AC 2009-2: TEACHING ARCHITECTS AND ENGINEERS: UP AND DOWN THE TAXONOMY

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Abstract

Engineering faculty and Architecture faculty both address student learning through the prism of Bloom's taxonomy of the cognitive domain, but do so in diametrically opposite manners. Engineering faculty tend to assess student learning starting at the lowest taxonomy level, *Acquisition of Knowledge*, and progress in their curriculum and courses to the higher levels of *Synthesis* and *Evaluation*. Compare this 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. Thus, the paper's hypothesis is that Engineering faculty typically move up Bloom's taxonomy of the cognitive domain, whereas Architecture faculty typically move down the taxonomy.

The implications of this hypothesis are interesting from both a pedagogical and practical point of view. Can we learn from each other and benefit from each other's experience? Can we aid the students who seek larger global understanding, yet are often discouraged during their preliminary acquisition of fundamental factual knowledge?

This paper explores this thesis by studying the literature surrounding the Cognitive Domain in both Civil Engineering and Architecture, and gives some suggestions for providing engineering students with more opportunities to explore higher levels on Bloom's taxonomy in the undergraduate curriculum.

Introduction

The authors have acted as guest jurors in each other's courses when students have made public presentations of the work, otherwise known as the critique (or final crit). A striking revelation was made to the engineer that in an architecture critique, many of the issues brought up by jurors and by the student peers appeared to touch on relatively high level concepts in Bloom's Taxonomy of Learning. The taxonomies are a language that is proposed to describe the progressive development of an individual's cognitive understanding of material.

Thus, this paper began as an exploration of the thesis that Architecture faculty are comfortable moving up and down the continuum of Bloom's Taxonomy, whereas Civil Engineering faculty traditionally move up from the lowest levels of the taxonomy and they are challenged to reach the higher levels with their students.

The purpose of this paper is to review the literature that might support this thesis, and to recommend how Civil Engineering faculty might learn to move up and down the taxonomy from their Architectural peers.

Bloom's Taxonomy

Bloom's Taxonomy is the seminal work of the 1950's educational committee chaired by Benjamin Bloom. The committee established a set of taxonomies in three domains of learning: cognitive, affective and psychomotor. The cognitive domain taxonomy is widely accepted in many fields and has been identified as, "arguably one of the most influential education monographs of the past half century [1]." The taxonomies are a language that is proposed to describe the progressive development of an individual in each domain and are defined as follows[2]:

- Cognitive: of, relating to, being, or involving conscious intellectual activity.
- Affective: relating to, arising from, or influencing feelings or emotions.
- Psychomotor: of or relating to motor action directly proceeding from mental activity.

A set of development levels for each domain are shown in Table 1 based on work by Bloom (1956) [3], Krathwohl et al. (1973) [4], and Simpson (1972) [5], respectively. The levels are shown from simple to complex development in each column.

Table 1. Domain Levels

Cognitive Domain [1]	**Affective Domain [2]**	**Psychomotor Domain [3]**
Knowledge	Receiving	Perception
Comprehension	Responding	Set
Application	Valuing	Guided Response
Analysis	Organization	Mechanism
Synthesis	Characterization by a Value Complex	Complex Overt Response
Evaluation		Adaptation
		Origination

In this paper, we will focus exclusively on the Cognitive Domain, and we will refer to the ranking of these as Levels 1 through 6 as shown in Table 2.

Table 2. Cognitive Domain

Knowledge	*Level 1*
Comprehension	*Level 2*
Application	*Level 3*
Analysis	*Level 4*
Synthesis	*Level 5*
Evaluation	*Level 6*

PART 1 Civil Engineering Undergraduate Curriculum

The authors propose that traditional undergraduate programs in Civil Engineering begin at the lower level of Blooms and work up, yet may not achieve the highest levels. This position is based upon review of the ASCE's Civil Engineering Body of Knowledge for the 21st Century, a review of the literature describing such programs, and the authors' experience in our own schools.

The Civil Engineering Body of Knowledge (BOK) for the 21st Century" (2008)[6] was prepared by BOK Committee of the Committee on Academic Prerequisites for Professional Practice. In this report, fifteen ABET outcomes were linked to the six levels of Bloom's taxonomy for cognitive development, as shown in Figure 1. It is clear from this report that undergraduate Civil Engineering programs are primarily focused on the lower levels of achievement in terms of Bloom's taxonomy. It is noteworthy that the level of achievement expected for the "Design" outcome does not include *Evaluation* (Level 6) (see line 9 in Figure 1). In Figure 1, the icon "E" stands for fulfillment via post-baccalaureate, pre-licensure work experience.

Outcome Number and Title	*Level of Achievement*					
	1	*2*	*3*	*4*	*5*	*6*
	Knowledge	*Compre-hension*	*Application*	*Analysis*	*Synthesis*	*Evaluation*
Foundational						
1. Mathematics	B	B	B			
2. Natural sciences	B	B	B			
3. Humanities	B	B	B			
4. Social sciences	B	B	B			
Technical						
5. Materials science	B	B	B			
6. Mechanics	B	B	B	B		
7. Experiments	B	B	B	B	M/30	
8. Problem recognition and solving	B	B	B	M/30		
9. Design	B	B	B	B	B	E
10. Sustainability	B	B	B	E		
11. Contemp. issues & hist. perspectives	B	B	B	E		
12. Risk and uncertainty	B	B	B	E		
13. Project management	B	B	B	E		
14. Breadth in civil engineering areas	B	B	B	B		
15. Technical specialization	B	M/30	M/30	M/30	M/30	E
Professional						
16. Communication	B	B	B	B	E	
17. Public policy	B	B	E			
18. Business and public administration	B	B	E			
19. Globalization	B	B	B	E		
20. Leadership	B	B	B	E		
21. Teamwork	B	B	B	E		
22. Attitudes	B	B	E			
23. Lifelong learning	B	B	B	E	E	
24. Professional and ethical responsibility	B	B	B	B	E	E

Key:

B	Portion of the BOK fulfilled through the bachelor's degree
M/30	Portion of the BOK fulfilled through the master's degree or equivalent (approximately 30 semester credits of acceptable graduate-level or upper-level undergraduate courses in a specialized technical area and/or professional practice area related to civil engineering)
E	Portion of the BOK fulfilled through the prelicensure experience

Figure ES-1. Entry into the practice of civil engineering at the professional level requires fulfilling 24 outcomes to the appropriate levels of achievement.

Figure 1. ASCE BOK Outcomes and Levels of Achievement

Engineering programs commonly employ a capstone course as the culminating event for their students' development – particularly in design. The 2005 national survey of capstone design courses by Howe and Wilbarger (2005)[7] reported on 444 programs from 232 institutions. This survey found that 79% of institutions reported a one, or two course sequence for their capstone experience. The premise of such end-of-program culminating experiences was that students eventually gained proficiency at the "design" level, apparently reaching higher level of Bloom's. We note however, that recently there is a trend for curricula to move towards integrating the design experience earlier in the students' program; thereby reaching higher cognitive levels in courses other than the capstone experience. Examples include the "design focus curriculum" at Olin (2008)[8], a pre-capstone approach at Oklahoma State University (2008)[9], and the emerging inclusion of freshman engineering courses such as those at the University of Southern Indiana (2008)[10]. However, it is the still capstone experience that many programs use (2007)[11] to assess their ABET Design Outcome (2001)[12].

The authors' own experiences contributed to the realization of the difference between Civil Engineering and Architecture programs, with respect to Bloom's taxonomy. Civil Engineering programs are typically formulated as one might design an actual building, that is, they are built from the ground up. CE programs begin with the design and analysis of individual components in Statics, Mechanics of Materials, etc. Those components are then combined to form sub-systems and eventually are fully integrated with reference to design codes. It is not till late in most CE programs that students grapple with the complete design of buildings and structures. Clearly this stems from that fact that most CE educators believe one must "build civil engineers" from the ground-up, as one would build a building. However, the authors have come to appreciate that a different model, and potentially a more fruitful and pedagogically sound model, can be created by emulating the best practices from Architecture programs.

PART 2 Undergraduate Architecture Studio:

In his influential book *Educating the Reflective Practitioner* (1987), Donald Schön, argues that professional education should be centered less on developing a specific set of skills in students and more on their ability to reflect first, then act in situations where established theories may not apply. He addresses the implications of the "ground-up" approach to educate Civil Engineers mentioned above, when he writes, "Civil engineers know how to build roads suited to particular sites and specifications. They draw on their knowledge of soil conditions, materials, and construction technologies to define grades, surfaces, and dimensions. When they must decide what road to build, however, or whether to build it at all, their problem is not solvable by the application of technical knowledge, not even by the sophisticated techniques of decision theory. They face a complex and ill-defined mélange of topographical, financial, economic, environmental, and political factors. If they are to get a well-formed problem matched to their familiar theories and techniques, they must construct it from the materials of the situation…" (1987)[13] The ground-up approach, it seems, would prepare students if they only work with straightforward, well-formed cases and problems to which they can apply standard theories. "But as we have come to see with increasing clarity over the last twenty or so years," Schön continues, "the problems of real-world practice do not present themselves to practitioners as well-formed structures. Indeed, they tend not to present themselves as problems at all but as messy, indeterminate situations" (1987)[14]. This ability to "construct the problem" is precisely the type of skill addressed by the higher levels of Bloom's taxonomy. In other words, the very ability that aspiring engineers need most may be the skill that professional schools seem less able to teach.

Of course, the "ground-up" approach is not unique to CE programs. It characterizes many professional schools in the University setting. Schön believes that most professional programs are premised on technical rationality, due in part to a desire to gain prestige from the science/research communities when joining universities at the beginning of the twentieth century. He writes, "their normative curriculum…still embodies the idea that practical competence becomes professional when its instrumental problem-solving is grounded in systematic, preferably scientific knowledge. So the normative curriculum presents first the relevant basic science, then the relevant applied science, and finally, a practicum in which students are presumed to learn to apply research-based knowledge to the problems of everyday practice" (1987)[15]. In other words, the curricula of most professional programs are premised on taking students to the level of *Application* (Level 3) in Bloom's taxonomy but no higher.

What does Schön suggest as a course of action for professional programs? He suggests that practitioners would be far more competent in indeterminate zones of practice if they became more like artists (he defines artistry as "an exercise of intelligence, a kind of knowing, though different in crucial respects from our standard model of professional knowledge. It is not inherently mysterious; it is rigorous in its own terms…") (1984)[16]. We will return to this key of idea of rigor in the third and final part of our paper. By looking at the skills of extraordinarily gifted practitioners and by assessing how these masters acquired such skills, Schön realized that professional artistry was best fostered under conditions similar to those in art studios and music conservatories, namely environments where students "learn by doing" in a relatively low risk situation, where just about everything is practicum, and where they have access to mentors who coach more than teach. After having the chance to observe architectural education firsthand, he became convinced that "architectural designing is a prototype of the kind of artistry that other professionals need most to acquire; and the design studio, with its characteristic pattern of learning by doing and coaching, exemplifies the predicaments inherent in any reflective practicum and the conditions and process essential its success. Thus, other professional schools can learn from architecture" (1987)[17].

Whereas Schön believes the architectural design studio may be a model for all of the professions, we argue that it is particularly well suited for the education of engineers due to its attempt to blend both art and science in the "learn-by-doing" experience. Of architecture programs and the education they provide, Schön writes, "they are interesting because they occupy a middle ground between professional and art schools. Architecture is an established profession charged with important social functions, but it is also a fine art, and the arts tend to sit uneasily in the contemporary research university. In their curricula, some applied sciences may be taught, although the status of such sciences is often ambiguous and controversial. For the most part, however, these schools preserve a studio tradition centered on the art of designing" (1987)[18].

How do architecture programs use the studio model? Generally most schools offering an undergraduate degree in architecture introduce students to building design studios in the second year of a five-year program. These studios typically present students with a hypothetical building project (e.g. design an art gallery with living spaces for the gallery owner for a vacant infill site in San Francisco's SOMA district) and are guided through its design by the studio instructor. At the end of the process (and sometimes at several intermediate points) outside critics are invited in to offer criticism, insights and advice to help the students in their progress. This model is repeated throughout the students' education, with the complexity of the project components (site, building type, construction systems, etc.) increasing as students progress through the program.

It is typical for Architecture students to ***initially be guided*** by both instructors and critics via an analysis or "reading" of the project, i.e. a thorough understanding of the project's social, environmental and programmatic context. This equates to the formation of a general understanding of project determinants, influences and parameters before the proposal of any specific design. The pedagogy that supports this is that design should be ***informed by the project's broad context***, and that a design proposal should not move into specific terms until general terms are vetted. Upon completion of this analysis phase, students are encouraged to formulate a conceptual framework for their project that sometimes draws from wide sources of inspiration or influence, often beyond the discipline of architecture. These sources may include disciplines such as philosophy, literature, biology, and others. How refreshingly different this is from the traditional Civil Engineering model!

In the paper "Models of Design in Studio Teaching" (1985), Stefani Ledewitz refers to the process described above as the "Analysis/Synthesis Model" and argues that it is the major component of the design studio experience. Ledewitz writes of this model, "A studio project is often divided into two discrete and identifiable parts. The first part, which might take from a few days to many weeks, is the analysis phase, in which site, program, building type, context and other investigations are carried out…At some point, the studio shifts in focus to the design concept, and assignments change from analytic exercises to design proposals. During this stage, references are made back to analysis work." (1985)[19]

Ledewitz goes on to argue that "all the aspects of design education- the skills, the language, and the approach to problems- are more effectively taught indirectly through experience than taught directly by explanation" (1985)[20]. This is not the engineering approach! The ability to "think architecturally" is the most difficult to explain to a student who lacks design experience, yet this is a primary goal of the undergraduate architectural design studio.

The very words "*Analysis*" (Level 4) and "*Synthesis*" (Level 5) are telling in this study. Ledewitz describes the typical design studio as moving up and down taxonomy to touch these two levels. Ledewitz also states that at the introductory studio stage it is unlikely that design instructors would impose upon a student a predefined procedure to solve a problem. Again, this is totally different from the engineering approach wherein textbooks often now include a map of strategies for how to solve various problems.

A strong endorsement for the studio pedagogy is made by Ernest L. Boyer and Lee D. Mitgang in their study of architectural education sponsored by the Carnegie Foundation for the Advancement of Teaching (1996). In it they wrote that "architecture education, at its best, is a model that holds valuable insights and lessons for all of higher education as a new century approaches…in short, architecture education is really about fostering the learning habits needed for the discovery, integration, application and sharing of knowledge over a lifetime." (1996)[21]

PART 3. Synthesis and Suggestions

We close by offering a suggestion of how to integrate the best practices of the undergraduate architecture design studio with the traditional undergraduate Civil Engineering curriculum. We begin by analyzing the word "design". Scruton (1979)[22] argues that architecture concerns itself with the expression of a set of "values"

> "A value, unlike a mere preference, expresses itself in language…and it pursues what is right, fitting, appropriate and just. A value is characterized not by its strength but by its depth, by the extent to which it brings order to experience…Values are a special case of ***ends of conduct***; they define what we are aiming at, not just in the particular case, but generally. It is through the acquisitions of values that we are able to arrive at a ***conception of an end***… To have such a "conception of an end" enables one to ***envisage what it would be like*** to achieve that end.

When Scruton uses the phrase "conception of an end" or to "envisage what it would be like", he is arguing that the acquisition of "design values" is partly imaginative, requiring envisaging a non-existing state of affairs. It is also *evaluative*, i.e. it involves a sense of appropriateness of one's actions. What a fascinating definition of design this is! If we could only encourage our students to develop such a rigorous design ethic, one that seeks to impart order on an as-yet unbuilt project, it would nurture a future generation of leading thinkers in structural design. Clearly such a design ethic, or set of values, requires high levels of cognition on Bloom's taxonomy.

Jones (1981)[23] has analyzed Scruton's quote regarding the ***attachment of value*** to a series of "ends". Jones has argued that architecture students must be educated in the appreciation of a vast array of accomplished "ends", as well as in "the imaginative construction of ends yet to be". Jones goes on to argue that the undergraduate study of architecture must "establish a balance between the appreciation of the socio-cultural process of expressing 'ends in view' and the techniques of building these". Surely, this line of thinking is reflected in the two accrediting agencies, ABET for the structural engineers and NAAB for the architects. ABET endorses a linear, progressive march through higher and higher taxonomy levels, essentially advocating the laying of foundations for "techniques" of the "ends in view". NAAB (2006)[24] advocates tipping the balance in favor of establishing an "appreciation of the socio-cultural processes" surrounding these "ends in view". Another interesting insight occurs when we consider that ABET relegates experience of the highest taxonomy to the post-B.S. workplace environment, whereas NAAB actively promotes the idea that the architecture student will master the lowest taxonomy levels through his or her Intern Development Program (IDP), post B.Arch. The IDP carefully monitors competence in basic comprehension of a wide range of practical architectural experiences prior to allowing the junior architect to sit for the licensing exam.

Conclusions

We close by advocating that in upper level interdisciplinary or in capstone projects, that faculty encourage students to explore both ends of the taxonomy. A practical way of ensuring this is to continually nurture in the students a sense of appreciation of the context of their work, both historical and contemporary/global, along with guidance in the techniques necessary to achieve these ends. A pedagogically sound way of achieving this goal is to implement the Analysis/Synthesis Model we have described, and to encourage undergraduate students to develop and to articulate a set of "design values". Our findings have convinced us that it is through ***our careful mentoring of our students' public articulation of "design values", such as those in a studio critique***, that we will encourage them to develop a sense of design ethics. Brilliant structural designers of the past century such as Robert Maillart, Felix Candela, Pier Luigi Nervi and Fazlur Khan have all written extensively about the "structural logic" that has informed their design worldview. These giants of the past still retain the power to inspire and to challenge the structural designers of the future. All these exemplar designers had a strong and clear set of design values which framed their groundbreaking designs. It is our challenge as educators to present these historically significant ideas in a new 21st model of engineering education that incorporates the best features of the undergraduate Architecture design studio.

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