Developing Knowledge Landscapes through Project-Based Learning

Paul S. Chinowsky[1]; Hyman Brown[2]; Alberto Szajnman[3]; and Allison Realph[4]

Abstract: The traditional civil engineering-based approach to construction engineering and management education focuses significant attention on core subjects such as scheduling, estimating, and contracts. This paper introduces an alternative approach to this education based on the concepts of project-based learning. Through the introduction of courses developed by the writers, the paper provides a foundation for changing current education approaches from a lecture-based format to a project-based format. In this format, students are challenged with open-ended problems requiring greater application of multiple engineering concepts as well as requiring interaction with outside experts from within the construction industry and related professions. An outline for a project-based learning course is presented with experiences and lessons learned from four implementations of the course. Student responses are presented to indicate the potential benefits of such an approach. This finding is further supported by the introduction of the Knowledge Landscape concept for construction education that emphasizes greater use of context, scope, and multiple intelligences in construction engineering education.

DOI: 10.1061/(ASCE)1052-3928(2006)132:2(118)

CE Database subject headings: Engineering education; Construction industry; Training; Project management; Landscaping.

Introduction

Engineering achievements accomplished throughout history are examples of individuals striving to solve problems that are often considered untenable at the time. These problems may encompass the achievement of great heights in structures, or the ability to span great divides with new bridge technology, or the ability to enhance transportation modes with multimodal transportation. In each scenario, it is the engineer with the vision to integrate conflicting demands into an elegant solution that is pivotal to the final outcome. The continued importance of this ability to integrate multiple demands is the basis for the position in this paper that engineering education is not addressing the needs of the modern society. Specifically, engineering specialization is overriding the need to provide new engineers with the breadth required to address the integration of demands that is a central part of engineering achievements (Chinowsky and Diekmann 2004).

[1]Associate Professor, School of Civil, Environmental, and Architectural Engineering, Univ. of Colorado, Boulder, CO 80309 (corresponding author). E-mail: paul.chinowsky@colorado.edu

[2]Senior Instructor, School of Civil, Environmental, and Architectural Engineering, Univ. of Colorado, Boulder, CO 80309. E-mail: hyman.brown@colorado.edu

[3]Research Assistant, School of Civil, Environmental, and Architectural Engineering, Univ. of Colorado, Boulder, CO 80309. E-mail: alberto.szajnman@colorado.edu

[4]Research Assistant, School of Civil, Environmental, and Architectural Engineering, Univ. of Colorado, Boulder, CO 80309. E-mail: realpha@colorado.edu

Note. Discussion open until September 1, 2006. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on November 25, 2003; approved on June 28, 2005. This paper is part of the ***Journal of Professional Issues in Engineering Education and Practice***, Vol. 132, No. 2, April 1, 2006. ©ASCE, ISSN 1052-3928/2006/2-118–124/$25.00.

This focus on specialization is particularly significant in the construction engineering domain. Demands from clients, political bodies, government agencies, and numerous private constituents are each pushing the construction professional into a domain that is characterized by multiple, and often conflicting, goals that must be balanced and mediated to produce a completed project. However, the development of the knowledge to achieve this outcome is often given lower priority than the core of the civil engineering-based construction courses that focus on skills such as estimating, scheduling, and contracts. Project-based learning (PBL) presents one opportunity to reverse this trend and reintroduce breadth into the construction engineering curriculum. Adopted by educators in many domains, including a strong emphasis in medicine (Barrows 2000), the concept of project-based learning is receiving increased attention within the construction domain (Fruchter 1999). This paper introduces a PBL course where students participate in real projects as a practical implementation of a Knowledge Landscapes-based education approach. As introduced by the writers and discussed below, Knowledge Landscapes emphasize a cognitive solution process that integrates existing and new knowledge to address a broad spectrum of technical and nontechnical project issues. Finally, the paper provides anecdotal evidence that the PBL approach is not only a viable approach, but is receiving positive reviews by current and former students.

Alternative Approaches to Construction Education

Although the decision was made by the writers to use project-based learning, it is not the only option being employed within construction education. At least five alternative teaching approaches are evident within construction education as follows.

Traditional Approach

This approach is based on precise, well-defined problems and formal definitions exposed to students in a one-way, lecture format. Concepts are presented as fixed, well-structured entities that are interconnected by the professor. As a general expression, this approach is a three-step system of lecture, reading and homework, and testing (Angelides et al. 2000). Although the students finish the courses with a good understanding of limited concepts, the specialization of the courses provides little opportunity to integrate concepts. The exception to this rule is in the capstone course where many universities have placed additional emphasis on concept integration as a response to the fragmentation found in other areas of the curriculum (Dutson et al. 1997).

Integrated Engineering Curriculum

This approach can be summarized as the integration of technical design with construction-related "Real World" constraints. An example of this is the "construct first–design later" concept employed at the Department of Civil and Environmental Engineering at the United States Air Force Academy (Jenkins et al. 2002). In this approach, students are presented real-life obstacles at the freshman level before encountering formal classroom theory. Subsequently, students take traditional civil and environmental engineering courses to understand alternative approaches to similar problems.

Model Approach

Simulating the construction site in the classroom using scale models or computer models adds an invaluable element to teaching technical aspects of design and construction. An example of this simulation, or model approach, to construction education is the Building System Modeling, Assembly, Research and Teaching Tool (*BSMARTT*) (Setareh 2001). *BSMARTT* is a scale-model kit of building components and computer software used to teach processes and methods of construction. Through these modeling approaches, students become familiar with building components and the processes required to construct final entities.

Case Study Approach

The case study approach is based on the theory that cases should be provided to students to allow a range of possible solutions (Padmanabhan and Katti 2002; Williams and Pender 2002). This method emphasizes that construction does not have one correct answer, but best solutions exist depending on the relative importance one assigns to various criteria. In selected implementations of this approach, students are provided the opportunity to visit case sites to obtain the benefit of experiencing first hand the use of equipment and materials to assist in the decision-making process. The case approach is intended to provide a motivating environment that prompts students to explore options, feel comfortable stating opinions, and build the communication skills necessary to make a successful transition to industry.

Non-Civil Engineering Approach

This approach, which is receiving attention as construction programs increase in popularity outside engineering departments, emphasizes a focus on the life cycle of a physical facility, usually restricted to buildings (Abudayyeh et al. 2000). In contrast to the math and physics foundation of the civil engineering programs, nonengineering programs focus on topics such as estimating and scheduling as well as introducing concepts such as finance and real estate. Graduates from these programs often enter the job market with immediately applicable skills desired by general contractors, but at the expense of gaining an overall industry and career perspective that is necessary for long-term career growth.

Education Research on Project-Based Learning

The educational foundation for PBL is based on the concept that students should not be passive recipients of knowledge. In this role, students may never be challenged to gain a deeper understanding of what is said or to apply the content to a real situation (Gijsaelers 1996). Current educational theory does not align with this traditional teaching style as a stand alone means to producing capable graduates. Instead, universities should provide students with an arena to construct their own knowledge landscapes. By empowering students to learn outside of classroom lectures and developing contextual situations in which they can apply content, universities are much likelier to produce graduates who are able to apply their knowledge in the real world and continue to build upon it in the absence of lectures.

Modern cognitive psychology describes learning as using a base knowledge to build new knowledge (Gijselaers 1996). Traditional lectures provide this base knowledge, but generally do not give students the opportunity to build upon it. Project-based learning (PBL), provides this opportunity by giving students an opportunity to synthesize knowledge into knowledge landscapes. In PBL, students have a framework where they are presented with open-ended problem descriptions that lack certain pieces of pertinent information. To solve such problems, students are required to extend their knowledge through external resources. In this setting, learning is transformed from a receptive to a constructive process.

Additionally, PBL challenges students to connect theory with reality by presenting problems that arise in real life situations. By associating content with context, PBL is building on the fundamental structure of memory. Specifically, when new knowledge is gained, it is placed into a network of related concepts called a semantic network. The manner in which semantic networks are organized determines how readily information can be recalled and applied (Gijsaelers 1996). Project-based learning teaches concepts through real problems, creating an association between theory and practice. This association enables students to better retrieve the pertinent theoretical knowledge when faced with real problems.

Finally, aside from learning processes, PBL also differs from traditional curricula in the role of the instructor. Normally, instructors are responsible for monitoring student progress and assessing solutions. Studies have shown, however, that expert performance is typically accompanied by self monitoring (Gijsaelers 1996). Generally referred to as metacognition, self-monitoring skills include understanding how a problem is analyzed and being able to determine whether solutions make sense. Students who possess such skills tend to learn more quickly (Gijsaelers 1996). The role of the instructor in PBL is to help students develop these skills. By presenting classes with open-ended problems that lack specific solution objectives, students are forced to create their own strategies and goals. Instructors become coaches as students attempt to reach these self-defined goals (Steinemann 2003).

These fundamental concepts of PBL are currently being implemented in a growing number of engineering education settings. For example, design–construction integration has been a focus of PBL at several universities including Worcester Polytechnic Institute (Albano and Salazar 1998), Stanford University (Fruchter 1999), Georgia Institute of Technology (Steinemann 2003), and

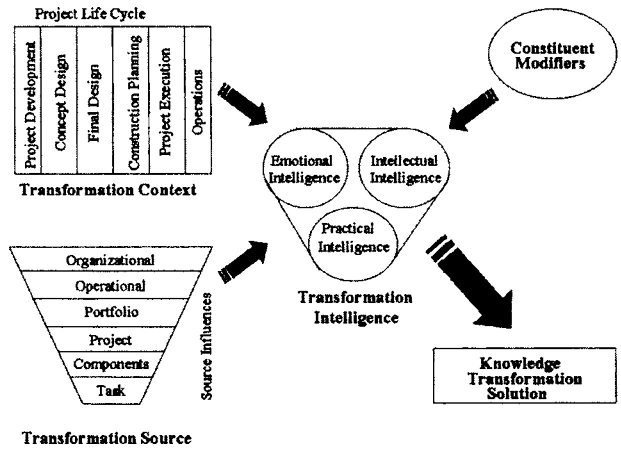

Fig. 1. Knowledge transformation components and process

the University of Glasgow (Williams and Pender 2002) among many others. Similarly, PBL and the related case-based focus on education has been introduced in civil engineering disciplines ranging from hydraulic engineering (Johnson 1999) to forensic civil engineering (Delatte and Rens 2003). In each of these cases, the faculty are introducing expanded problem-solving concepts and nontraditional engineering variables.

PBL and Knowledge Landscapes

The emphasis of PBL on integrating theory with practice, or content with context, provides students with an initial exposure to the professional world where it is expected that a broad knowledge foundation can be applied to specific projects. However, the writers propose that PBL by itself is only the first step in revising engineering education in general and construction education specifically. To enhance the education experience, educators should move further toward integrating the cognitive concept of broad knowledge application and transformation in all levels of courses and not limited to capstone experiences. Specifically, it is proposed that construction educators adopt a cognitive concept that has emerged from the writers' PBL experience and introduced as the Knowledge Landscape approach. In this approach, students are required to solve project scenarios with a diverse range of external and internal project variables that require both technical and nontechnical skills to be applied during the solution process. This concept supports the PBL perspective that engineering is a knowledge transformation process where solutions are generated by transforming and integrating existing and context-dependent knowledge. To support an understanding of the Knowledge Landscape cognitive process, the writers propose the following model of the knowledge integration and transformation process (Fig. 1).

Transformation Context

The foundation of the constructor's knowledge base is an understanding of the project life cycle. In this context, the constructor combines desires, goals, specifications, and considerations from every project participant. Conflicting goals such as desire for aesthetic prominence or limited construction funds are balanced against needs such as ease of construction or reductions in long-term maintenance costs. The constructor does not isolate solutions to specific life-cycle phases, but rather, attempts to recognize the influence of each phase on each decision.

Transformation Source

An additional influence in the solution process is the organization or project level from which requirements originate. As illustrated in Fig. 1, requirements can originate from a detailed task level all the way to a corporate directive. These levels are referred to in this model as the transformation source. The constructor must understand that responses to these requirements have effects that are not limited to the level at which they originate. Rather, decisions made at either end of the source spectrum can significantly affect the entire spectrum. For example, a decision at the organization level to enhance the reputation of the organization through exceptional quality will be reflected at the task level through increased implementation times at critical project phases.

Constituent Modifiers

Each project contains requirements that must be addressed during the transformation process. For example, each project has a unique site on which it located, and each project has specific infrastructure integration constraints such as traffic, electric, and sewer integration. Each of these issues is an example of an issue that modifies an existing solution which the constructor has previously addressed. These project-specific requirements are the constituent modifiers. As the transformation process proceeds, the constructor must transform existing knowledge to address the constituent modifiers. The transformation of the existing knowledge to accommodate the constituent modifiers results in the unique solution for the current project.

Transformation Intelligence

Transformation intelligence is a combination of intelligences used by professionals to transform knowledge (e.g., context and source knowledge) into solutions (Sternberg 1996). Specifically, intellectual intelligence, as measured by traditional IQ tests, is the analytical component derived from formal education. Practical intelligence, emerging from experience in the field or office, balances the intellectual intelligence with pragmatic considerations. Providing students with practical intelligence prior to entering the profession is a significant factor in the PBL approach. Finally, emotional intelligence, as measured by emotional quotient, provides the creativity to develop new solutions and the interaction and communication skills to get the solutions implemented.

Incomplete Transformations

The relationship of PBL to the transformation process described above is that PBL is intended to expose students to the concept of addressing the transformation context, the transformation source, and using multiple intelligence perspectives to produce integrated solutions. This is in contrast to traditional and mainstream construction engineering education where the focus is largely on teaching individual points rather than educating individuals to perform complete transformations. Specifically, in the knowledge point focus, the combination of a single source reference, a single context reference, and a single intelligence is used to generate an answer. These answers are referred to as incomplete because the student fails to consider influences outside of the single problem context.

To illustrate this incomplete concept, two examples are considered. First, in a typical scheduling problem, students are taught to analyze problems from a manipulative perspective. In this perspective, tools such as the critical path method are used to develop a technical answer to a specific question such as the shortest duration through the schedule. However, this approach fails to educate the student on how to examine the effects on other transformation source levels or how to examine influences originating in other life-cycle phases. A second example is the introduction of productivity studies into field operation courses. Although analytical attention is given to the productivity impact on a project through numerical or simulation studies, the analysis often remains focused on project execution impacts rather than exploring the additional organizational, competitiveness, and human resource considerations. Although these answers may be technically correct, they fail to challenge students to recognize potential impacts, potential influences, or the opportunities to develop creative solutions. Stated another way, complete solutions result from transformations based on a Knowledge Landscape, while answers result from the application of individual knowledge points.

Complete Transformations

In contrast to the focus on knowledge points, the writers propose the adoption of a Knowledge Landscape approach to developing complete knowledge transformations. The Knowledge Landscape approach is a cognitive concept that emphasizes students and educators leveraging opportunities to explore the full complexity of problems by incorporating appropriate influences from the context and scope, and employing all three intelligence types during the transformation process. The word opportunity in this description is a necessary component of the education process. Although each problem given to a student provides the opportunity to utilize a complete Knowledge Landscape approach, it may not be necessary or appropriate to indulge in a full problem analysis to achieve an answer to a simple problem. For example, determining the cost of concrete may require only a fraction of the Knowledge Landscape. However, the understanding that this direct action is appropriate is just as important as employing the full Knowledge Landscape. Stated in another way, the ability to determine the appropriate use of knowledge is just as important as employing the knowledge itself. The opportunity to introduce a practical implementation of the Knowledge Landscape approach was the motivation for introducing project-based learning at the University of Colorado.

Past PBL Projects

The development of a project-based learning course encompassing the concepts of Knowledge Landscapes has moved through several iterations at the University of Colorado. Specifically, three previous small-scale PBL courses have set the stage for the current PBL structure and provide the foundation for the curriculum outlined for the current course. In each of these efforts, the students were given real projects with real clients and were placed in the roles of construction managers under faculty supervision. The advantage of using real projects is that students obtain an appreciation for the differences between an artificial problem and a real project. For example, the urgency for project decisions, the interactions with project constituents, the changing of the project scope, and the introduction of new requirements are each introduced in the context of a real project without a need for artificially introducing them into the solution. The following short summaries provide an overview of these previous efforts.

Quaker Meeting House

The first PBL project undertaken by the civil engineering faculty and students was the construction management of a meeting house for the Boulder Meeting of Friends (Quakers). Since this was the first PBL effort, the number of students was limited to a test group selected by the faculty. The group consisted of six graduate students who had each taken entry-level construction management courses. The students did not receive credit for this test experience. Rather, they participated for the experience and the opportunity to gain a greater understanding of the civil engineering profession. The responsibility of the students focused on pulling necessary permits, hiring a superintendent, awarding construction contracts, approving bills for payment, and meeting with architects. Essentially, the students served as the construction management team, assuming responsibility for the entire \$630,000, $7{,}000\ \text{ft}^2$ project. The PBL project lasted for 1 year, covering the time required to complete preconstruction and construction of the actual project. The lessons learned from this first experience included a better understanding of the faculty oversight time required in a PBL setting, the limitations of the knowledge students receive in the classroom, and the enthusiasm that students have for applying knowledge to a real problem.

United Church of Christ

After the Quaker Meeting House was completed, faculty and students moved on to a slightly larger project for the United Church of Christ. Once again, six students were selected to work on the project; two undergraduates and four graduate students. As with the Quaker Meeting House, students were given the responsibility of construction management during final plan development and construction. The final budget for the $13{,}000\ \text{ft}^2$ remodel project was \$770,000. Two primary lessons emerged from this effort. First, students have to understand that commitment is a key element of PBL. Two graduate students left the team during the project for personal reasons. The loss of team members results in the remaining members being forced to pick up the pieces. An incomplete solution is not an option. Second, students need to understand that the final problem may not be the problem introduced in the beginning of the course. For example, the UCC project experienced scope creep where the owners expanded the budget of the project from \$630,000 to \$770,000, resulting in the need to alter plans on a real-time basis before construction could begin.

Lutheran Church

In a third PBL effort, faculty and students were involved in a proposed facility for the Lutheran Church in Boulder. Once again, six students; five graduates and one undergraduate were chosen for the project. The Lutheran Church project lasted for approximately 1 year, but did not result in construction. The project was intended as a mixed-use facility, but church members were never able to come to a resolution of its exact components. Although the project did not result in a constructed facility, a valuable lesson

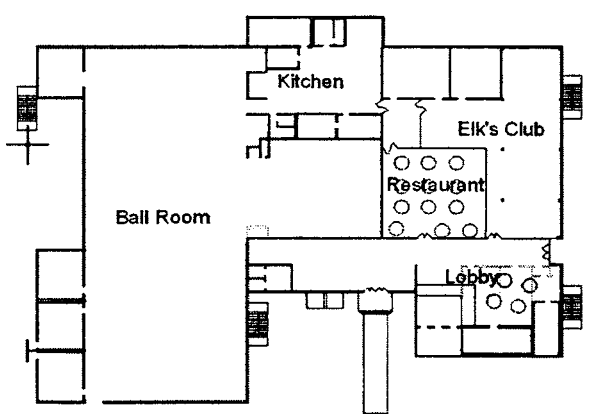

Fig. 2. Existing Elks facility floor plan–interior of main lodge building

emerged from the experience that every project does not turn into a final construction project due to owner concerns.

Elks PBL Course

The concept for the most recent PBL course was to combine the lessons learned from the three trial courses into a consolidated, credited course that provided students with a PBL experience based on a Knowledge Landscape approach as well as providing a benefit to the surrounding community. Subsequently, when the opportunity was presented for the construction faculty to assist the Elks Lodge of Boulder in investigating the redevelopment of their Boulder, Colo. site, the faculty ensured that the opportunity to implement a PBL course was in place. Specifically, the PBL course was established to provide students with the opportunity to conduct a one semester preconstruction analysis of the Elks site to determine the optimum combination of uses for the property. As illustrated in Figs. 2 and 3, the Elks property presented the students with a site consisting of an existing $28{,}500\ \mathrm{ft}^2$ lodge building with a swimming pool at the southwest corner of the building. Adjacent to the property, but not part of the Elks site, is a park and a congregate care facility for senior citizens. The goal for the project team was to find an appropriate use for the site that would increase current revenues, and provide an appropriate return on a $12 million construction investment.

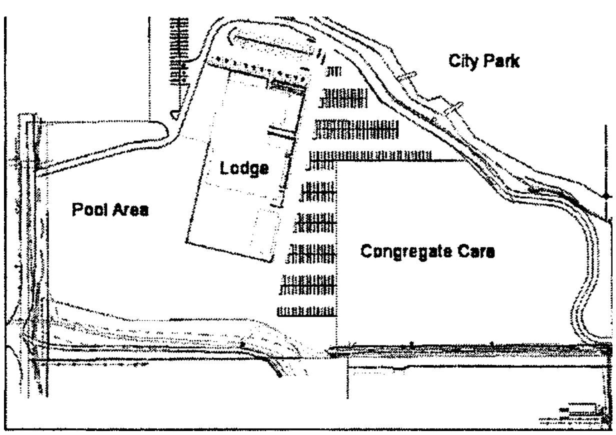

Fig. 3. Existing Elks site layout including main lodge building, pool area, and neighboring congregate care facility

Given the broad outline from the Elks organization, the PBL project was formulated by the faculty to provide the students with an opportunity to experience the complete range of activities associated with a feasibility analysis of a significant construction effort. Within this experience would be the opportunity to interact with the project owners, potential architects and engineers, project investors, and bankers, and the construction team including the general and subcontractors. The intent of this exposure being to provide a foundation for a Knowledge Landscape approach to the PBL experience.

Elks PBL Curriculum

The students enrolled in the Elks PBL course varied in experience and education levels. Although concerns were initially held concerning this heterogeneous mix, the concern later turned to be unfounded due to the fact that the students turned into resources for each other based on their experiences and education. Fourteen construction emphasis students participated in the course; six graduate students, four seniors, two juniors, and two sophomores. The 14 students were overseen by two construction faculty who team taught the course. Each of these students independently requested to participate in the three-unit course, providing the faculty the opportunity to determine if the students were committed to such an effort.

The structure of the PBL course revolved around the needs of the project to progress from idea to formal feasibility analysis and construction. This structure combined formal meetings with the faculty with independent student meetings and external project meetings. The students were required to meet as a group with the faculty once a week to both review project status reports and receive new information that would assist them in addressing the next stage of analysis. In addition, the students met independently as a single group or several small groups to collaboratively find solutions and alternatives as the project progressed. For example, during the project financing stage, the students met to develop several alternatives for project financing that may have been relevant options for the client. Finally, the students were required to meet once a week with either the project owner or an outside project participant to ensure that they were both communicating progress of the project as well as receiving input on real constraints and opportunities related to the project (the constituent modifiers for the project).

As illustrated in the following list, the course was divided into five parts corresponding to the chronological progress of the project:

1. Feasibility analysis—The feasibility analysis emphasized the financial viability of creating a multiuse redevelopment effort on the given property. Included within this section were requirements for the students to interview the owners, develop alternative financial models, and examine current market forces surrounding a new development.
2. Project alternatives—The project alternatives section examined alternative project solutions in terms of potential demand and return for various mix alternatives.
3. Conceptual estimates—The third section required conceptual estimates of the alternatives based on estimating techniques the students had learned in previous courses.
4. Participant interviews—The fourth section required the students interview potential project partners to determine schedules, fees, and the qualifications of each participant.
5. Final recommendation—The final project component re-

quired the students to produce a recommendation for the project owners. The students were required to consolidate all of the information gathered during the previous sections into a single presentation and report that was presented at a formal meeting with the project owners.

The advantage of the Elks PBL process was the opportunity to require students to address real problems during the project development process. For example, at the beginning of the project it was determined that a hotel would be a good use of the property in addition to the existing lodge. The demand for a hotel in the proposed section of the city was favorable and the room rates being generated in similar locations appeared to indicate that a strong return on investment was possible. However, as the project progressed, the economy dropped and the demand for a hotel rapidly declined. The students were therefore faced with a real decision of whether to continue on the current path, or adjust their recommendations to an alternative use pattern that eliminated the hotel. After considerable discussion and further interviews of outside professionals, the students decided to make a final recommendation that eliminated the hotel option and instead focused on senior housing to accommodate the Elks membership. This was an example of problem solving in real time with no correct answer, just an informed answer based on a Knowledge Landscape approach addressing the full complexity of the problem.

Initial Results

The knowledge landscape learning approach adopted by the writers in this study is designed to reflect the need to broaden and challenge the student learning process. The limited number of students participating in the PBL courses up to this point prevents substantive statistical numbers from being presented. However, three key indicators resulting from followup interviews with the students participating in the courses and their employers provide positive feedback for the incorporation of PBL-based experiences.

1. Employment opportunities—Of the 32 students who have participated in the PBL courses, 24 have graduated. Interviews with these students found that each believed that their ability to communicate their PBL experience to potential employers provided them with a significant advantage in obtaining employment. In corresponding interviews with six employers, the personnel directors each reiterated this sentiment by stating they believed the PBL graduates were more mature, had greater communication skills, and had a greater understanding of working with clients.
2. Subject understanding—A universal belief of the students interviewed by the writers was the thought that PBL provided a greater context for their other engineering and construction subjects. For example, statements included, "Hands on experience while being in school is valuable not only for when you graduate but can help one relate their school studies to a reality-based project" and "Working on actual projects increased my understanding of the subject matter taught in class." This sentiment was reinforced by faculty members who had the students in later courses and commented on the students' ability to form questions that extended beyond the normal boundaries of an assignment.
3. Domain understanding—A third benefit of the PBL experience, that every student interviewed either agreed or strongly agreed with, is that they gained a deeper understanding of the construction industry. This is a critical advantage of PBL in that it provides students with an introduction to the industry prior to their first employment. This can significantly reduce the number of students who graduate and then find they are dissatisfied with their career choice. Example comments included, "PBL was an eye-opening experience that exposed me to the construction industry and gave me relevant experience" and "The real-world experience that I gained from PBL was unattainable through the standard classroom procedures."

In summary, the students participating in the PBL experience understood that they were being introduced to a real perspective on construction. Additionally, they recognized the need to respond to the challenges and develop solutions to open-ended problems. Although there were some negative comments regarding the amount of work that was required to successfully address a PBL problem while attending other courses and some concerns over the changes in problem definition as the course progressed, in every case, the students recommended that other students should experience this learning approach.

Faculty Considerations

Although these positive results provide an indication that PBL and Knowledge Landscapes hold educational promise in construction engineering, it should be noted that departments who are considering a PBL approach in other courses consider the following potential issues in this approach:

1. Need for interaction—The faculty time required to implement a PBL course is a significant investment beyond that associated with a traditional class. Issues arise in a PBL context that are not anticipated at the start of the course due to the variability inherent in an actual versus an artificial problem. Faculty members must be willing to put this additional interaction time into the course that may result in little or no recognition from the administration.
2. Preparation time—In addition to the time normally associated with class preparation, a PBL course requires the faculty member to prepare the external project participants for the unique attributes of working with students. Depending on the scope of the PBL project and the number of external participants, this time can be significant.
3. Course expansion—The final point is the concern over the expansion of PBL projects beyond a small course focus. In an era of reduced budgets, civil engineering departments may be reluctant to invest faculty commitments to a course that may not work in a context of 30–40 students. Can PBL work in a class of this size? This is a question that must be resolved prior to PBL being accepted as a broad answer to change in engineering education.
4. Unexpected events—PBL projects are subject to unexpected results throughout a course. Issues such as project delays, participant changes, or access restrictions can each occur during the course of a class. In these circumstances, instructors must make changes to the syllabus, project requirements, and course schedule to accommodate the new scenario. This may not be practical in a large class or over an extended period of time.

PBL in Knowledge Landscape Education Approach

The positive student response documented above provides the motivation for recommending that departments explore PBL and

Knowledge Landscapes in the context of individual curricula. Although opportunities to introduce this concept exist throughout the engineering curriculum, two opportunities have primary significance as follows.

Move into Earlier Years of Curriculum

The focus on the analytical development of engineering students in the first 2 years of the engineering curriculum has been a staple of engineering programs since the inception of the discipline. Subjects such as calculus, physics, statics, and chemistry are core elements of the engineering education. Although the introduction of freshman design courses is becoming increasingly common, these courses remain the exception compared to the analytic emphasis in the first 2 years of engineering education. The issue with this analytic focus is that students begin to believe that an overemphasis on analytic thinking is the key to engineering success. By the time these same students are asked to develop creative solutions in their capstone design courses, their ability to draw upon their alternative intelligence is hampered by previous solution patterns based on a single analytic focus. Therefore, to balance this analytic emphasis, the writers strongly advocate the integration of project-based learning concepts throughout the early engineering curriculum. Issues such as creativity, leadership, group interaction, and communications in the context of actual problems need to be introduced and fostered throughout the curriculum.

Broader Scope of Upper Division

The introduction of capstone design courses has broadened the design experience of engineering students. However, limiting breadth to the capstone concept does not go far enough in addressing the issue of breadth in the engineering curriculum. Rather, if engineering programs are going to significantly address the issue of breadth and the support of Knowledge Landscapes, then concepts such as political influence, financial interactions, human resources, and market fluctuations need to be introduced throughout the curriculum. These issues will challenge students, educators, and administrators to move beyond analytic solutions to address issues that affect the development and implementation of real projects. This concept of challenge lies at the heart of project-based learning and a Knowledge Landscape approach to education. When students are challenged to achieve outside of established boundaries, then their interest and curiosity in problems will be enhanced. Therefore, the writers put forward that engineering programs reexamine the potential for incorporating project-based learning in design experiences throughout the curriculum to promote intellectual curiosity and the development of broader problem-solving skills.

Conclusion

In conclusion, the introduction of project-based learning in the civil engineering curriculum provides two primary advantages: (1) educators have the opportunity to expand beyond a knowledge point concentration; and (2) students have the opportunity to explore problems that encourage skills beyond traditional analytic intelligence. This paper illustrated these advantages through the context of a series of PBL courses introduced at the University of Colorado. Of particular interest has been the introduction of the PBL concept within the context of the Knowledge Landscape education approach. In a departure from traditional engineering approaches, this approach places significant emphasis on understanding context and scope as well as challenging students to incorporate nontraditional intelligences. Although real barriers exist for implementing PBL on a widespread scale in the near future, the benefits from a PBL experience warrant further exploration of the technique as a viable alternative to the traditional emphasis on knowledge points as education goals.

References

Abudayyeh, O., Russell, J., Johnston, D., and Rowings, J. (2000). "Construction engineering and management undergraduate education." *J. Constr. Eng. Manage.*, 126(3), 169–175.

Albano, L. D., and Salazar, G. F. (1998). "Project-based course for integration of design and construction at WPI." *J. Prof. Issues Eng. Educ. Pract.*, 124(4), 97–104.

Angelides, D. C., Poulopoulos, A., Avgeris, I., and Haralampous, P. (2000). "Case studies and information technology in civil engineering learning." *J. Prof. Issues Eng. Educ. Pract.*, 126(3), 125–132.

Barrows, H. (2000). *Problem-based learning applied to medical education*, SIU School of Medicine, Springfield, Ill.

Chinowsky, P. C., and Diekmann, J. E. (2004). "CEM Educators: History and Deteriorating Community." *J. Constr. Eng. Manage.*, 130(5), 751–758.

Delatte, N. J., and Rens, K. L. (2003). "Forensics and case studies in civil engineering education: State of the art." *Proc., Perspectives in Civil Engineering: Commemorating the 150th Anniversary of The American Society of Civil Engineers*, ASCE, Reston, Va., 207–218.

Dutson, A. J., Magleby, S. P., Sorensen, C. D., and Todd, R. H. (1997). "A review of literature on teaching engineering design through project-oriented capstone courses." *J. Eng. Educ.*, *J. Eng. Educ.*, 86(1), 17–28.

Fruchter, R. (1999). "A/E/C teamwork: A collaborative design and learning space." *J. Comput. Civ. Eng.*, 13(4), 261–269.

Gijselaers, W. H. (1996). "Connecting problem-based practices with educational theory." *Bringing problem-based learning, to higher education: Theory and practice*, L. Wilkerson and W. H. Gijselaers, eds., Jossey-Bass, San Francisco, 13–21.

Jenkins, R. S., Pocock, J. B., Zuraski, P. D., Meade, R. B., Mitchell, Z. W., and Farrington, J. J. (2002). "Capstone course in an integrated engineering curriculum." *J. Prof. Issues Eng. Educ. Pract.*, 128(2), 75–82.

Johnson, P. A. (1999). "Problem-based, cooperative learning in the engineering classroom." *J. Prof. Issues Eng. Educ. Pract.*, 125(1), 8–11.

Padmanabhan, G., and Katti, D. (2002). "Using community-based projects in civil engineering capstone courses." *J. Prof. Issues Eng. Educ. Pract.*, 128(1), 12–18.

Setareh, M. (2001). "Development of teaching tool for building construction." *J. Archit. Eng.*, 7(1), 6–12.

Steinemann, A. (2003). "Implementing sustainable development through problem-based learning: Pedagogy and practice." *J. Prof. Issues Eng. Educ. Pract.*, 129(4), 216–224.

Sternberg, R. J. (1996). *Successful intelligence: How practical and creative intelligence determine success in life*, Simon & Schuster, New York.

Williams, K., and Pender, G. (2002). "Problem-based learning approach to construction management teaching." *J. Prof. Issues Eng. Educ. Pract.*, 128(1), 19–24.