Effects of Project-based Practice on Self-efficacy and the Pursuit of Engineering Studies

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Abstract: *This research explores the value of Project-based Learning (PjBL) in strengthening aspects of student confidence in their engineering skills (self-efficacy) and their subsequent decisions to major in engineering. The paper provides a brief review of the self-efficacy concept, the growing use of self-efficacy to evaluate changes in engineering competencies, and the role of self-efficacy in predicting persistent career behaviour. Using measures of teaming and technology self-efficacy, we then assess the effects of optional freshman Project-based Learning courses offered at MIT in 2007-2008 and 2008-2009. The results show that these PjBL courses increased student self-efficacy both for working in teams and for using technology, and that MIT students with heightened technology self-efficacy are more likely to pursue a degree in engineering in the following year.*

Introduction

Like many universities with strong engineering programs, the Massachusetts Institute of Technology has given Project-based Learning (PjBL) a central place in its engineering curricula. Depending on their disciplines, most second year engineering students participate in design projects, and all engineering disciplines have a required capstone course during their senior year. While the value of PjBL and undergraduate engagement in practice for upperclassmen is widely supported by the faculty, there are differing opinions about the appropriateness and value of PjBL for first year undergraduates. This paper presents the results from a three year program designed to understand the problems involved in offering PjBL courses to MIT freshmen and assess the educational value of PjBL with special attention to courses with engineering or technology content.

The program began with an experimental year that provided an opportunity for instructors to gain experience with their new courses and allowed for testing the assessment design and measures. This first year's PjBL results were positive, showing gains in students' self-efficacy as assessed by the available measures. The results were set aside, however, because of several confounding effects. Since preparation of a number of the new courses had been rushed, and they might therefore have been less effective, there was a concern that the results measuring their impact might underestimate the value of PjBL. Conversely, a possible source of upward bias was the possibility that educational gains were over-estimated due to Hawthorne or special attention effects that might follow from the students knowing they were part of a new and closely watched initiative.

This paper reports on the results from the second and third years of the program, beginning with a review of the self-efficacy concept and the case for why it is an appropriate measure of practice-based education. The method and results section reviews the levels of student participation in the study, describes the self-efficacy measures that were used, and presents results showing that engineering and technology PjBL courses had a substantial positive effect on the self-efficacy of MIT freshman. The concluding discussion of the analysis offers the further finding that those with higher technology self-efficacy at the end of the year were more likely to elect an engineering major, a decision that is not made at MIT until the start of the undergraduate's second year. The conclusion suggests that PjBL increases specific aspects of engineering self-efficacy, and that higher levels of these forms of self-efficacy are associated with increased student persistence in engineering courses of study.

The Self-efficacy Concept and Assessment of PjBL Education

Self-efficacy has become a central concept in research and program assessment across a vast array of human behaviours. Bandura, the original and leading scholar in research on self-efficacy, defines the concept (1997, 3): "Perceived self-efficacy refers to beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments," where individuals may have different levels of self-efficacy for each of their diverse domains of competence.

A quick search for the word "self-efficacy" in the abstracts and titles in ProQuest found over 9,600 books, articles and PhD dissertations in which self-efficacy is a central concept; it is most often used because it successfully predicts some form of behaviour. While much of the research using the concept is in the fields of health and psychology, it is also a central concept in research on career and professional development. Two reviews using meta-analysis methods to summarize research on self-efficacy support the assumption that measures of self-efficacy predict professional intentions and behaviour. In their review, Sadri and Robertson (1993) conduct a computer search identifying articles relating self-efficacy to work-related intentions and behaviour, and find that self-efficacy consistently predicts work performance. Stajkovic and Luthans (1998) identify 114 studies that used a task performance measure of self-efficacy to study work behaviour. They analyze data on the 21,616 subjects in those studies and conclude that enhanced self-efficacy for the performance of tasks does indeed predict work performance. Career self-efficacy has been used to understand what occupations individuals pursue, and the research shows that adolescents and later young adults form career goals in domains where they have higher self-efficacy (Lent, Lopez, and Bieschke, 1991).

A major line of research in career self-efficacy studies has used self-efficacy to explore why younger students do and do not pursue technically-related careers. Lent, Lopez, and Bieschke (1996), Mau (2003), and Pajares and Miller (1995) are among those who address the role of mathematics self-efficacy among middle and secondary school students in predicting whether students will pursue continuing careers in science, technology, engineering and mathematics (STEM). Mau (2003) notes that a consistent level of math self-efficacy is particularly important because the decisions about math courses made early in the educational process are often irreversible, precluding STEM careers. The literature using the self-efficacy concept as a predictor of the pursuit of engineering careers by undergraduates is also well developed, and in general tends to focus on gender and other background differences. Marra, Rodgers, Shen, and Bogue (2009) and others represent a substantial line of research on the role of gender in engineering education and retention, and Lim, Chua, and Wee (2003) use self-efficacy in the study of at-risk students expected to have difficulty staying in engineering courses of study.

Even more closely related to the focus of this report, there is growing use of highly specific forms of engineering self-efficacy to assess engineering courses. Shull and Weiner (2002), for example, report on a program educating women on computer problem diagnosis and repair with activities organized around the theory of self-efficacy. Grimes, Warschauer, Hutchinson and Kuester (2006) use self-efficacy to study visualization in civil engineering and Kinse, Towle, O'Brien, and Bauer (2008) use self-efficacy to study the ability to perform spatial tasks and its effect on retention for students in engineering.

Predicting change in self-efficacy

While self-efficacy is an excellent concept to organize assessment of any number of engineering educational activities, it is particularly well suited to study PjBL because of its correspondence with the known predictors of self-efficacy. Bandura (1997) suggests that self-efficacy is most reliably enhanced (1) by the performance of tasks; that it might also be influenced (2) by vicarious learning (observing others perform a task); (3) by social influence (being told you can perform a task) and (4) by a change in emotional states (reducing the anxiety one feels when considering or performing a task). Support for the relevance of these four determinants of heightened self-efficacy for engineering is found in Dunlap (2005), Hutchison, Follman, Sumpter, and Bodner (2006), Marra, Rodgers, Shen, and Bogue (2009), Ponton, Edminster, Ukeiley, and Seiner (2001) and Shull and Weiner (2002).

The assumption that these four elements are causes of increased self-efficacy are subject to a number of methodological challenges, as most self-efficacy research in engineering is based only on measures of statistical association. There is, however, a small literature that places the assumption of a causal relationship on a stronger footing. Examples include the use of qualitative collection of undergraduate memories by Lent, Brown, Gover, and Nijjer (1996) who find that, when asked about what has influenced their mathematics ability, most students cited performance that indicated their degree of mastery of the subject. Very few students in the study mentioned vicarious experience or social influence, supporting Bandura's view that task performance is of first importance. More compelling is the experimental research with random assignment to treatment conditions that manipulate and then compare task performance, vicarious learning, and social influence. Luzzo, Hasper, Albert, Bibby, and Martinelli (1999) set up an experiment that compares a group engaging in performance, a group receiving a mixed form of vicarious learning and social influence, and a control group to show that actual performance has much greater effect. This latter work is particularly interesting because it finds evidence of a temporal lag originally suggested by Bandura and Shunk (1981). The lag theory suggests that while self-efficacy changes directly with performance, outcomes such as corresponding interests and career goals that are expected to correlate highly with self-efficacy only change with the passing of time. This result provides a useful warning that program assessment at the end of a course may identify self-efficacy change, but it is to be expected that for a time there will be less or even a lack of change in concomitant outcomes like career interest.

PjBL and the determinants of self-efficacy

By definition, PjBL involves the performance of tasks involved in working with others (Helle, Tynjälä, and Olkinura, 2006), the principal determinant of self-efficacy. PjBL courses might also be expected to provide numerous opportunities for students to observe others performing tasks, be encouraged by them, and have an opportunity to reflect and work through any anxieties about one's competencies. Given that these activities are the factors that predict self-efficacy in a domain, it would seem evident that the successful performance of tasks working as a team should be expected to increase self-efficacy for working on project teams. And similarly, to the degree the PjBL courses involved learning about and applying technology to problems, that PjBL activity should increase self-efficacy for working with technology.

Method and Results

This research uses pre- and post- online surveys taken by freshmen in the academic years 2007-08 and 2008-09. These data were then augmented by attaching the students' later selection of major at the beginning of their second year, the point when that choice is first confirmed at MIT. Of the 2,116 students who entered as freshmen in both the Fall of 2007 and Fall 2008, 87% (N = 1841) completed the Fall pre-tests and 46.5% of that number completed one of the corresponding Spring post-tests. The study thus focuses on 856 who completed both a Fall pre-test and a Spring post-test in their first year at MIT.

Measures

In addition to the selection of an engineering major, the outcome measures used in this study are technology and teaming self-efficacy. The PjBL courses were generally similar in that they relied on the creation of student project teams, and a teaming self-efficacy scale was created to assess that activity by offering descriptions of teamwork tasks and asking students to provide their confidence that could successfully perform them.

The subject matter of the PjBL courses offered to freshmen in this period were quite diverse, including the development of web software, creation of a toy that depended on a scientific principle, design and construction of an autonomous device that could be flown, and work with micro-fluids devices with possible medical applications. Rather than trying to deal with the tasks that were specific to the different courses, the decision was made to measure self-efficacy at the level of working with technology, and the research adopted a technology self-efficacy scale found in Lucas, Cooper, Ward, and Cave (2009). That scale had proven successful in measuring self-efficacy for working with technology in a study of the impact of industry work placements on engineering undergraduates, with a Cronbach's alpha coefficient of .87. That set of set of task items was modified to make them more appropriate for first year undergraduates, and the scale used here yielded an alpha of .91 for the pre-test and .95 for the post-test in the present study.

How confident are you in your current skill and ability to do the following:	***Not at all confident 0%***										***Completely confident 100%***
Sample technology tasks											
Translate user needs into requirements for a design so well that users will like the outcome.	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Turn a technical idea into a practical prototype.	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Design and build something new that performs very close to your design specifications.	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Sample teamwork tasks											
Facilitate a group with members who strongly disagree with one another to a successful project solution.	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Insist that team members contribute what they promised to a project.	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Persuade your team to give up on an approach that you're sure will be unsuccessful.	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Figure 1: Selected items from the technology and teaming self-efficacy scales

Beyond the study's principal variables, several key controls known to be important in various aspects of engineering self-efficacy are incorporated into the analysis. In order to hold constant the effects of academic preparation, we leverage a weighted composite measure used by the MIT admissions office to evaluate academic preparation. The index is a composite of standardized test scores (SAT I, SAT II, ACT), high school GPA and other academic indicators. Gender is included as a binary 0/1 variable with female students coded as 1. In addition, a communication self-efficacy measure ($\alpha = .91$) was constructed and administered for the purposes of a parallel evaluation. Given the traditionally high correlation between various measures of self-efficacy, we include the communication measure here as a control factor that helps to isolate the effects of teaming and technical self-efficacy.

Results

Table 1 presents descriptive statistics and correlations among the variables. As might be expected from the discussion of gender differences above, despite the fact that female freshmen had almost identical levels of academic preparation ($r = -.01$, n.s.), as well as the same level of confidence in their teaming self-efficacy ($r = .04$, n.s.), females entering MIT have lower self-efficacy for working with

Table 1: Measures of relationships among variables
For all MIT freshman with pre- & post-year data, (N = 833)

Variable	*Mean*	*St. Dev.*	*1.*	*2.*	*3.*	*4.*	*5.*	*6.*	*7.*
1. PjBL course, eng. content (1/0)	.19	.40							
2. Female (1/0)	.51	.50	-.04						
3. Academic Preparation Index	4.03	.74	-.01	-.01					
4. Teaming self-efficacy, pre-test	7.04	1.75	.00	.04	-.17**				
5. Technology self-eff., pre-test	6.79	1.79	.03	-.21**	-.07*	.45**			
6. Teaming self-eff., post-test	7.04	1.78	.09*	-.04	-.11**	.52**	.35**		
7. Technology self-eff., post-test	6.87	1.77	.14**	-.20**	-.05	.23**	.54**	.63**	
8. Selected engineering major (1/0)	.62	.49	.24**	-.14**	-.11**	.04	.07*	.04	.08*

* $p<0.05$, ** $p<0.01$

technology (r = -.21, p < .01). Notably there is only a very weak and not significant relationship between gender and the selection of a PjBL course (r = -.04, n.s.), suggesting that female freshmen nonetheless are equally interested in gaining engineering project experience.

Students enrolling in PjBL courses, on average, demonstrated higher levels of both teaming and technology self-efficacy on the end-of-year post-test survey measures. Table 2 presents means, differences and significance test results for the pre-test/post-test comparisons. On the teaming self-efficacy scale, this statistically significant difference represents an effect size of .18. The larger statistically significant difference in technology self-efficacy represents an effect size of .27. The increases in both forms of self-efficacy stand in contrast to lack of statistically significant change in self-efficacy among students not enrolling in PjBL courses.

Table 2: Average self-efficacy scores before and after PjBL
For all MIT freshman with pre- & post-year data (N = 836)

	Teaming self-efficacy		*Technology self-efficacy*	
	Non-PjBL	PjBL	Non-PjBL	PjBL
At pre-test, preceding first year	7.04	7.04	6.77	6.89
At post-test, Spring of first year	6.97	7.36	6.75	7.36
Difference	-.07	.32*	-.02	.47**
T	1.17	-2.30	.22	-3.34

* p<0.05, ** p<0.01

Driven by theory of the impact of self-efficacy on career decisions, we further investigated the relationship between teaming and technology self-efficacy and selection of an engineering major in the third semester (the beginning of the students' second year at MIT). Logistic regression provides a suitable analytic approach for this exploration, as the outcome of interest is dichotomous (our dependent variable is a 0/1 binary variable coded 1 if the student is enrolled as an engineering major) and regression allows for statistical control of other key variables.

Table 3 presents the parameter estimates and standard errors from a logistic model predicting third semester enrolment in an engineering field. This analysis controls for academic preparation as well as for communication self-efficacy (a measure that includes the use of graphics and written as well as oral communications), another dimension of self-efficacy that would be correlated with our outcomes of interest and for which we control in order to more effectively isolate the specific impacts of teaming and technology self-efficacy), higher levels of technology self-efficacy are positively associated with greater probability of majoring in engineering. Specifically, fitted probability estimates from the model suggest that a positive one-point difference in technology self-efficacy is, on average, associated with a four percentage-point positive difference in the likelihood that a student will select an engineering major (when controlling for academic preparation and other forms of self-efficacy).

Table 3: Logistic regression model predicting enrollment in engineering
For AY2008 and AY2009 entering freshman cohorts

Variable	Parameter estimate	Standard error
Academic Preparation Index	-.270**	0.097
Communications self-efficacy (post)	-0.153*	0.071
Teaming self-efficacy (post)	0.031	0.057
Technology self-efficacy (post)	0.174**	0.062
Constant	1.239*	0.531
N	895	

* p<0.05, ** p<0.01

The model further suggests that the higher the student's academic preparation, which would include math performance on the SAT, the lower the likelihood that a student at MIT will select an engineering major, and that the impact of teaming self-efficacy on probability of selecting an engineering major is not statistically significant.

Discussion

The results of this study confirm that enrolling in a PjBL course is associated with statistically significant gains in technology self-efficacy. The data further support the view that among MIT freshman, higher levels of technology self-efficacy are positively associated with increased likelihood of pursuing engineering studies. These findings align with the literature that argues that it is the practice of career-related tasks that increases career-specific forms of self-efficacy, and career self-efficacy increases the likelihood that individuals will engage in behaviour pursuing careers in that same domain.

Equally interesting, teaming and communications self-efficacy and academic preparation either do not relate to an engineering choice or affect it negatively. A possible explanation for the lack of change in teaming self-efficacy for the PjBL courses is that the students did not have an opportunity to perform tasks that were new to them. The teams among the freshmen were small and informal, and most had the same types of experiences that many had seen in high school and elsewhere. Theory suggests that to the degree that the PjBL students did not need to perform at a level higher than they had in the past, no increase in teaming self-efficacy should be expected.

The fact that academic preparation is not a predictive factor is notable because that measure includes the SAT for mathematics despite the discussion above of the repeated finding that mathematics capability and self-efficacy have been repeatedly important in predicting the pursuit of engineering careers (Lent, Lopez, and Bieschke, 1991). This supports the assumption in the PjBL literature that it is practice, not knowledge, which drives career decisions.

Conclusion

The experience of offering PjBL courses at MIT has led to three major findings that are consistent with both the general literature on self-efficacy and prior work specifically on engineering self-efficacy. First and foremost, pedagogies that rely on the engagement of students in engineering practice heighten undergraduate confidence in their competencies that are engaged by the practice activity. PjBL courses that provide practice opportunities for first year undergraduates in teaming and even very simple technical work may be expected to heighten corresponding forms of self-efficacy. Equally important, heightened self-efficacy in the domains of engineering practice increase the persistent pursuit of an engineering education, and may be expected to predict a higher likelihood that the individual will pursue an engineering career.

Looking across past years, attrition at MIT from baseline interest at the beginning of the freshman year to the selection of a major in the third semester has historically been around 23 percent. By contrast, attrition for those students participating in the PjBL courses during this study was approximately 12 percent. The change suggests that offering elective PjBL engineering courses has had an impact on the early persistence of engineering majors, and will increase the number of engineering students graduating from MIT.

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