AC 2009-1839: ABET OUTCOMES VIA PROJECT-BASED SERVICE LEARNING ATTRIBUTES: ASSESSMENT VIA SUCCESSFUL INTELLIGENCE

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Abstract

Project-based service learning (PBSL) is an amalgamation of two types of pedagogical methods: problem-based learning (PBL) and service learning (SL). The dynamic interplay between the two methods creates a synergistic pedagogy that is stronger than either one alone. While the collaborative nature intrinsic to problem-based learning engenders development of technical (classroom-learned concepts) and professional skills (teamwork, communication, leadership, diversity), the service learning aspects allows students to gain knowledge of societal, cultural, economic, and environmental impacts of their solutions. ABET-based educational outcomes require degree programs to provide technical and professional skills while acknowledging and addressing societal and global issues in the impacts of engineering work. While technical skills can be routinely measured, the issue of providing quantitative measures of professional skills is more challenging and lacks a reliable precedent. So, how can one effectively quantify the attributes provided by PBSL to show how they satisfy the non-technical attributes of ABET educational outcomes?

This paper discusses how the attributes associated with PBSL can be mapped to the desired outcomes of ABET-accredited programs and how these attributes can be measured. First, an overview of PBSL and its attributes are described and connected to the desired, ABET educational outcomes. Then, a possible assessment methodology, based on Sternberg's triarchic theory of human cognition, is introduced as a possible theoretical basis for quantitative measurement of PBSL attributes. A case study performed at Tufts University, is presented that illustrates how this evaluation process, based on the triarchic theory, leads to quantifiable measures of technical and professional skills.

I. Introduction

Engineering education has conventionally focused on developing students' technical skills. Over the last few years, concerns have escalated among many national organizations that technical expertise solely is no longer sufficient. As stated by the American Society of Civil Engineers (ASCE), "The manner in which civil engineering is practiced must change" [(2)]. Engineering education must be restructured to adequately prepare engineers for the anticipated future challenges; globalization, sustainability, complexity, and adaptability. Publications such as the Engineering Criterion 3 (EC 2000) from the Accreditation Board for Engineering and Technology [(1)], *Engineer of 2020* by the National Academy of Engineers (NAE) [(15)], and ASCE's *Body of Knowledge (BOK2)*[(3)] are aimed at revising the current engineering curriculum to shift the existing paradigm of the engineering curriculum towards a more well-rounded education. Although the premise of each report is unique, there is a consistent, resounding theme: the engineering curriculum must be expanded beyond technical skills to develop students' proficiencies in those skills traditionally considered "soft"; i.e. leadership, project management, teamwork, and communication [(5)].

In chartering the *Engineer of 2020* project, the NAE's primary goal was to develop a curriculum framework that would provide engineers with the necessary skill set to "overcome future

challenges" [15]. This combination of skills will require engineers to integrate technical knowledge with practical ingenuity to identify problems and develop solutions. ABET recognized in the late 1980s that "effective preparation for engineers of the twenty-first century practice demanded fundamental changes in the dominant engineering-science paradigm" [17]. In the 1992 annual report, ABET President John Prados challenged the Board of Directors to consider radical revision in accreditation philosophy, criteria, and procedures. Thus, Engineering Criteria 2000 (EC 2000) was developed and was structured similarly to previous criteria, but with the addition of the engineering "professional" skills. Criterion 3 of EC 2000 lists the following outcomes of engineering education [1]:

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs
(d) an ability to function on multi-disciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

II. Project-Based Service Learning

The first step towards broadening the curriculum is to establish those skills which are to be the "outcomes" of engineering education. Creating an extensive equation bank and memorizing problem solving methods contradicts the very nature of engineering. Rather, it is the ability to apply knowledge in formulating creative solutions that epitomizes an engineer. This paper is focused on project-based service-learning (PBSL) as a mechanism that will allow engineering students to find and achieve a balance between technical and professional skills. Project-based service-learning combines problem-based learning with service learning. Problem-based learning is a team-driven process, conceptualized by Hunt (1971) as "a collaborative form of learning in which active construction of coherent mental models of knowledge, rather than simple processing of subject matter, is the focus of the activities"[10]. Service-learning is defined by Jacoby (1996) as "a form of experiential education in which students engage in activities that address human and community needs together with structured opportunities intentionally designed to promote student learning and development"[11]. Thus, PBSL represents a synergistic form of experiential education that has the potential to advance leadership, communication, team-building, and critical thinking skills, while instilling a sense of social responsibility. The developmental processes continually occurring throughout the experience are explained by the cognitive, social, and moral development theories of Dewey [6, 7], Piaget [16], Vygotsky [21, 22], Kohlberg [13], and Kolb [12].

The benefits of PBSL are derived from its pedagogical basis. When properly performed, PBSL creates a problem-centered, educational environment that gives rise to cognitive processes;

combinations of thought and action, reflection and internalization, experience and development. Active team engagement in PBSL projects provides opportunities for knowledge seeking, problem-solving, and collaborating to attain a common goal. While benefits of PBSL are widely recognized by universities across the nation, robust validation and corroboration of this claim are presently lacking [(4)]. The PBSL experience in engineering education results in a unique amalgamation of technical and professional skills that is dependent on the project and the student's involvement. The potential skills attained, aligning with ABET's accreditation criteria, cannot be accurately evaluated via conventional testing methods. This paper presents an alternative set of assessment instruments to measure the benefits of PBSL. The proposed instrument is then implemented in a pilot study to compare the skill sets of students who have had a PBSL experience with those who have had a more traditional, classroom based education.

The triarchic assessment methodology presented in this paper represents a first step towards creating a fuller instrument for PBSL assessment. Although the instrument will be subject to continual revisions and improvements, it provides an initial model for developing an alternative assessment technique that will improve the prediction of post-college success, which will, in turn, help educators to revise the existing curriculum. It is hoped that by broadening the range of skills tested to include both practical and creative skills in addition to analytical and memorization skills (thus proportionately lessening the importance of the latter two on tests), another piece of the puzzle will be discovered in defining which pedagogical methods provide a more well-rounded education.

Our hypothesis was that students who become engaged in PBSL projects enrich their education by enhancing their engineering skill sets; developing new problem-solving techniques; and strengthening the leadership and teamwork abilities that comprise professional skills. This paper presents a proposed assessment methodology - a piloted classroom assessment instrument to measure students' problem solving approaches and the professional skills they employ in reaching a solution. The assessment goal driving instrument design was to explore whether students' technical and professional skills are enhanced as a result of participating in a PBSL project.

III. Triarchic Assessment: Theoretical Justification of Implementation

Sternberg (1996) introduced the "triarchic theory of human cognition," involving a three-part model corresponding to analytical, creative, and practical cognitive abilities[(18)]. In brief, analytical skills encompass the abilities of one to judge, evaluate, compare and contrast, and critique. Practical skills include one's ability to implement, use, apply, and put into practice what they have learned. Creative skills entail the abilities to invent, discover, imagine and suppose [(8, 18)]. According to Sternberg, intelligence is not a function of skill strength, but of one's ability to *balance* analytical, practical, and creative skills in adapting to, shaping, and selecting the environment that best matches one's strongest skills, values, and desires[(18)]. When a person is able to fine tune his or her skills to maximize effectiveness in the most suitable environment, that person has achieved a deepened sense of self-awareness. For Sternberg, this entails (1) recognizing one's own strengths and finding a way to capitalize on the strengths and (2) knowing one's weaknesses and finding a way to compensate or remediate weaknesses [(18)].

Remarkably, the NAE's three main attributes for the Engineer of 2020 overlap the three attributes that Sternberg claims will help students achieve "successful intelligence". As presented in NAE's "The Engineer of 2020", future engineers can overcome obstacles if they are equipped with "strong analytical skills" and "practical ingenuity". The third "indispensable quality for engineering" is creativity, which, "given the growing scope of the challenges ahead and the complexity and diversity of the technologies of the 21st century, will only grow in importance" [14]. Similarly, BOK2, ASCE's document that describes the specific attributes of future civil engineers, builds upon why creativity is essential for the future, claiming "Fostering creative knowledge in students prepares them to handle a future of increasing complexity that relies on a multidisciplinary approach to problems."[3]. Expectedly, ABET leaders have recognized the necessity of innovativeness and problem-solving ability and have also incorporated these skills into the curriculum requirements. ABET's EC 2000 states that "The engineering design component of a curriculum must include at least some of the following features: development of student creativity, use of open-ended problems, development and use of design methodology, formulation of design problem statements and specifications, consideration of alternate solutions, feasibility considerations, and detailed system descriptions" [1].

Similarly, BOK2 regards self-awareness as crucial, especially as it relates to leadership qualities; a leader must be capable of "knowing oneself and seeking self-improvement."[3] Furthermore, the leader must recognize the strengths and weaknesses of the team members and delegate duties accordingly. Sternberg's formula for success, which will potentially provide engineers with the skills they need to overcome future challenges, sparks the question: How can this be taught to, and measured in, students?

Classrooms that focus on "teaching for memory" limit students' learning capacities by reducing the ways in which they can encode new information. Students who have excellent learning skills may not be able to apply them in a classroom setting because their preferred modes of learning do not match the conventional mode of teaching. When students are prevented from experiencing new approaches to learning, the opportunities to discover their own strengths and recognize weaknesses may be lost. Therefore, extracting students from the classroom setting and allowing them to solve complex, real-world problems in teams not only induces creative methods of applying abstract theories, it engenders a new awareness for practicality, constructability, and social impact [8]. Based on the EC 2000 framework, it can be seen that service-learning projects can fulfill ABET outcomes (f), (h), (i), (j), and (k). However, coupled with these claimed advantages of "real world" teaching are the complexities of developing appropriate methods of assessment. The methodology presented herein is a potential materialization of Sternberg's recommended alternative.

IV. Research Design

An assessment instrument derived from Sternberg's triarchic model was used to evaluate and compare the skill sets of engineering students who have participated in PBSL and those who have not. Sternberg's triarchic model, which "can be applied to any subject matter at any grade level" was represented as a set of reality-based open-ended questions, designed to facilitate measurement of analytical, practical, and creative skills. The first component of this effort was an "Individual Assessment" where individual responses were obtained and compared across

PBSL participation status. The results of the comparison were then used to determine whether students who have participated in service-learning projects have developed the skills that comprise the "Engineer of 2020," thereby achieving a heightened level of "successful intelligence". The second component was a "Group Assessment," which involved each member assessing the group's ability to work together by answering a series of Likert scale questions. Below is a brief description of the research method and assessment process. Please note that the research methods are described in detail in previous work [(14)]. This paper will focus on the results from one aspect of the research, namely the group assessment.

***Participants**:* The pilot study, deemed Engineering Challenge Night, consisted of engineering students at Tufts University. Students ranging from sophomore to seniors and from various engineering disciplines were recruited for the event - all on a volunteer basis. In total 44 engineering students, both with and without PBSL experience (PBSL and NPBSL, respectively) participated in this one-time-only event. For students in the "PBSL" category, service learning-type experiences were predominantly in efforts with Tufts student chapter of Engineers Without Borders, as well as with K-12 outreach efforts through Tufts Center for Engineering Education and Outreach (CEEO). Student in the "NPBSL" group had not actively participated in service learning-type activities; curricular or extracurricular, but were likely to have had project-based or problem-based learning (PBL) experience (i.e., PBL is a part of the first-year engineering curriculum at Tufts, but not all engineering majors enter engineering in the first year). Table 1 displays the demographics of the sample. There are two points of note about this set of students: 1) though the male/female ratio was about equal (n = 23 vs 21, respectively), female PBSL students significantly outnumbered male PBSL students (n = 8 vs 3); and 2) relative to their NPBSL student counterpart, the PBSL students were familiar with each other having already worked together on various PBSL projects prior to this assessment event.

Table 1: Demographics of Student Participants in Engineering Challenge Night

Participants of Assessment Study			
	n	% of Gender	% of Total
		Female (n = 21)	
PBSL	8	73	18
NPBSL	13	39	29
		Male (n = 23)	
PBSL	3	27	7
NPBSL	20	61	46

Instrumentation: Two reality-based questions were designed for group assessment. The issues in the open-ended questions concerned either 1) the development of a small lot in an urban setting or 2) addressing issues associated with explosive growth of suburban town. The two sets of parallel questions were of comparable difficulty level and were designed to encourage variety of answers and to discourage students from sharing answers with neighbors or other groups. After responding to their question, the groups were asked to self-assess their efforts. The Group Assessment Form consisted of 3 open-ended questions on leadership, role fulfillment within the group, and challenges faced by the entire group. Each member of the group was then asked to

rate on a Likert Scale of 1 to 5 (1 = Very Poor, 5 = Excellent) his or her perception of the group's abilities to collaborate, communicate, apply abstract classroom theories to new problems, and work together efficiently and effectively.

***Data Collection Procedure**:* From the 44 students, three PBSL groups and eight NPBSL groups were assembled. Group sizes ranged from 3 to 5 members. Other than creating groups with all PBSL or NPBSL students, groupings were randomized - no attempt was made to match gender, ethnicity, academic class/discipline, or PBSL/NPBSL level of experience. Each group was given only one question to answer. Groups were given approximately 45 minutes to complete the question. Upon completion of the group question, each member of the group individually completed the Group Assessment Form.

***Item Analyses**:* The items employed during the in-classroom portion of this research included an instrument to measure technical, problem-solving skills (based on the triarchic model) and an instrument for professional skills (group assessment). The triarchic model instrument consisted of four parallel rubrics that were designed iteratively based on the questions and student responses to facilitate accurate and unbiased assessment of analytical, creative, and practical skills. A rubric scale of 0 to 7 was used (0 = lowest score).

Each rubric detailed the points awarded for answers that demonstrated analytical, practical, and creative abilities. Given the inherent subjectivity of these types of ratings, it was necessary to verify interrater reliability before examining results. A trained member from the Center for Enhanced Learning and Teaching at Tufts University (CELT) used the rubrics to score each student's and group's answer. The interrater reliability showed strong correlations with Pearson-r ranging from 0.88 to 0.99. The second measure of reliability involved verifying that the parallel questions were in fact parallel measures of difficulty and student abilities. Differences in test performance resulting from nonequivalence of questions would reduce the accuracy in results. The distributions of scores for the individual questions and for group questions in all three constructs demonstrated strong correlation coefficients, as shown in Table 2.

Table 2: Summary of Parallel-Forms Reliability

	Q1: Q2 Correlation		
	Analytical	Practical	Creative
Pearson-r	0.76	0.90	0.87

The professional skills instrument (Group Assessment Form) allowed group members to evaluate themselves and each other. Ideally, peer evaluations should be objective, accurate, and fair; however this is rarely a reality [(9)]. There are numerous potential sources of distortion, the most frequent of which are dishonesty or exaggeration. There are additional factors, such as inter- and intra-group competition, that often sway answers. Furthermore, if students don't know their group members well, or if there are personality conflicts (i.e. they do know them or are intimidated enough to give undeserved high scores), the assessment will be skewed. There is also potential for collusion; two students may agree to give each other high evaluations at the expense of the other group members. Although the combination of open-ended and Likert Scale questions will not negate the sources of bias and process deficiencies, it will hopefully minimize them.

V. Results

Table 3 compares the PBSL and NPBSL students for group questions. Since the individual and group questions were on different scales (0 to 5 and 0 to 7), the scores were standardized as z-scores for comparison. The z-score indicates how far above or below the mean a given score in the distribution is in standard deviation units [20].

Table 3: Individual and Group Z-Score Results from Engineering Challenge Night

Group Z-Score Results					
	z Score	Experience	Mean	Std. Deviation	Std. Error Mean
	(PBSL n = 3, NPBSL n = 8)				
Group	Analytical	PBSL	0.66	0.54	0.16
		NPBSL	-0.22	1.03	0.18
	Practical	PBSL	1.04	0.61	0.18
		NPBSL	-0.35	0.86	0.15
	Creative	PBSL	0.96	0.79	0.24
		NPBSL	-0.32	0.85	0.15

Note [1]: PBSL = Students with PBSL experience, NPBSL = No PBSL experience

The results indicate that PBSL students scored higher in all three abilities, as both individuals and groups. Comparing all z-scores indicates that, on average, PBSL students' mean scores were consistently higher than NPBSL students' mean scores, regardless of whether students worked individually or collaboratively. Student responses were then analyzed with a 5% significance level using a 2-tailed t-test, as shown in Table 4. The differences are small in most cases; the only measure that is statistically significant is Group Creative ability ($t(9) = 3.17$, $p = 0.01$).

Table 4: Statistics of Group Analytical, Practical, and Creative Skills Assessment

Summary of t-test for Equality of Means of PBSL and NPBSL Scores										
	Score	Raw Score Mean	Raw Score St. Dev.	t-test for Equality of Means	deg. of free-dom	Sig. (2-tailed)	Mean Difference	Std. Error Diffe-rence	95% Confidence Interval of the Difference	
									Lower	Upper
Group	Analytical	4.18	0.87	1.14	9	0.28	0.76	0.67	-0.75	2.27
	Practical	3.73	0.79	1.71	9	0.12	1.06	0.62	-0.34	2.46
	Creative	2.82	0.75	3.17	9	**0.01**	1.55	0.49	0.44	2.66

Similarly, the differences in PBSL and NPBSL professional skill ability as measured by the Group Assessment show the PBSL students' scores to be higher on all attributes than the NPBSL students. As shown in Table 5 and illustrated in Figure 1, the difference in mean PBSL and

NPBSL scores across all attributes ranges from approximately 0.18 to 0.39; the greatest difference between PBSL and NPBSL students is evidenced in communication ability. However, none of the differences in means achieve statistical significance (all $p > 0.05$).

Table 5: Summary of Professional Skills Statistics

Professional Skills Statistics					
		Mean	Std. Deviation	Std. Error Mean	Sig. (2-tailed)
(PBSL n = 11, NPBSL n = 33)					
Collaborate	PBSL	4.18	0.87	0.26	0.47
	NPBSL	4.00	0.66	0.12	0.54
Communicate	PBSL	4.45	0.82	0.25	0.15
	NPBSL	4.06	0.75	0.13	0.18
Theories	PBSL	3.82	0.98	0.30	0.51
	NPBSL	3.61	0.90	0.16	0.54
Teamwork	PBSL	4.09	1.14	0.34	0.39
	NPBSL	3.79	0.96	0.17	0.44

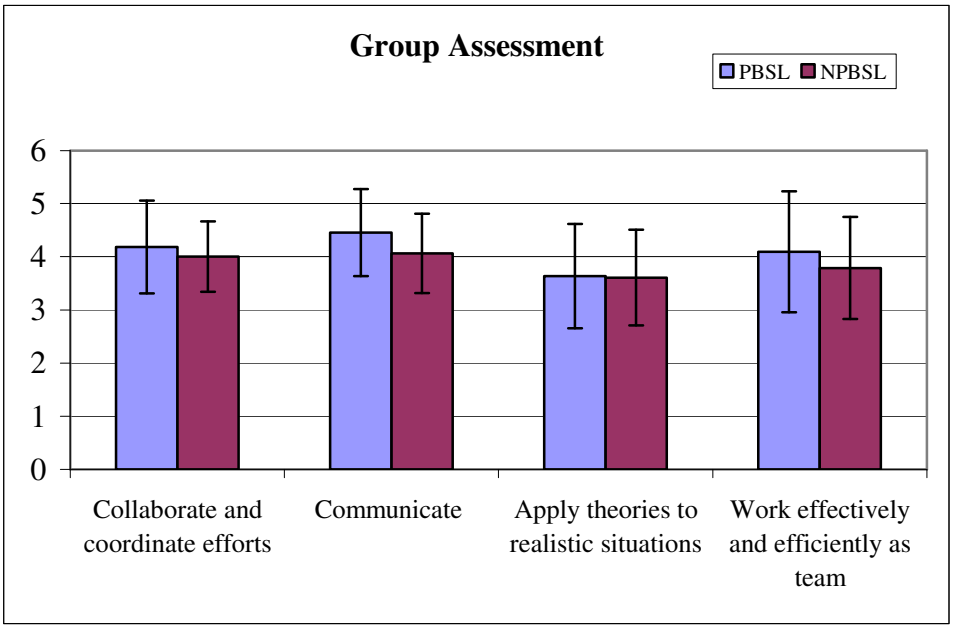

Figure 1 Summary of Group Assessment for Professional Skills
(solid bars represent mean rating, on scale of 1 to 5, from participants; error bars represent ± one standard deviation from mean)

VI. Discussion of Results

This research sought to answer the research question of whether students' technical and professional skills are enhanced as a result of participating in a PBSL project. Comparison of analytical, practical, and creative abilities indicates that there are significant differences in PBSL

and NPBSL groups. Linear regression analyses indicate that the group creative ability is most strongly influenced by students' PBSL experience ($R^2 = 0.527$, $\beta=-1.167$, $p = 0.011$). This result suggests that PBSL students, when working together in a group, are capable of formulating more creative solutions. To further investigate this phenomenon, linear regression analyses were performed to determine if any of the measured professional skill attributes had a strong influence on group abilities. The regression results indicated that the effect of each professional skill on group abilities was not significant ($p > 0.05$); however, the cumulative influence of all professional skills on group score proved to be a strong indicator of group abilities (Analytical $R^2 = 0.238$; Practical $R^2 = 0.397$; Creative $R^2 = 0.368$).

The professional skill abilities of collaboration, communication, theory application, and teamwork as self-assessed by each group member generated statistically significant differences in PBSL versus NPBSL student abilities. The small differences in means are again likely to be a consequence of the size and homogeneity of the sample. The intrinsic biases, such as experimenter and volunteer bias, in conjunction with the small size and homogeneity of the student sample limit the generalizability of the results. Even so, preliminary examination of both the individual and group environment results indicates that this sample of PBSL students have stronger problem-solving and professional skills, and are able to outperform the students who have had predominantly classroom-based education.

It can be inferred that PBSL students' technical (hard) and professional (soft) skills were more advanced than NPBSL students' skills because their out-of-classroom experiences had catalyzed and strengthened development of abilities ranging from cognitive thinking to social interaction and moral reasoning. With each new experience, students learned how to adapt to unexpected environmental constraints and developed the necessary technical and non-technical skills to overcome conflicts. Consequently, many of the students became more self- and globally- aware, recognizing their own strengths and weaknesses, and glimpsing their potential impact as engineers. The PBSL experience is thus an efficacious educational vehicle for students; each participant will forge his or her own path, learning and developing uniquely along the way, but will ultimately all arrive at a shared final destination with an enhanced education in engineering.

VII. Conclusions and Recommendations for Future Work

The goal of this study is to evaluate the educational benefits of skills, both technical and professional, that students attain through participation in project-based service learning. Specifically, this study examined whether the breadth and depth of skills - technical and professional - attained during a PBSL experience spans not only the ABET Criteria, but achieves many of the outcomes proposed by the NAE and ASCE reports, such as adaptability to changing environment, sustainability, globalization, public policy, and project management. A quantitative evaluation was piloted applying Sternberg's triarchic model to engineering students' problem-solving strategies. The assessment methodology used in the study indicated that PBSL can lead to satisfying desirable outcomes, as described by ABET, NAE's Engineer of 2020, and ASCE's BOK2, for the adequate preparation of engineering students for future challenges.

In addition, proper application of PBSL allows students to experience what can be called Dewey's model of experiential learning insofar as PBSL projects will inevitably trigger new

conflicts in real-world situations, forcing students to struggle in a fog of unfamiliarity until, finally, the solution is clear and attainable. According to NAE and ASCE, persevering to overcome the unanticipated is an indispensable skill for future engineers.

Future work will include applying Sternberg's triarchic assessment method to a larger student group. In addition, work should be pursued to evaluate if the method's application should be extended to all of engineering education as a way to quantify the array of outcomes/attributes/skills desirable in future engineers.

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