Using the CDIO Syllabus 2.0 to Assess Leadership Self-efficacy

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ABSTRACT

This paper presents a method of using the CDIO Syllabus as a structure for the development of self-efficacy measures for the assessment of the Gordon Engineering Leadership Program. It begins with a brief review of the increasing interest experiential learning in engineering education, and provides an overview of Bandura's (1986, 1997) self-efficacy concept and his guidance on the development of items that can be considered as a set representing a particular self-efficacy domain. The paper then introduces the MIT Gordon Engineering Leadership (GEL) Program, maps its learning objectives found at the 4th level of the CDIO Syllabus 2.0, and provides examples of corresponding self-efficacy scale items. The third section presents the findings of a pre-test/post-test design that provides evidence for the relative success of the Gordon program.

KEYWORDS

Engineering self-efficacy, assessment, leadership, CDIO Standards: 2, 3.

INTRODUCTION

While this paper focuses on an engineering leadership program at MIT, the broader purpose of this paper is to demonstrate the use of the CDIO Syllabus (Crawley, Malmqvist, Östlund & Brodeur, 2007), and Bandura's view of the concept of self-efficacy to assess engineering programs. What follows first is a discussion of the growth of engineering education courses and activities that include experiential learning, increasing the need for measures that can capture change in engineering competencies instead of focusing on acquired knowledge. The paper then presents a process for developing measures based on the self-efficacy concept, starting with the selection of 3rd and 4th level capabilities that a course or program is expected to improve, and then writing descriptions of more detailed tasks that represent the selected 4th level capabilities.

In engineering education, self-efficacy is becoming more and more appropriate for the study of engineering education because of the growing importance of experiential learning. The forms of the experiences vary. Starting with the ABET requirement that capstone courses with project work were to be required by ABET for engineering seniors, there has been a steady expansion of experiential forms that now reach into all years of engineering education. One version is called Active Learning, occurring, "when a person is actively involved in the learning process and able to experiment with the learning activity using trial and error" (Scheibe, Mennecke & Luse, 2007, 23.) Problem-Based Learning (PBL) tends to place more emphasis on the development of critical thinking (Pan & Allison, 2010), and typically includes student interaction with their peers in the process of working together on complex problems that do not have a single answer (Hmelo-Silver, 2004). Like Active Learning, Problem-based Learning is expected to make material more interesting and engaging, and increase the understanding of material because students find information for themselves and then actively use their skills to complete tasks. Project-Based Learning (PjBL) is similar in that it generally involves problem solving while working in teams, and Dunlap (2005) treats them together describing their many common elements.

Today universities in the CDIO movement and others favoring the PjBL approach stress the value of hands on experience carrying out engineering tasks. Pan and Allison (2010) point out the importance of the design workshop with an emphasis on "design-implement experience" (Young & Hallstrom, 2007, 103). Both PBL and PjBL stress the importance of students being asked to deal with ill-formed problems and complexity, but the PjBL community feels that building some artifact or creating a process has substantially more educational value. An emphasis here is on the nature of the problem to be solved, as PjBL engineering problems may be, "different in that they create additional unanticipated problems, and add considerably to the authenticity of the educational experience (Neal, Ho, Fimbres-Weihs, Hussain & Cinar, 2011).

Self-efficacy and Project-based Learning

While traditional education based on knowledge acquisition continues to hold a central place in engineering education, this movement towards increasing the use student engagement in activities related to engineering practice in education requires new assessment tools. Perhaps one of the best known methods is the use of student self-efficacy because it captures the effects of experiential learning, identifying change in what students believe that they can do, in addition to what they know. The self-efficacy construct can be used to determine whether students see themselves as having greater capability at the end of a course, which generally depends on whether their experiences feel *authentic,* like they were engaged in real world endeavors and not just a learning exercise (Turnbull, 2002). Perhaps most importantly, enhanced self-efficacy in a domain substantially increases the likelihood that students will over time exert effort to develop their skills further.

The decision to use self-efficacy for assessment is based on research that supports a view that self-efficacy relates effective work behavior in general, predicts the formation and selection of what career areas the individual will enter, and specifically predicts the selection and persistent pursuit of engineering careers. At the more general level of work studies, the use the self-efficacy concept is supported by a number of meta-analysis studies showing the predictive power of self-efficacy (Sadri & Robertson,1993), including Stajkovic & Luthans (1998) who investigate 114 different studies of self-efficacy in work environments and conclude:

> First is the understanding that, overall, self-efficacy was found to be positively and strongly related to work-related performance. [These findings] represent something that usually sceptical practicing professionals may rely on with a reasonable amount of confidence." (1998, 255).

The confidence that one can perform the tasks required to pursue an occupation has been found to predict initial interest in a career domain, both in general (Lent, Brown & Hackett, 1994), and for engineering students (Reynolds, Mehalik, Lovell & Schunn, 2009). Other findings in this area of research are that low self-efficacy is a primary explanation for gender-bias in engineering education. The inclination of young women to avoid entering engineering career paths, and the experience that many women who enter but then exit engineering studies despite having equivalent knowledge about math and science to that of men, is largely due to lower self-efficacy (Marra, Rodgers, Shen & Bogue, 2009).

Given the close tie between practice and experiential learning and its subsequent effect on future career behavior, a decision was made to develop an inventory of measures that were first designed to assess engineering education for a number of programs including the Gordon Engineering Leadership Program.

The Gordon Engineering Leadership Program

Founded in 2008, the Gordon Engineering Leadership Program was formed to provide selected students with a foundation of leadership capabilities that would strengthen their contributions to engineering teams, and then enable them to advance over time into leadership roles. Students must be either in their third or fourth year of their engineering major. Over time, the program has grown to include a current level of roughly 100 third and fourth year engineering students who participate in a one year program, consisting of two lecture courses and a two-hour leadership laboratory that extends across both terms.

At the end of the first year, roughly 30 to 35 of the third year students are accepted into a second GEL year offered in their senior second year. They are given opportunities to have a high quality internship in an engineering-based company for the summer, and then they take two more lecture courses and play leadership roles in the laboratories and other activities. A reader interested in other GEL requirements and activities will find information at http://web.mit.edu/gordonhelp/. However, the focus here is on the Gordon Leadership students completing their first year of the program.

The first year of the Gordon program is organized to provide a number of substantial experiences that provide a feeling that they are practicing leadership skills. Now divided into three sections, the students meet once a week for over 12 weeks during the Fall and work in teams of 5 or 6 students. Then in the Spring new teams are created to give the students an experience of learning with a new team.

In each leadership lab the Gordon staff assigns one member of each of the teams to serve as leader for that session, an assignment that rotates so all the team members have a leadership experience two or three times a semester. Each week the teams are given a task representing a different leadership capability such as Negotiation or Critical Thinking that they must practice in and reach a solution in 90 minutes. The teams are usually competing to reach the best outcome, and in a number of labs there will be role players to act as sources of information. For example, the team might be working to obtain permissions for a wind farm and need to negotiate rights from Federal and local officials represented by staff, industry representatives or graduate students.

At the end of each laboratory, there is a period when each team leader is asked in turn to review his or her performance in front of the other teams. Then their respective team members are polled for comments on that leadership. The tone of the student criticism is relatively frank but generally supportive. Then at the end of the lab period, each of the team leaders for that day are taken aside by a member of the Gordon staff and given a form with comments and a private set of written performance ratings. These student leaders are then asked to sign that paper and place a copy in their personal files to be available for reflection on their performance at the end of the year.

Assessment of the Gordon Engineering Leadership Program

The first step in this process for developing an assessment instrument is to specify a series of CDIO elements that represent the capabilities that are being taught in the program. Leadership learning objectives for the Gordon students are found throughout the Syllabus 2.0 as amended (www.cdio.org/files/crawleyetcdiosyllabus2.0) and would include among other skills Critical thinking (2.4.4). Ethics (2.5.1), and Professional behavior (2.5.2), as well as elements in Section 4 like Roles and responsibilities of engineers (4.1.1) and Working in organizations (4.2.4). However for the purpose of this short paper, the focus is on the steps taken to specify the capabilities and their measurement under Teamwork (3.1) and Communications (3.2).

Specifying leadership capabilities to be measured

The tasks the GEL students are more likely to perform that feel like mastery experiences are believed to be found in 3.1Teamwork and 3.2 Communications capabilities. Within those categories (see Table 1, column 1), it is believed that at the end of the first year the primary Gordon student gains in capability would be found in Team formation (3.1.1), Team operations (3.1.2}, Team growth and evolution (3.1.3), Team leadership. Inquiry, Listening and Dialog (3.2.7), Negotiation, compromise and conflict resolution (3.2.4) and Advocacy (3.2.9).

Task writing and the role of specificity. There is a line of research on what is called General self-efficacy that asks about confidence for general capabilities. If applied to engineering environments, it might suggest using a task broadly framed item like "Design a system or product." This approach should be avoided as being less predictive of behavior. The tasks should contain some feeling of the conditions surrounding the task and the elements that might make it easier or more difficult. Bandura's expresses this concern: "In no case are efficacy items disassociated from context and the level of task demands." (1997, 50). More generally, tasks should be written with as much detail as possible (Pajares & Miller, 1995). However, this must be accomplished in as few words as possible. (The author's recommendation is one should limit task descriptions to perhaps 12 or 14 words if at all possible, preferably on a single line. However, experience suggests that to have sufficient specificity it is often necessary to use two lines. One should never break the flow of the task description into three lines.) Otherwise the readers are likely to see and respond to different elements of the self-efficacy statement.

The items describing capabilities used in the Gordon assessment are presented in Table 1, column 2. By following the selected Syllabus categories one can demonstrate that at the top level items are generally representative of the various CDIO activities that are relevant. Within each category, an effort was made to write items as that third year engineering students would understand, and that the Gordon program might be able to influence.

Table 1

Selected Syllabus 3rd and 4th levels with Representative Self-efficacy Items

From the CDIO Syllabus v2.0: An Updated Statement of Goals for Engineering Education. www.cdio.org/files/crawleyetcdiosyllabus2.0

3.1 Teamwork	
3.1.1 Forming effective teams	
3.1.1.3 Team roles and responsibilities	Take time and review the team roles and responsibilities that will be needed to complete a project.
3.1.2 Team Operation	
3.1.2.1 Goals and agenda	Insist that your team members agree on objectives and a work schedule at the start of the project.
3.1.2.3 Team ground rules	Get your team to agree on a process for making decisions and hold them to that process.
3.1.2.6 Planning, scheduling & execution of a project	Make sure your team members stay aware of and deliver on the schedule the team had agreed upon.
3.1.2.7 Solutions to problems (team creativity and decision-making)	When only limited funds are available, compete for and get additional resources for your team.
3.1.2.8 Conflict mediation, negotiation, and resolution	Help two of your team members with a strong difference of opinion reach an agreement.
3.1.3 Team growth and evolution	
3.1.3.3 Skills for individual growth within the team	Give team members constructive criticism that improves their performance.
3.1.4 Team leadership	
3.1.4.1 Team goals and objectives	Set up a process to create a shared vision that captures the essence of the team's project.
3.1.4.2 Team process management	When there are other major demands on your time, still find time to prepare for all team meetings. Step forward and take responsibility for a project activity when others fail to get started on it. Make sure your team members stay aware of and deliver on the schedule the team had agreed on. Get a team to drop an idea innovative idea and use an approach that can be more easily delivered on time.
3.1.4.4 Approaches to motivation (incentives, example, recognition)	Acknowledge teammate ideas at the time they make useful contributions to discussions.
3.1.4.5 Representing the team to others	Briefly and effectively represent your team's vision to outsiders. When only limited funds are available, compete for and get resources for your team.
3.2 Communications ***3.2.7 Inquiry, Listening and Dialog***	
3.2.7.1 Listening carefully to others, with the intention to understand. *3.2.7.2 Asking thoughtful questions of others* *3.2.7.4 Constructive dialog*	Listen very carefully to arguments made by a team member who disagree with you. Ask questions that help others think through and clarify their ideas. Raise critical questions that reveal both strengths and weaknesses of a team member's new idea.
3.2.8 Negotiation, Compromise and Conflict Resolution	
3.2.8.1 Identifying potential disagree-	Recognize when a team argument is a result of differing or unclear assumptions.

ments, tensions or conflicts	
3.2.8.4 Diffusing conflict	Help two of your team members with a strong difference of opinion reach an agreement.
3.2.9 Advocacy	
3.2.9.2 Explaining how one reached an interpretation or conclusion	Persuade a team to give up on a strategy that at the moment only you can recognize cannot succeed.
3.2.9.4 Adjusting approach to advocacy on audience characteristics	Briefly and effectively represent your team's project vision to outsiders.

Given the goal of the study, it seemed prudent to include additional items that are explicitly about leadership. Four additional items have been written for 3.1.4.2 so that analysis could have a number of items to explore whether self-efficacy for when one is a named leader differs from the other tasks. These tasks are intended to be more difficult, such as competing successfully for resources for your team, stepping forward and assuming responsibility, and delivering results on time despite external constraints.

Survey administration. The survey was distributed in the classroom to the three Gordon Engineering Leadership sessions in their first meetings in September 2012, and again in May 2013. The panel contains a total of 66 students completed both the pre-test and post-test

Results

In general, one finds that the Gordon program has had widespread benefits for the GEL students over a period of an academic year. Among the communications-related items, it is found that confidence in these skills has increased. They are more confident in their ability to listen to team members who disagree with them (3.2.7.1) but the amount of change is relatively small (80.3% to 84.7%, $p < .01$). Others under CDIO 3.2.7.2 and 3.2.8.1 showed considerable growth in student self-efficacy. Asking questions to clarify issues rose from 75.6% to 82.6% ($p < .001$), and using questions to reveal strengths and weaknesses of team ideas also increased from 72.0% to 81.4% ($p < .001$). Under negotiation, compromise and conflict resolution, recognizing when a conflict is a result of poor assumptions (3.2.8.1) started relatively low and increased from 69.7% to 78.3% ($p < .001$). Their confidence that they can diffuse conflict (3.2.8.4) increased from 64.2% to 75.2% ($p < .001$). Then self-efficacy for persuading the team to give up on an approach (3.2.9.2) also went up from 64.1% to 72.4% ($p < .001$).

One communications task did not follow this pattern: Self-efficacy for engaging in advocacy by representing the team's project vision outside the team (3.2.9.4) did not change a meaningful amount (77.3% rising only to 81.2%, not significant). The notable difference is that while the other communications activities that involved working within the team showed significant improvement, the one communications item that involved work outside the team did not significantly change.

Table 2: Pre-test and Post-test Results for Communications Self-efficacy

Engineering and Leadership Tasks	Mean	Std. dev.	t	df	sig

e. Listen very carefully to arguments made by a team member who disagrees with you. 3.2.7.1	Pre Post	80.3% 84.7%	1.44 1.32	2.79	65	.01
k. Ask questions that help others think through and clarify their own ideas. 3.2.7.2	Pre Post	75.6% 82.6%	1.38 1.31	3.46	65	.001
b. Raise critical questions that reveal both strengths and weaknesses of a team member's new idea. 3.2.7.4	Pre Post	72.0% 81.4%	1.94 1.14	4.33	65	.001
h. Recognize when a team argument is a result of differing or unclear assumptions. 3.2.8.1	Pre Post	69.7% 78.3%	1.82 1.57	4.09	65	.001
t. Help two of your team members with a strong difference of opinion reach an agreement. 3.2.8.4	Pre Post	64.2% 75.2%	1.83 1.54	4.39	65	001
g. Persuade a team to give up on a strategy that at the moment only you recognize cannot succeed. 3.2.9.2	Pre Post	64.1% 72.4%	2.02 1.55	3.56	65	.001
m. Briefly and effectively represent your team's project vision to outsiders.	Pre Post	77.3% 81.2%	1.78 1.57	1.78	63	ns

The different types of the self-efficacy tasks were interspersed so similar activities would not be side by side. Thus communications item (b) above was separated from next communications item (e).

Forming teams, Team operation, and Team growth. Self-efficacy for many of the remaining tasks showed significant improvement. Acknowledging teammate ideas rose from 79,2% to 86.2% (p < .001), Self-efficacy for setting up an internal process for the team to have a shared vision increased from 65.4% to 76,4% (p < .001), and self-efficacy for being able to listen to criticism of their work – something demonstrated each week in the Gordon labs, increased from 72.7% to 82.1% (p < .001). Other significant self-efficacy increases were found for many of the items, including some that are central to leadership. Giving a team member constructive criticism (70.0% increasing to 79.5%, p < .001). Others leadership activities increased to a more modest degree (For example, competing for funds for your team, 63.8% to 73,2%, p < .01; get a team to set up agree on objectives, 67.1% to 74.4%, p < .05; and show initiative and step forward and take responsibility, 80.5% to 86,2%, p < .05)

The more interesting differences may be what did not change significantly because they tended to be about tasks that were less practiced. There was no significant change in taking time to prepare for meetings when there are major demands on their time (74.1% and 78.5%, n.s.), or to get a team to deliver on time when one has encountered major problems not under the student's control (73.0% to 76.5%, n.s.). When one adds the lack of change in the competency in for presenting a project vision outside the team, it appears that the labs have done somewhat better preparing students for work inside a team than for work in the outside environment.

Table 3: Pre-test and Post-test Results for Team Self-efficacy

Engineering and Leadership Tasks		Mean	Std. dev.	t	df	sig
a. When there are other major demands on your time, still find time to prepare for all team meetings.	Pre Post	74.1% 78.5%	1.70 1.62	1.91	65	ns
c. Acknowledge teammate ideas at the time they make a useful contribution to discussions.	Pre Post	79.2% 86.2%	1.49 1.25	4.10	65	.001

d. When only limited funds are available, compete for and get additional resources for your team.	Pre Post	63.8% 73.2%	2.22 1.84	3.22	65	.01
f. Despite major problems caused by actions outside your control, get a team to deliver results on time.	Pre Post	73.0% 76.5%	1.95 1.44	1.69	65	ns
i. Give a team member constructive criticism that improves his or her performance.	Pre Post	70.0% 79.5%	1.71 1.33	4.68	65	.001
j. If your project requires more of a resource than others think is fair, get them to agree to your taking more.	Pre Post	61.4% 72.9%	2.06 1.46	5.04	64	.001
l. Set up a process to create a shared vision that captures the essence of the team's project.	Pre Post	65.0% 76.4%	2.01 1.52	4.16	65	.001
n. Objectively evaluate strongly critical comments about your approach to your assigned activity.	Pre Post	72.7% 82.1%	1.80 1.33	4.10	65	.001
p. Make firm decisions and take action even though the facts about the best choice are still not clear.	Pre Post	67.0% 79.7%	2.14 1.49	5.26	65	.001
q. Take time and review the team roles and responsibilities needed to complete a project.	Pre Post	73.3% 79.7%	1.80 1.35	2.48	65	.05
r. Insist that your team members agree on objectives and a work schedule at the start of a project.	Pre Post	71.8% 80.3%	1.64 1.67	3.40	65	.001
s. Get your team to agree on a process for making decisions and hold them to that process.	Pre Post	67.1% 74.4%	2.00 1.49	2.56	65	.05
u. Get a team to drop an innovative idea and use an approach that can be more easily delivered on time.	Pre Post	62.4% 75.3%	1.65 1.59	6.13	65	.001

Conclusion

Self-efficacy measurement requires the description of a set of specific tasks representing a well-defined domain of interest, and the task statements must include varied elements of difficulty. There are many sources of ideas one might use for selecting representative actions, but the CDIO Syllabus 2.0 is particularly useful because it can serve as a sampling frame for the areas of activity that should be included, the 4th level of the Syllabus provides useful ideas for the type of task items that could be written, and the use of the Syllabus provides evidence for the future reader that a rigorous approach had been used.

Whatever the area of investigation, the self-efficacy concept can be useful in program assessment for many educational programs and activities, and it is particularly useful for any education effort that includes experiential learning. Such measures are sensitive to change and perhaps more importantly, if self-efficacy changes one can then say with considerable confidence that individuals will invest future effort in areas where they have higher self-efficacy.

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