AC 2007-1407: BUILDING SELF-EFFICACY IN ROBOTICS EDUCATION

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Building Self-Efficacy in Robotics Education

Abstract

While the cognitive and attitudinal aspects of robotics education have been actively discussed in literature, little attention has been paid to the analysis of student beliefs that underlie their learning behavior, self-evaluation, and orientation. This paper reports an educational experiment designed by the authors to promote and evaluate self-efficacy beliefs among members of the Trinity College Robotics Study Team (RST). This team of engineering undergraduates designs autonomous robots for the Intelligent Ground Vehicle Competition and Trinity College Fire-Fighting Robot Contest. In this experiment we focus the instruction on helping students to develop their sense of self-efficacy. RST students' self-efficacy beliefs are studied through pre-course and post-course surveys, observations, interviews, and project assessment. In the paper we report the results of this experiment and, based on those results, propose recommendations for fostering self-efficacy in robotics education.

Introduction

Recent research has emphasized the role of affect in constructivist learning and revised the traditional tendency to explore cognitive processes of science and engineering education in isolation from affective functions. Picard et al. [1] call for "redressing the imbalance between affect and cognition" and "constructing a science of affective learning". This study focuses on developing learning technologies, systems, and environments that incorporate affect.

DeBellis and Goldin [2] in their study of affect in problem-based mathematical learning partition the affective domain into four sub-domains: emotions, attitudes, values, and beliefs. Emotions describe changes in states of feeling experienced by the learner; attitudes describe orientations toward certain emotional feelings in learning situations; values refer to personal commitments that underlie priorities and choices; beliefs are convictions of the truth of specific statements and the reality of certain phenomena based on some evidence.

The learner's mind involves different types of beliefs: foundational, epistemological, and self-beliefs. Foundational believes relate to perception of the context (the world), epistemological beliefs are about the nature, organization, and sources of knowledge, and self-beliefs concern the learner's identity and self-perception [4]. A central role in the study of self-beliefs in learning has the concept of perceived self-efficacy [5]. Accordingly, self-efficacy beliefs are evaluations of the personal capability to successfully complete a task based on validation experience.

Studies in science and engineering education have indicated the following features of students' epistemological and self-efficacy beliefs [6-9]:

- The beliefs can serve as predictors of academic outcomes;
- To learn successfully, students need the goal orientation and the sense of efficacy to use these abilities and skills well and to regulate their learning;
- The students develop (strengthen, diminish or change) their beliefs during the learning process.

Bandura proposed developing the learner's self-efficacy in four directions: mastery experiences, social models (vicarious experiences), social persuasions, and reducing negative emotional reactions. Many science and engineering courses with focus on cultivating students' sense of efficacy in the course subject have been developed and evaluated. The studies indicated that the development of students' self-beliefs is influenced by the culture and context of the learning process [10].

In this connection, the goal of our paper is to characterize epistemological and self-beliefs and their development in a collaborative learning by doing context of team projects in robotics. The paper reports our educational experiment aimed to promote and evaluate self-efficacy beliefs among members of the Trinity College Robotics Study Team (RST). This team of engineering undergraduates designs autonomous robots for the Intelligent Ground Vehicle Competition and Trinity College Fire-Fighting Robot Contest. This educational experiment is based on our almost decennial experience of research collaboration in robotics education [11-12].

Education Design Experiment

This section describes a pilot project—an education design experiment (EDE) undertaken at Trinity College in the fall semester of 2006. The goal was to create mastery experiences and an associated learning environment that can promote development of student self-efficacy following four principles of Bandura, paraphrased below (keywords underlined):

(1) Students gain self-efficacy through successful mastery experiences.
(2) Effective social models (vicarious experiences) encourage development of self-efficacy
(3) Persuasion strengthens students' beliefs about learning success, and
(4) SE beliefs are modified by reduction of stress and negative emotional reactions.

The locus for this EDE is the Trinity College Robotics Study Team (RST), based in the Engineering Department at Trinity College. RST membership includes engineering and computer science students from all four college years. Students may participate in the RST for one or more semesters, and each semester new students join the team and some leave because they graduate or have other commitments. Some design projects last one semester while others continue for one year or more. Sometimes previously designed robots serve as prototypes for new designs. In the Fall 2006 there were 12 RST members, nine registered for independent study credit ranging from one semester-hour to three semester hours; the other four students had full academic schedules and could not elect this extra credit or they were new members who acted as apprentices.

Since its establishment in 1995, the RST has competed in two robot contests, the Trinity College Fire-Fighting Home Robot Contest (TCFFHRC, see http://www.trincoll.edu/events/robot/) and the AUVSI Intelligent Ground Vehicle Competition (IGVC, http://www.igvc.org). Successes in these competitions, including first- and second-place finishes in the TCFFHRC and a fourth-place finish in the Navigation Challenge of the 2005 IGVC, naturally have built student confidence. The RST is divided into project groups, each focusing on a specific robot design. Every member of the RST chooses one or more projects and is expected to report regularly to the weekly RST seminar, which the second author supervises. In the fall of 2006, the team worked on four projects:

(1) A new autonomous land vehicle (named Q). From 2000-2006 this group designed and competed with another IGVC robot, ALVIN. Q is an entirely new design based on an electric racing wheelchair. In the fall of 2006 the group's focus included system architecture, motor control, mechanical design, vision systems, and navigation algorithms. This group numbered eight students.
(2) An improved a fire-fighting robot (DJA-3). Two students repaired and tested this robot, now in its third generation. At semester's end, DJA-3 successfully navigated the fire-fighting maze and extinguished a flame.
(3) Fire-fighting walking robot. Two students developed a walking robot platform and successfully simulated the walking behaviors. The robot will compete in the 2007 TCFFHRC.
(4) Fire-fighting robot swarm. A prototype swarm of eight low-cost ($55/robot) robots competed as a team in the Expert Division of the TCFFHRC in 2006. An improved eight-member swarm is under development by this design group. The group's focus is to improve communication among swarm members, upgrade software, and improve mechanical reliability.

Experimental Methodology

The initial experiment, conducted in the fall of 2006, aimed to improve self-efficacy among RST members by requiring every member to undertake a mastery project exercise. Successful completion of this project would address Bandura's first principle. Another goal was to assess the RST environment in view of Bandura's three social/psychological principles 2-4 above. One premise was that development of area masters would enhance horizontal restructuring of the RST while maintaining the vertical project group structure, enhancing overall team performance. The students were told at the outset that those who succeeded in the evaluation would become area masters who would be called upon by RST design groups for advice and assistance, and that area masters would train other students in mastery areas in succeeding semesters. Student projects were graded on the basis of oral seminar reports, a written mid-term report, and a written final report. Evaluation of the EDE itself was carried out by a post-semester survey.

Pre-semester Survey

This questionnaire asked RST students to reflect on their backgrounds, interests, and confidence levels in robotics and to identify directions for further work. In this way the survey tried to help students to clarify their plans for future studies and careers and to direct their learning towards development of skills and self-beliefs that they would need to implement their plans. The first section of the pre-semester survey asked students to list their post-graduation plans, identify knowledge and skills required by these future positions, express their levels of confidence that they can obtain the intended positions, and describe extent to which their current knowledge and skills prepared them to succeed in the intended positions. This survey also asked them to identify the expected contribution of the RST project experience to the acquisition of knowledge and skills needed for future positions, and it asked them to identify what team organization would best help them to learn.

The results of this survey give insight into student intentions, interests, and levels of confidence. Of 12 respondents, eight indicated interest in graduate study in an engineering field including robotics and six of them indicated interest in graduate study in robotics. Four were interested in jobs, either after completing undergraduate studies or graduate studies, in robotics. Students also indicated interest in graduate study in other fields including nanotechnology, VLSI, and Bio-MEMS, and two students expressed interest in law school.

Then the survey asked students to rate their levels of confidence in response to the three questions below using the following scale: E = extremely, V = very, A = average, W = weak.

(1) What is your level of confidence in obtaining intended positions?
(2) To what degree their current knowledge and skills prepare them for their intended positions; and
(3) The degree to which work on RST projects will help them to acquire knowledge and skills needed for future positions.

The data suggest (in this small sample) that students strongly expect RST projects to help in future positions (Table I). They are somewhat less confident that RST projects will impart knowledge and skills needed to succeed in intended positions and in their confidence to obtain intended positions.

Table 1. Pre-Semester Survey Confidence Levels N=12
(E = extremely, V = very, A = average, W = weak, NR = no response)

Confidence Area	E	V	A	W	NR
Confidence in obtaining intended positions	0	8	4	0	0
Knowledge/skills to succeed in intended positions?	0	7	4	1	0
RST project work helps in future positions	5	4	1	0	2

In order to help students identify personal projects, the second part of survey presented a list of twelve skill areas related to the RST's current design projects. Students were encouraged to add skill areas to the list. The survey asked students to rate each skill area in relationship to four criteria: (1) importance to personal goals; (2) importance to RST projects; (3) level of confidence with work area; and (4) the student's personal priority of each skill area given the individual's goals and the area's perceived importance to RST projects. Table 2 presents the results; observations include the following:

(1) Almost all of the skill areas received average ratings about or above 4 for their importance; these areas were recognized as very important to RST projects. High ratings were assigned also for importance of the areas to personal goals; i. e., the students considered them relevant for their professional orientation. Those seven received an average of 3.37 on the confidence level scale, indicating a moderate level of confidence in the most important skill areas.
(2) CAD-base mechanical design was one of the most important skill areas but had the lowest confidence level.
(3) Students gave teamwork/project management very high importance ratings and the highest average confidence level.

Table 2. Average Ratings of Skill Areas by RST Members, Pre-Semester Survey N=12
(5 = extremely, 4 = very, 3 = average, 2 = little, 1 = not at all)

Skill Areas	Importance to personal goals	Importance to RST projects	Confidence Level	Priority Rating
Sensors and vision	3.75	4.25	3.46	3.56
PCB design	4.08	3.83	2.75	3.56
Navigation	3.58	4.08	3.58	3.56
Software development	3.92	3.92	3.54	3.55
CAD-based mechanical design	3.25	4.25	2.50	3.50
Testing and quality control	3.92	4.20	3.50	3.56
Teamwork/project management	4.42	4.42	3.75	4.22
Communication systems	3.92	3.67	2.83	3.11
Energy and power supplies	3.42	3.75	3.08	2.33
Motors and motor control	3.00	4.25	3.10	3.00
Electronics and interfacing	4.33	4.50	3.73	4.11
Artificial Intelligence	3.83	3.92	2.83	4.00

Post-Semester Survey

Table 3 presents evaluation data about the personal mastery projects including titles, grades, and instructor's comments. The project grade was based on degree of completion and quality of the proposals, mid-term reports, and final reports. Only students enrolled for credit submitted final reports.

Table 3. Mastery Project Titles and Final Grades

Mastery Project Title	Project Grade	Comments
1. PCB Design for Walker	A	Project completed. Strong final report.
2. Intelligence Systems	A-	Proposal & mid-term reports solid. Demonstrated working navigation program.
3. Algorithms for Autonomous Navigation	B-	Shallow comparative survey.
4. SolidWorks Modeling of Swarm Robots	B	Accomplished goals. Trained another student. Weak final report.
5. Team Management and Documentation	A	Fully integrated with design group's work.
6. JAUS Communication Control	B+	Introduces JAUS architecture and design methodology. Report lacks technical depth.
7. Proficiency in Quality Control	B+	Strong suggestions applicable to RST's work. Lacks formal implementation plan.
8. Use of Matlab & Simulink Toolboxes (to detect surface texture)	B	Good start. Requires more analysis and evaluation of test cases.
9. Communication Protocols	B	Short report, non-technical.
10. CMUCam Vision	NR	Project incomplete. Student not enrolled for academic credit.

The post-semester survey asked students to describe their projects and to state the project goals, reiterate the purpose of the mastery project assignment, and rate ten project-related statements (Table 4). The statements reflect student attitudes about the project and allow them to reflect on the mastery project experience. Question 7 indicates an average self-confidence score equal to 3.88 with all responses in the average to highest range. This suggests a generally successful result. We found that, in this small sample, an individual's project grade and self-confidence level were in agreement. Other responses show that students took the project seriously (Question 8) and found the project challenging (Question 3). Some students reported the lack of sufficient time for the project (Question 1) and some gave low scores on the level of completion (Question 2). Most felt able to mentor others in the project area (Question 6) and most felt that the mastery project helped them to reflect on their interests (Question 10). These results suggest some success of this pilot project in promoting self-efficacy through mastery experiences. However, we note negative reactions (related to Bandura's fourth principle) in the responses to Questions 1 (enough time) and Question 2 (project completion).

Table 4. Summary of Mastery Project Survey
(5 = High/strongly agree; 1 = Low/disagree), N=9. "MP" = Mastery Project.

Statement	**Highest Score**	**Lowest Score**	**Average Score**	**Std. Dev.**
1. Enough time to complete MP	4	2	3.25	0.89
2. Completed my MP	4	2	3.25	0.85
3. MP was challenging	5	3	3.88	0.83
4. MP valuable to design group	5	2	3.81	0.84
5. MP motivated study	5	2	4.00	1.31
6. Able to mentor in project area	5	2	4.13	1.13
7. MP increased self-confidence	5	3	3.88	0.99
8. I took this project seriously	5	3	4.13	0.83
9. Had background/skills for MP	5	2	3.88	0.83
10. MP helped me reflect on interests	5	3	4.38	0.74

The post-semester survey provided space for student comments. The following excerpts provide a spectrum of views about the mastery projects.

> The mastery project was very helpful to sharpen my skills with PCB design.
>
> The mastery project is a great idea; it allows for modular design and individual team members to explore on their own.
>
> The mastery project was helpful in developing my skills and interest in the area of image processing. However, my initial goal for the mastery project was too wide. It would have helped me more if those goals were more streamlined…
>
> I think it is a good idea that should be used in the future.

The post-semester survey focused on the effectiveness of the RST as a learning environment that addresses Bandura's three social principles. The survey presented five statements (Table 5) rated on a scale of 1 (lowest) to 5 (highest). Responses to questions 2 and 4, connected to Bandura's second principle (social models), indicated that the RST provided peer models and a constructive social environment. Responses to questions 1 and 3 pointed to a supportive environment in which help from other team members led to success. These latter responses, and the response to Question 10 of Table 4 suggested success in providing students scaffolds for both personal and intellectual development.

Table 5. Summary of RST Learning Environment Survey
(5 = high/strongly agree; 1 = low or disagree), N=9

Statement	Highest Score	Lowest Score	Average Score	Std. Dev.
1. RST provided supportive environment	5	3.5	4.50	0.61
2. RST provided peer models for learning	5	3	4.33	0.71
3. Other RST members helped me to succeed	5	3	4.11	0.60
4. RST offers constructive social environment	5	3	4.11	0.78
5. RST offers challenging environment	5	4	4.56	0.53

We conclude from these data that students view the RST as a challenging but highly supportive, project-based setting in which they gained considerable confidence during the pilot experiment. Negative reactions stemmed primarily from a felt lack of time to complete projects. Student comments below reflect on the RST learning environment as well as the importance of team-based experiential learning at the undergraduate level.

> RST has helped me in building my skills, knowledge and confidence in robotics. The easily accessible assistance from the members and from the instructor, and the weekly meeting to discuss our problems, help a lot in problem solving and designing. In addition to our own interest in robotics, this help and therefore, the inspiration from the team members and instructor have aided us to work enthusiastically in the field.

> RST offers a significant opportunity to work on a substantial project. I learned a lot of new things and diversified my engineering interests. The successful completion of a project, even a small part of a project such as completing an algorithm, helps in the future when faced with similar tasks.

> RST is an incredible opportunity and environment for learning practical real world applications of what we are learning in our classes. It provides experience with working on a team, which is so prevalent in the real world of engineering. I have learned a large number of things while working on robots for the RST that I would have never learned, being an ME, from my required classes.

> RST has been great in offering opportunities for practical and hands-on work as well as self-motivation to get things done and see a project come to fruition. I feel like you can't get this anywhere else and is really a gem opportunity…especially for juniors after coming out of circuit theory and mechanics courses. RST gives this fundamental material immediate context.

> There is a lot of opportunity in the RST for independent and teamwork. My confidence in these types of work has increased since I joined the RST. In terms of skill development, I have acquired knowledge about many new areas such as image processing, motor control, and simulation. There is plenty of opportunity to take leadership positions and learn about team management. Also, RST provides a unique environment to freely exchange ideas and learn from team members. This is very helpful in arriving at solutions to problems.

Discussion and Conclusion

We have described an education design experiment aimed to evaluate and improve self-efficacy beliefs in the Robot Study Team of Trinity College. As described in our Introduction, the foundation for this experiment originates in the theories of affective education and stems directly from the educational theories of Bandura, who enunciated four key principles (mastery experiences, social models, persuasion and scaffolding, and reducing stress and negative emotional reactions) that lead to perceived self-efficacy. A pre-semester survey helped students to identify professional aspirations, identify projects useful to the team, and evaluate project choices. A post-semester survey asked students to rate their mastery project experience and to evaluate the RST in terms of Bandura's three social principles.

During the fall semester of 2006, every RST member undertook an individual project that promoted mastery of a robotics subject important to the team's design work. The goal was to create experts in these subjects who could train other students and lend expertise to all design groups within the RST. The post-semester survey indicated that some students felt that they needed more time for their projects. Other reflections indicated positive attitudes toward the new learning framework—the mastery project—and included constructive suggestions on how to improve it.

> Perhaps more discussion and coordination needs to go into determining a mastery project, whether student wants to develop a new skill or use the mastery project to dig deeper into a particular area that they may be working on for their team projects.

> I feel like a number of members didn't like the mastery idea because it presented more work and writing in addition to the essential project work and development…

> I did not have much if any time this semester to work on things other than the five classes I was taking. I taught another student how to use CAD tools and he is now working with them.

We believe that the pre-semester survey directed most students successfully to a project choice, but that the added workload presented by the individual mastery project was burdensome—especially in the RST environment where students already engage in team-based projects. The team's robot design projects provide mastery experiences consonant with Bandura's principles. However, completed individual mastery projects provide area expertise that can be shared among design groups and applied to the mentoring and training of other students. As a result, we remain supportive of individual mastery projects.

Our evaluation of the RST as an environment for realizing Bandura's three social principles is highly positive. We summarize by addressing each principle below.

1. Social models. The team engages students of all levels of expertise. Experienced students naturally serve as mentors and teachers to the new members. Students meet and work with others who have similar interests in robotics.
2. Persuasion and scaffolding. Within RST project groups, experienced students and mentors provide a supportive framework, or scaffold, and convey expectations of success.
3. Reducing stress and negative emotional reactions. An experienced team that has survived success and failure in robotics projects mitigates stress and negative emotional reactions related to design faults, last minute troubleshooting, and expected failures. Self-selection of projects, weekly presentations, advice from the instructor, discussion within design groups, and shared responsibility by group members also tend to mitigate stress.

From this educational experiment we propose a model for learning outside the regular classroom. While classroom-based instruction remains the *sine qua non* for engineering education, there is room for project-based extra-classroom experiences that engage students of different backgrounds and levels of skill. Such environments promote peer-based learning and mentoring. The RST is an example of such learning outside the regular classroom. In our model, learning is motivated by team projects that focus on engineering design. Design problems naturally suggest mastery project areas. Successful individual mastery projects add to the team's accumulated knowledge base. Time and attention from faculty are necessary for this model's success, and students must earn academic credit for their work. Successful robotics projects require a budget for equipment and materials and sufficient laboratory space.

In closing we emphasize specific characteristics of beliefs and their development in robotics-based education. It is possible to extend Bandura's self-efficacy concept to development of new belief constructs: *team-member-efficacy* and *team-efficacy*. Teamwork is so pervasive in the engineering world that well educated students must gain confidence with working in team environments; this is what we call *team-member-efficacy.* Growth of the team's collective efficacy beliefs, gained through successful team mastery projects and by working in an environment that offers social models, scaffolding, and stress reduction, will help the team to achieve best performance; this is what we call *team-efficacy*.

Also, we propose extending the scope of the self-efficacy study to recognize the close relationship between learning and doing and the interdisciplinary nature of the robotics environment. These suggest studying self-efficacy in relation to different disciplines and in connection with epistemological beliefs.

The RST framework enables students to focus learning activities on acquisition of knowledge and skills which are most important for their intended professional occupations. We believe that in this setting projects can help students to clarify their professional goals and foster development of self-efficacy in future careers.

Finally, we subscribe to the call [2] for further research of affective learning in engineering education.

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