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Application of Project-based Learning within the Context of Sustainable Development in Education of International Engineer Citizens

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Abstract – This paper outlines a project-based learning approach to engineering education. This approach directly employs sustainable development as a vehicle to prepare students for global engineering challenges. The theoretical concept of the presented work utilizes the extended situational teaching model. This model explains the role of the teacher-leader in engineering classroom to help students with gaining essential elements of engineering education, including superior knowledge, reliable skills, and professional attitude. Case studies and examples of experiential learning projects demonstrate the development of links between classroom teaching, research advising, laboratory works, and field projects, including both domestic and international projects.

1 INTRODUCTION

The sustainable development is one of the great global challenges, if not the greatest one, as it directly linked to the extinction of humanity. The significant of this challenge has invited numerous academic research projects and industrial practices to invest in sustainable development of built environment. Further, the rise in climate-related-disasters and the crisis in energy sector has shifted the perception of public toward consumerism. This shift has potentials to promote conscious decision making to conserve natural resources and protect natural environments. However, implementation of such conservation and protection efforts require substantial investment in engineering capabilities. Engineered solutions are particularly essential for developing communities that need to continue development with the least amount of financial resources, and preferably without any environmental footprint. In addition, the current spread and magnitude of harmful human activities that are

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linked to the climate change warrant development of well-planned and sophisticated engineering programs to make a meaningful progress toward addressing this global challenge. It is important to note that the state of crisis in many parts of the world require engineering efforts to exceed basic objectives of conservation and protection, and provide solutions to reverse certain environmental damaging processes, if possible. Ultimately, where political obstacles prevent any meaningful progress toward a sustainable future, engineers may still contribute to risk management and resiliency to alleviate disastrous outcomes [1].

A. *International Engineer Citizens*

As an example, civil engineers share a social responsibility as public stewards toward protection of life and safety of the public. This ethical mandate forms the design philosophy in infrastructure development. Modern design concepts such as performance-based design aim to hold human life paramount over economic gains. This approach fits well to satisfy expected outcomes of a sustainable project, e.g., improving quality of life through enhancing health and safety. Developing earthquake resistant infrastructures is a good example of an engineering practice that contributes to the well-being of individuals across multiple generations. Simultaneously, local and global communities have certain expectations from engineering infrastructures out of concerns for their impact on the well-being of the society. Engineers share the responsibility to educate public and develop their expectations, in addition to addressing those social needs. Many sustainable practices, e.g., using local materials or developing local skills, are easy targets to promote infrastructure development in a community. However, convincing local population about using non-local recycled materials with significant environmental benefits to the global population requires a fully engaged public education program. Such challenge has given rise to the context-sensitive design approach that utilizes value engineering and benefits from community leadership to optimize engineering solutions [2].

B. *Lifecycle of Engineering Education*

As presented in this paper, engineering education is the key to social and technical development of communities. Engineering education relies on three elements of knowledge, skills, and attitude. Development of each element often spans beyond college years. Like many other forms of education, engineering education may begin with pre-school activities, reach the pinnacle during higher education, and continue through post-graduation practice years. Each stage of education has distinguished requirements or pre-requisites as inputs to the process, favored activities that enhance learning throughout that specific stage, and defined measurable outcomes that signal preparation for the next stage. In this approach, definition of an engineering degree based on certain achievements, e.g., successfully passing courses within a curriculum with a minimum grand point average is helpful for academic institutes to qualify degree granting. Similarly, legal entities utilize combination of education, experience, and examination to qualify engineers for licensure. Regardless, continuous development of knowledge, skills, and attitude are essential for engineers who need to stay up-to-date and solve contemporary problems, generally decades after they have earned their degree and licensure. In addition, as the nature of problems evolve through time; required engineering qualifications to solve those problems shall change as well [3].

The extent of required achievement at each stage of engineering education may vary by discipline and subject, as needed to reach expected outcomes. For instance, an engineering curriculum often has a matrix to show the relationship between each course and student outcomes. However, the number and content of courses are also sensitive to the level of eco-socio-political support that is available to schools and colleges. The manifestation of this sensitivity is apparent in the gradual reduction of requirements, e.g., number of units, to obtain an engineering degree, over the past several decades. This ongoing problem warrants additional effort to literate public about engineering, education, and sustainability [4].

2 SIGNIFICANCE OF THE STUDY

The shift from a curriculum-based approach to an outcome-based approach emphasizes the need for enhancing efficiency in engineering education. Furthermore, engineering education shall be able to re-invent itself as a resilient system to stay current and address contemporary problems. The combination of a fast-paced crisis linked to climate change and the needs of developing communities for essential infrastructures urge new approaches in engineering education. Experiential learning is a promising approach in engineering education and have potentials to enhance knowledge, skills, and attitude of future citizens toward engineering problems, and particularly sustainable development. Therefore, it is essential to understand and evaluate application of project-based learning in engineering education with a focus on sustainability.

3 PEDAGOGY

A. *Extended Situational Teaching*

The extended situational teaching model has roots in the Situational Leadership developed by Reddin (1967) and Hersey and Blanchard (1969) for organizational management. The classic theory of Situational Leadership expresses the psychological exchanges between leaders and followers as a fit between leading style of the leader (Guide, Coach, Support, and Delegate, labeled with T numbers) and maturity level (Low and High) of the follower in respect to task and relationship (Fig. 1) [5]-[6]. Many scholars have studied the applicability of this model in education [7]-[12]

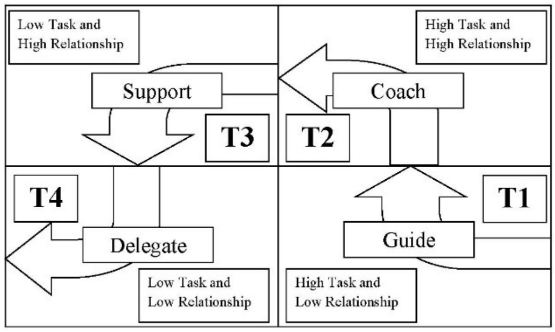

Figure 1: . Situational Leadership, after Hersey et al. (1982) [8].

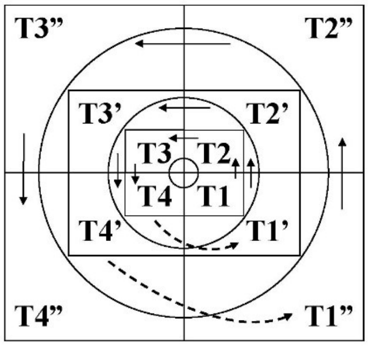

Figure 2: . Extended Situational Teaching [13].

Tehrani (2011) extended this model to cover the lifecycle of engineering education as the extended situational teaching model (Fig. 2) [13]. In this model, teaching styles (T1 to T4) apply to various layers of the education process (T, T and T).

As an example, this extended model simply explains that an engineering course always covers several closely related subjects. For each subject, the faculty guide students to gain interest through preliminary assignments, coach them to learn through lectures, support them to apply learned materials in solving assignments, and delegate the solution to a given problem to them through term projects. This development cycle will be repeated for each subject, where the work on prior subject streamlines the path to initiate the learning of the following subject. Similarly, the extended situational teaching can describe

Table 1: Student Outcomes with Respect to Experience [2].

Technical	Professional
Design	Communication
Sustainability	Public policy
Contemporary issues	Business and public administration
Risk and uncertainty	Globalization
Project management	Leadership
Technical specialization	Teamwork
	Attitudes
	Lifelong learning
	Professional and ethical responsibility

the link between consecutive engineering degree programs from undergraduate to doctoral levels with potentials to extend the spiral form to pre-school or professional years. McComb and Tehrani (2014) and Blackburn, Bluestein, and Tehrani (2016) described and assessed the application of this extended model in project-based learning for engineering students [14]-[15]. Similarly Tehrani et al. (2014) used this model to educate prospective elementary school teachers about engineering [4].

B. *Project-based Learning* Experience is a key component in engineering education. Nearly all student outcomes require experience as shown in Table 1. Further, post-graduation experience is typically a prerequisite for engineering licensure. Table 2 provides a sample comparison between different student outcomes and the level of achievement for experiential learning, including analysis, application, synthesis, and evaluation. In this respect, experiential learning bridges the gap between academic education and practice learning. Thus, implementing experiential learning in engineering college programs facilitate their transition to professional career [2]-[3].

Simple forms of experiential learning may include simplified term projects in design courses. More advanced framework of experiential learning incorporates senior capstone projects, independent studies, thesis, dissertations, and other forms of culminating experience. These projects generally simulate realistic constraints, but may not necessarily result in an implemented outcome. Students competitions and extracurricular activities also serve as appropriate platforms to expose students to experiential learning. Delivering community-focused projects is the ultimate opportunity for students to act as professionals and solve real problems without any compromise or simplification. Such projects often require students to design a complete system with respect to realistic social, political, economic, and environmental constraints. Further, the receiving community, as the real stakeholder, often expects students to address their needs throughout the full life-cycle of the project, including maintenance, retrofit, and decommissioning efforts [14]-[16].

4 APPLICATIONS

A. *Teaching: Engineering Literacy and Pedagogy*
The lack of a solid foundation of engineering literacy is an obstacle to student success in undergraduate engineering programs. Further, the lack of engineering literacy in public tends to undermine political and economic support of engineering education and infrastructures. A fundamental approach to raise public literacy about engineering is to incorporate engineering in elementary schools. Thus, there will be a need to educate prospective elementary school teachers. A course was designed to facilitate this approach as part of a new area of concentration, STEM (Science, Technology, Engineering, and Management), for liberal studies majors. The proposed course is a three-unit combined laboratory and lecture course with hands-on activities, which emphasize on sustainability. Sustainability played a key role in motivating students

Engineering outcomes	Civil engineering outcomes	Experiential learning
(a) Mathematics, science, engineering	1. Mathematics 2. Natural science 3. Materials science 6. Mechanics 14. Breadth in civil engineering areas 15. technical specialization	Application
	3. humanities 4. Social sciences	Application
(b) Experiments	7. Experiments	Synthesis
(c) Design	9. Design	Evaluation
	10. Sustainability 12. Risk/uncertainty	Analysis
(d) Multidisciplinary teams	20. Leadership 21. Teamwork 22. Attitudes	Analysis
(e) Engineering problems	8. Problem recognition and solving	Analysis
(f) Professional and ethical responsibility	24. Professional and ethical responsibility	Evaluation
(g) Communication	16. Communication	Synthesis
(h) Impact of engineering	11. Contemporary issues and historical perspectives 19. Globalization	Analysis
(i) Lifelong learning	23. Lifelong learning	Synthesis
(j) Contemporary issues	11. Contemporary issues and historical perspectives 19. Globalization	Analysis
(k) Engineering tools	8. Problem recognition and solving	Analysis
	13. Project management	Analysis
	17. Public policy 18. Business and public administration	Application

in the course and kept them engaged throughout the learning process. Furthermore, students were able to deliver meaningful projects to serve conscious purposes in community. The objectives included: (a) increasing interest in teaching engineering; (b) provide an opportunity to learn engineering; (c) modeling project-based learning for engineering; and (d) raising awareness of the Engineering practices and products [4], [17].

B. *Research: The Research and Practice Group*

The research and practice group consists of junior and senior undergraduate and graduate students as well as former members who are participating as alumni.

The major focus of research is sustainable and resilient structural engineering, mechanics and materials (SR-SEMM). Students have a chance to meet frequently and present their work-in-progress, either in-person or via web. Students receive 360-degree feedback from their advisor and alumni, peers, and junior students in a friendly environment. This would also allow them to improve their presentation skills to reach audience at various academic levels, from undergraduate freshmen to practicing engineers [14].

Projects are customized based on the level of academic preparation of the individual student. Projects are generally planned for one or two semesters with possibility of extending the project in multiple years. Limiting each phase to one or two semesters would give students an opportunity to present their work, obtain feedback, and gain sense of accomplishment at least once a year. This will certainly motivate them to continue working on long-term research programs. These projects may include undergraduate and graduate thesis, projects and independent studies, as well as self-sustained projects. An ideal research program for students begins at junior level. At this stage, students explore possibilities in research under supervision of the faculty advisor. They learn key components of research and proposal development through general studies, attending presentations, and helping senior students. As students make progress toward senior status, they begin writing proposals on selected topics. At senior level, students may choose to enroll in an independent study, implement their research skills in senior design project, or define an undergraduate thesis. At graduate level, students incorporate all previous components at a higher academic level. Further, graduate students are expected to mentor their undergraduate assistants in the laboratory. Therefore, developing supervising and mentorship skills are another part of their training. To prepare graduate students for PhD programs, they also participate as teaching assistant and grader, as well as developing proposals for external funding.

Alumni members of the group maintain their contribution by presenting their work in other institutes and organizations as well as sharing their experience and advice with new students. Such contributions also provide an opportunity for networking and development of partnerships between students as well as institutes.

Essential outcomes include: (a) formulating problems and applying knowledge of engineering to solve them; (b) performing experiments, and interpreting the results; (c) organizing and delivering effective written and oral communications; (d) learning about contemporary issues; (e) functioning as a member of diverse, and multicultural teams.

C. *Service: Professional Organizations and Communities*

Student chapters frequently participate in various extracurricular activities. The main focus of these activities is to facilitate the transition from student to professional engineer. Roles and responsibilities of students in the group cover a wide range from leading the group to performing technical tasks. Each student competitions, e.g., concrete canoe or steel bridge, involve multiple stages of planning, design, construction, maintenance, and operation, and thus has potential to be a comprehensive experiential learning opportunity. General outcomes cover areas of professionalism, leadership, ethics, and business administration. The Fresno State Student Chapter of the American Society of Civil Engineers (ASCE) hosted the 2014 Mid-Pacific Student Conference. This event added another layer to typical competition activities as hosting required extra efforts in business planning and financial management. For this purpose, student leaders were trained within the framework of an independent study course [16].

Another service application opportunity is a community-focused project. Examples include the works of Engineer Without Borders (EWB) student chapters in University of Southern California, CalPoly San Luis Obispo, and University of California, San Diego. These projects served communities in Honduras (water tank and dams), Nicaragua (school building), and Ontario, CA (community garden sheds), respectively. A notable project was the work of Nicaragua team to broaden the impact of the experiential learning. Students planned a prototype construction in campus to prepare for the real project before their trip, and invited non-travelling students to join the experience. This daylong practice involved 46 students, while only 16 of them were part of travelling team. Thus, students were able to triple the benefits of experiential learning in this project [15].

5 CONCLUSION

The project-based approach to experiential learning is an essential component of engineering education and training. Teamwork enhances student success in this approach and prepares students to become professional researchers and practitioners. Further, involvement of the group in extracurricular organizations exposes students to unique challenges that allow them to grow in a project-based learning environment. The common goal of sustainable development provides a meaningful integrating theme for project activities and facilitate transition of students throughout cycles of extended situational teaching model. Applications included both engineering and non-engineering student with great potentials to raise public awareness about engineering practices.

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References

[1] ISI. Envision: A Rating System for Sustainable Infrastructure. (Version 2.0). Washington, DC: Institute for Sustainable Infrastructure (ISI), 2012.

[2] ASCE. Civil Engineering Body of Knowledge for the 21st Century. (2nd ed.). Reston, VA: American Society of Civil Engineers (ASCE) Press, 2008.

[3] ABET (Accreditation Board for Engineering and Technology). Criteria for Criteria for Accrediting Engineering Programs. Baltimore, MD: ABET, 2010.

[4] Fariborz Tehrani, Nell Papavasiliou, Frederick Nelson, Carol Bohlin, and Mara Brady. Engineering Literacy: Educating Prospective Elementary School Teachers to Lay the Foundation for a More Knowledgeable/Well-Prepared Generation of Engineering Students, In Proceedings of the 2014 American Society for Engineering Education Zone IV Conference, 2014, pp. 399-412. Retrieved from http://web.csulb.edu/colleges/coe/2014-asee-zoneiv

[5] J. E. Barbuto. Developing a Leadership Perspective in the Classroom. Journal of Adult Development, 7 (3), 2000, pp. 161-169.

[6] P. G. Northouse. Leadership: Theory and Practice (4th Edition ed.). Thousands Oak, California: Sage Publications, 2007.

[7] B. C. P. Johansen. Situational Leadership: A Review of the Research. Human Resource Developmen Quarterly, 1 (1), 1990, pp. 73-85.

[8] P. Hersey, A. L. Angelini, and S. Carakushansky. The Impact of Situational Leadership and Classroom Structure on Learning Effectiveness. Group & Organization Studies, 7 (2), 1982, pp. 216-224.

[9] G. O. Grow. Teaching Learners to Be Self-Directed. Adult Education Quarterly, 41 (3), 1991, pp. 125-149.

[10] S. F. Cramer. Assessing Effectiveness in the Collaborative Classroom. New Direction for Teaching and Learning, (59), 1994, pp. 69-81.

[11] L. P. Meyer. Athletic Training Clinical Instructors as Situational Leaders. Journal of Athletic Training, 37 (4 Supplement), 2002, pp. S261-S265.

[12] R. P. Vecchio, R. C. Bullis, and D. M. Brazil. The Utility of Situational Leadership Theory. Small Group Research, 37 (5), 2006, pp. 407-424.

[13] F. M. Tehrani. Implementing Situational Leadership in Engineering Classrooms. In Proceedings of the Pacific Southwest section of American Society for Engineering Education Conference, 2011, pp. 114-124. Retrieved from http://fresnostate.edu/engineering/asee

[14] C. McComb and F. M. Tehrani. Research and Practice Group Methodology: A Case Study in Student Success. In Proceedings of the 2014 American Society for Engineering Education Zone IV Conference, 2014, pp. 255-267. Retrieved from http://web.csulb.edu/colleges/coe/2014-asee-zoneiv

[15] Fiona Blackburn, Jesse Bluestein, and Fariborz M. Tehrani. Engineers Without Borders Nicaragua Public Elementary School Project: A Case Study in Enhancing Engineering Education through Project-Based Learning. In Proceedings of Pacific Southwest section of American Society for Engineering Education, Pomona, CA, 2016, pp. 292-301.

[16] F. M. Tehrani, F. M., J. Regier, and K. Hoffman. Modeling Civil Engineering Practice in Student Activities. In Proceedings of the 2014 American Society for Engineering Education Zone IV Conference, 2014, p. 519. Retrieved from http://web.csulb.edu/colleges/coe/2014-asee-zoneiv

[17] F. Nelson, C. F. Bohlin, M. Brady, and F. Tehrani. Growing future elementary teachers: Cross-disciplinary collaboration in STEM Education. First Annual State STEM Conference: Invest in California STEM Education: Innovate, Integrate, and Inspire!, Sacramento, CA, 2013.