ensure everything is recorded, help keep the group focused, and (here again) summarize learning that has occurred.

4. Cognitive development theories

Despite the documented need to update the way engineering is taught, McKenna, Froyd, King, Litzinger, and Seymour (2011) suggest far too little change has occurred. Forging ahead to develop understanding of how other fields achieve the types of results NSB desires may help transform engineering education. Helpful resources have emerged related to cognition and the development of design thinking skills. For instance, Eastman, McCracken, and Newstetter (2001) provide a comprehensive investigation of design research and student development in the realm of engineering education. Several chapters of their book, *Design Knowing and Learning: Cognition in Design Education*, describe ways to enhance engineering pedagogy. Many of the examples involve the use of design projects and placing assignments in context. Eastman, *et al*. (2001) and Christiaans (2002) have identified the need for better understanding of *design pedagogy* and *learning strategies* in design fields. Likewise, various articles published in the *Design Studies* journal highlight the need for research on pedagogy and learning strategies in design.

A relatively untapped resource for exploring such topics lies in fields known as "college student development," identity development, and intellectual and cognitive development theory. In 1970, Perry published a schema describing the intellectual development of college students based on their ability to navigate complex issues, view issues from multiple points of view, make decisions in context and commit to a contextualized and contextually "relativistic" way of thinking. Although architectural education helps students achieve high levels of contextual thinking, the literature also suggests that some architecture educators require students to take on challenges that exceed their level of readiness (AIAS, 2003; Boyer & Mitgang, 1996; Koch, Schwennsen, Dutton, & Smith, 2002). Stanford (1962) described the importance of balancing challenge and support in order to foster learning. Further study can lead to enhancements in the way project- and studio-based education is delivered—engineering educators who implement SCL may be of help in this realm. The remainder of this paper explores relevant theories that the authors are currently using to explore the efficacy of engineering and architecture education in order to better understand how students in these majors learn and develop.

Kolb (1984) maintained that hands-on, experiential learning helps students develop a healthy process for making well-balanced decisions (see Figure 6). Engineering educators such as Felder and Silverman (1988) agree. In balanced decision-making, the individual uses many different modes of thinking to identify problems, make choices, synthesize findings, and develop solutions. Not too surprisingly, Kolb found that differences exist in the way students in engineering, architecture, art, and sciences learn and haw they make decisions.

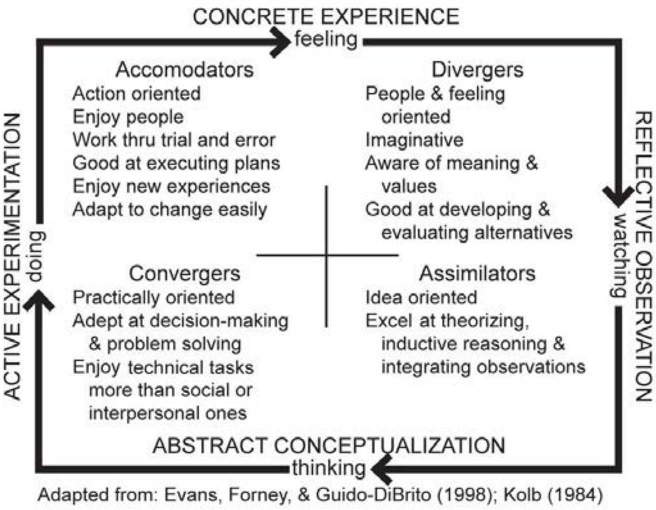


Figure 6. Kolb's (1984) learning styles chart overlapped with his decision-making model.

Table 1 describes typical changes in the way individuals view knowledge, which can be seen as development, over time. It relates these changes to Perry's (1970, 1999) schema of intellectual development. Perry's categories are listed across the top of Table 1, moving from simplistic ways of thinking (on the left) to sophisticated ways of thinking (on the right). The chart defines how an individual's perception typically changes with regard to: what knowledge is, how it is useful, where it comes from, and how it is learned. Most experts on student development believe that few students master the higher levels (*Relativism* and *Commitment*) during their undergraduate years (Love & Guthrie, 1999).

Measuring student performance gains is not new to the field of education. College Student Development scholars offer a number of theories and tools for gauging cognitive development—many of which reflect a high level of agreement. Figure 7 illustrates similarities among cognitive development theories. Various stage theories are shown in horizontal bands. Low-level development is shown to the left, progressing to high-level development on the right. Interestingly, the terms used by various theorists to describe high-level development (*relative, contextual, constructed, cross-categorical* and *trans-system thinking*) mirror architectural terminology.

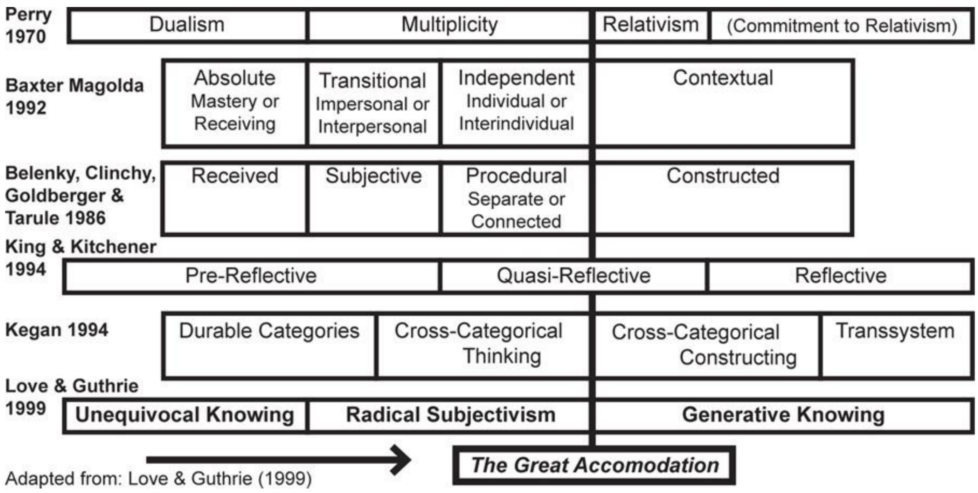


Figure 7. Comparison of student development theories.

Table 1 uses a bold, vertical line to indicate a feature common to most of these theories. This is the break between novice thinking (to the left) and refined thinking (to the right). Perry (1970, 1999) named this transition *revolutionary restructuring*, while Love and Guthrie (1999) describe it as *The Great Accommodation*. Crossing this threshold, the individual is capable of meta-cognition and realizes his or her own power to generate, produce, originate, author, or construct knowledge. The instruments proposed for use in this study were developed to measure development along this axis.

5. Summary

Architectural educators have not yet embraced cognitive development theory to any large extent. However, it appears that many engineering educators are beginning to embrace these theories. As such, architecture teachers have many valuable things to learn from parallel disciplines (student development and engineering education).

On the other hand, architectural educators have been using and refining hands-on, enquiry-driven, and studio-based pedagogies for hundreds of years. Project-based learning is at the core of their practice. In more and more instances, they are using group-based approaches as well. Engineering educators can learn from their knowledge and experience.

Cross- or trans-disciplinary learning is apparent today in design studies that engage engineering and architecture students and professors in teams working on projects. Researching the learning outcomes associated with these studios is essential to build knowledge regarding intellectual and cognitive development, and design process.

Low Level Development	→	Revolutionary Restructuring	→	High Level Development

	Dualism	Multiplicity	Relativism	Commitment
Motivation for Education	instrumental satisfy immediate needs	impress significant others; gain social acceptance; obtain credentials and recognition	achieve competence regarding competitive normative standards; increase capacity to meet social responsibilities	deepen understanding of self, world, & life cycle; develop increasing capacity to manage own destiny
What is Knowledge?	a possession which helps one get desired ends; ritualistic actions which yield solutions	general info required for social roles; objective truth given by authority	know how: personal skills in problem solving; divergent views resolved by rational processes	personally generated insight about self & nature of life; subjective & dialectical; paradox appreciated
What use is Knowledge?	education to get; means to concrete ends; used by self to obtain effects in the world	education to be; social approval appearance, status used by self to achieve according to expectations / standards of significant others	education to do: competence in work and social role; used to achieve internalized standards of excellence and to serve society	education to become; self-knowledge; self-development; used to transform self & the world
Where does Knowledge come from?	from external authority; from asking how to get things	from external authority; from asking what others expect and how to do it	personal integration of info based on rational inquiry; from setting goals, from asking what is needed, how things work and why	personal experience & reflection; personally generated paradigms, insights, and judgments
Learning Processes	imitation; acquire info, competence, as given by authority		discover correct answers through scientific method & logical analyses; multiple views are recognized but congruence & simplicity are sought	seek new experiences; recognize past conception on basis of new experiences; develop new paradigms; create new dialectics
Institutional Function	arouse attention and maintain interest; to show how things should be done	provide predetermined info and training programs; certify skills and knowledge	provide programs which offer concrete skills & info, opportunities for rational analysis & practice, which can be evaluated and certified	ask key questions; pose key dilemmas; confront significant discontinuities & paradoxes; foster personal experience & personally generated insights

Table 1. Typical changes in how students view "knowledge." (Derived from Chickering & Reisser, 1993; MacKeracher, n.d.; Perry, 1999).

A basic premise of our current research is that college students experience varying levels of cognitive development and that it is the role of educators to help move them along this continuum as effectively as possible. Students typically enter college with reliance on a limited set of familiar strategies for learning (Kolb, 1984) and with relatively fixed ideas about knowledge and the role of authority in determining truth and defining knowledge (Perry, 1970, Love & Guthrie, 1999). Factors affecting the student's learning include experiential (e.g., student-centered and/or project-based PBL) and traditional coursework as well as standard age maturation and immersion in university life. Students should leave college with an expanded set of learning strategies and with the skill to think contextually and to generate knowledge. Although it is rare for students to have reached this level of ability after four years of college (Love & Guthrie, 1999), it is the goal of student development scholars and many educators. It is also standard practice in architecture, where students are typically not permitted to continue past second year unless they have demonstrated significant ability in creativity and contextual thinking.

Theories describing how students develop cognitively and epistemologically can be of use to educators who want to promote positive growth and healthy development. In light of these theories, it appears that the architectural studio model has been highly successful, which also supports the continued use of such pedagogies over hundreds of years. It is accomplishing the type of student development that engineering educators and the NSB (2007) would like to see. It makes sense to apply such approaches to engineering disciplines in order to increase the field's overall success. Architectural education provides a valuable precedent that is typically overlooked by engineering educators. The irony is that students continue flocking into architecture schools (even while the economy is such that it can't employ all the architects that universities graduate in roles for which they have been educated). Architectural students appear to value the sense of engagement and creativity they associate with practicing architects. Engineering fields offer similar outlets for creativity, yet they struggle to attract students.

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