IMPROVING STUDENT LEARNING THROUGH PROJECT-BASED INTEGRATED TEACHING OF ROBOTICS

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ABSTRACT

Feedback from students at the Singapore Polytechnic (SP), obtained from both surveys and dialogue sessions, has consistently shown that many have a preference for more hands on learning experiences. They particularly enjoy practical laboratory lessons, project work, and solving real world engineering problems. Invariably, if students find their learning interesting, even enjoyable, we can make the inferences that they will pay better attention, participate more meaningfully and subsequently better master and achieve greater confidence in their learning. The challenge is to develop curriculum arrangements that consistently employ a more active and experiential learning approach, as well as developing the key understanding of conceptual knowledge both within the subject discipline as well as across important generic skills such as communication and teamwork. This paper documents how we have integrated different areas of our curriculum to provide interesting hands on learning experiences for students in a 3rd year Robotics Option of the Electrical and Electronic Engineering (EEE) program. It specifically highlights key curriculum design features and implementation activities and concludes with a summary of recent feedback from students on their experience of this curriculum initiative and how this has impact our thinking on curriculum integration and future planning in this area.

KEYWORDS

Project-based Learning, Integrated Curriculum, Curriculum Design

BACKGROUND

Students join the SP after 10 prior years of formal studies at the age of 16 or 17. Their academic ability is typically ranked between the 30th to 60th percentiles of their cohort. Given this profile of students, it is perhaps unsurprising that in-house faculty administered surveys, interviews and focus group discussions with our students consistently suggest that they prefer a more practical and authentic learning experience. They cite their favorite modes of learning as mini-projects, group work, laboratory work or assignments that involve conceiving, designing and implementing. Equally, many students raise questions about why they are learning a particular topic or how it can be applied whenever a lesson veers towards being theoretical. Furthermore, and perhaps most disconcerting, is that their learning appears to be compartmentalized and done mainly in silos where little connections are made between one course and the next. This is further confirmed by lecturer's appraisal of student responses to test items designed to assess integration and transfer of knowledge. We are concerned that their content understanding is only partial or situated, therefore inhibiting effective transfer of knowledge to other different but related contexts. The importance of such transfer is well illustrated by McTighe & Wiggins (2000):

> Transfer is our great and difficult mission because we need to put students in a position to learn far more, on their own, than they can ever learn from us. (p.44)

It is for this reason that SP has adopted the CDIO Engineering Education Framework as it main approach to curriculum development and innovation. Particularly pertinent are CDIO Standards 3, 7 & 8, summarized in Table 1 below:

Table 1: CDIO Standards 3, 7, & 8

3. Integrated Curriculum	A curriculum designed with mutually supporting disciplinary course, with an explicit plan to integrate personal and interpersonal skills; and product, process, and system building skills.
7. Integrated Learning Experiences	Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills; and product, process, and system building skills.
8. Active Learning	Teaching and learning based on active and experiential learning methods. (Crawley et al., 2007)

Integrated Learning Experiences

The Program Management Team, in response to concerns outlined above and in alignment with CDIO implementation plans, decided to introduce at least 1 "project course" at each semester of their program. In project courses, students learn new technical content, integrate prior learning and are required to conceive, design and implement projects of their choice as part of the course. These provide a more authentic learning experience and also enable the integration of specific types of thinking and other process skills such as communication and teamwork. Thinking is critical to understanding as Paul (1993) pointed out

> Thought is the key to knowledge. Knowledge is discovered by thinking, analyzed by thinking, organized by thinking, transformed by thinking, assessed by thinking, and, most importantly, *acquired* by thinking. (vii)

However, thinking without knowledge is limited at best, as Resnick (1989) summarizes:

> Study after study shows that people who know more about a topic reason more profoundly about that topic than people who know little about it. (p.4)

For example, in one project course - Microcontroller Applications, students firstly learn the fundamentals of Microcontrollers, how to interface them to different input and output devices, and how to program them. They are then required to conceive, design and implement any project they wish as long as it incorporated a microcontroller. In doing so, they will have to incorporate what they know about sensors and actuators, C++ programming, content form Program Design and Structured Programming courses taught earlier, as well as critical and creative thinking. Project courses such as Microcontroller Applications are consistently well received by students.

Given the positive experience we had with project courses, we decided to pilot something more ambitious with the Robotics Option. The Robotics option is offered to students in the final year of study, and consists of 3 courses - Robotics Fundamentals, Sensors & Actuators, and Robot Programming. Instead of teaching students each course separately in the more traditional explanation method, followed by laboratory experiments to verify theory, and then a structured projects format, we decided to integrate the courses and experiment with a more open-ended project structure.

Students are introduced to 3 very carefully selected robot artifacts and through lecturer facilitation, and collaborative learning in teams, they navigate and integrate the technical content of all 3 courses. For example, they are provided with a Robot kit and tasked to build a robot that can navigate to meet defined performance specifications (e.g., go past obstacles and navigate to a particular destination, etc.). In this process, they will need to learn key content knowledge underpinning the understanding of robot structures, kinematics and dynamics, the set of sensors and actuators that could do the job, and the programming that is required to achieve this task. Furthermore, the project specifications require students to meet certain learning outcomes relating the SP graduate attribute in Teamwork and Communication. Activities are structured into the project process, enabling ample opportunities for students to demonstrate their ability to communicate for different purpose and audiences, develop a range of critical thinking skills (e.g., analyze, compare and contrast, make inferences and interpretation, evaluate) as well as having to take greater responsibility for the learning process.

CURRICULUM DESIGN CONSIDERATIONS

In designing the integrated robotics curriculum, a number of key curriculum planning decisions needed to be negotiated. The following sections outline the salient issues from our perspective and how we approached them:

Integration Models

There are a number of models for integrating course curriculum as documented by Fogarty (2009). In our integration approach, we were especially interested in ensuring that content was appropriately integrated across the 3 courses, as well as the integration of thinking, communication and teamwork skills. As a guide we referred to the work of the *infusion* approach advocated by Swartz (1987) and the *nested* and *threaded* approaches documented by Fogarty (2009). The infusion approach argues that generic process skills such as thinking are best learned through “conceptual infusion” with the subject content. This involves identifying the ingredients of good thinking - “the skills, competencies, attitudes, dispositions, and activities of the good thinker”- and designing these into the structure of the lesson content (p.125). The essential point is that the thinking processes and skills mutually develop the meaningful acquisition of knowledge to form understanding. Furthermore, specific types of thinking can be systematically developed in terms of level of complexity and range of context application over the course duration. The same principle was applied to the naturally infuse and integrate communication and teamwork skills to support the learning of subject content matter from the integrated courses

For example, within the context of the Integrated Robotics Teaching and Learning environment, the following CDIO skills were effectively infused:

a) Defending one's choice of solution or proposal in a range of interpersonal situations
b) Working effectively in both natural and forced teams
c) Presenting project outcomes to different audiences (e.g., peers, academic experts, industry experts, non-technical persons, high school students).

Clarity and Appropriateness of Learning Outcomes

The syllabuses for each of the 3 robotics courses were already developed, and these systematically spelled out the learning outcomes for all 3 courses. As we felt they were clearly written and at the correct level of proficiency, they were left unchanged. However, as we were using a different instructional approach it was important to ensure that the project activities were aligned to the learning outcomes across the courses. This was ensured in large part through a mapping exercise to calibrate each of the courses learning outcomes to the various projects activities. The more specific activities and supporting resources are then aligned to the syllabus outcomes. The broad mapping is shown in Table 2 below.

Table 2: Mapping of Syllabus to Robot Artifact/Project

	Robotic Fundamentals	Sensors & Actuators	Robotics Programming
Robot discovery	History of Robotics; Social and Economic Issues/Impact; Survey of different Robot types	Identify different sensors and actuators; Robotic sensor characteristics	Robotic Software Architecture
Design and build robot	Robotic Standards – Industry & Service; Kinematics	Position & Speed Sensors; Force & Torque Sensors; Micro-Electromechanical Devices; Servo motors	Architecture; Modular Programming; Use of Timers, Interrupts & Polling
Multiple robots	Safety Issues; Robotic Standards; Kinematics; Coordination	Vision Systems; Semiconductor Sensors; Micro-Electromechanical Devices; DC motors (driving & control); Stepper motors	Multithreading; Multi-controller (distributed) programming; Communication Protocols (wired & wireless); Object Oriented Programming; Troubleshooting & Debugging

Robotic Arm and integration	Kinematics; Trajectory Planning	Force & Torque Sensors; Vision Systems; Solenoids & Relays; AC motors	Programming using Simulation; Troubleshooting & Debugging Off-line

Variation of Robot Artifacts, Activities and Learning Contexts

In order to sustain student interest and provide different platforms to deliver the different topics in the syllabuses, it was important to employ a diverse range of robot artifacts and project activities to ensure variation in the learning experience for students. Within the variation of student project activities, the teaching schedule was structured around the following broad areas:

a) Robot Discovery
b) Robot Design
c) Cooperative Robots
d) Industrial Robots

In Robot Discovery, students were given a broad overview of Robotics experiences and were introduced to a wide variety of different types of robots. These included service robots, industrial robots, robotic toys, therapeutic robot pets etc. They would analyze the components of the different robots, disassemble and re-assemble them in order to understand their key operating features, as well as do online research relating to robotic technology.

The second area, Robot Design, involved students being presented with a robot kit set to build and program robots to fulfill several open ended tasks. In the Cooperative Robots segment, students were tasked to design and program a team of robots to perform a task cooperatively. Finally, in the Industrial Robots segment, students were introduced to robots found in the manufacturing industry including robot arms and delivery platforms like Automated Guided Vehicles (AGVs).

Even with different learning platforms and a wide variety of robots to play with, it is still possible to design learning activities that become repetitive. To keep learning fresh, we decided at the onset to make use of a good variety of learning activities and experiences, which included

a) Self-study of core material and teaching each other
b) Researching online and presenting new learning
c) Keeping a blog to build up a personal portfolio
d) Collectively building a wiki to share knowledge
e) Conceiving, Designing and Implementing small as well as more challenging projects
f) Being posed challenges after the basic project has been accomplished for extra credits
g) Learning in a variety of workspaces e.g. in the library, the Robotics project lab and the Robo-Garage.
h) Industry and laboratory visits
i) Showcasing work done in exhibitions and the Singapore Polytechnic Open House
j) Conducting talks and running workshops on robotics for the public

Progression & Differentiation

Throughout the semester, the learning activities were designed to get progressively more complex and difficult. Hence Robot Discovery, Robotic Design, and then Cooperative Robots provide a natural progression with each new learning segment building on the knowledge of the former. Similarly, within each teaching segment (e.g., Robot Design), the activities were also introduced in ascending order of difficulty and complexity.

Also, as students were introduced to many learning activities and were tasked with several projects throughout the semester, it was important to ensure that each task was designed to match the competency range of the average student. We term this a "Goldilocks task", modeling the notion of ideal conditions – essentially a task that is not too easy but not too difficult, challenging but achievable with effort. For students who were weaker, scaffolding material and tutorials were developed to help them. Conversely, more challenging activities were available to stretch more competent students in order to provide a differentiated learning experience whenever possible.

Intrinsic Motivation

Essentially, the overall purpose for the integration initiative is to enhance aspects of the learning experience for student. As outlined earlier, many students do not relate well to more traditional explanation based method, preferring a more active and experiential learning focus. Hopefully this may add to a more intrinsically motivational base for learning, rather than the more instrumental or extrinsic base of grades. Furthermore to add an element of fun and competition to the learning environment, projects are often staged as competitions. For example, students may be tasked to get a team of 3 robots to collect and sort rubbish on a platform within a fixed time. Or they may be asked to move from start to a destination while avoiding obstacles along the way. Competitions can be organized to gauge which team can perform the task best, and prizes given to the winners and the most innovative teams, etc.

In some cases, students can showcase their achievements as exhibitions organized in our library. They can also get involved in publicity shows as SP periodically organizes an "open house", inviting members of the public to see SP exhibits. Some students have gone public themselves by showcasing there work online through the use of videos hosted on social media sites such as YouTube.

Conducive Workspaces

Most of the learning takes place in a specially designed studio called the Robo-Garage. This is a dedicated, flexible and customisable workspace which can be re-configured to meet different teaching and learning needs in the course of the semester Besides being a learning space, the Robo-Garage is also a personal and social space for students to share ideas, hangout, relax and even play. Students are given some flexibility to customise their work area depending on their preference. This is done to foster a sense of ownership for the workspace. It was designed to have the following features:

- Reconfigurable depending on teaching needs
- Accessible 24/7 using a card key
- Comfortable, functional, and friendly
- Conducive for learning sharing of ideas and relaxation
- Located close to Final Year Project Robotics Lab so that exchange of ideas can take place
- Space and storage for personal and project items

Assessment

Assessment drives the learning process, shaping what is learned and how. Ramsden (1992) aptly captured this when he wrote

> From our student's point of view, assessment always defines the actual curriculum... Assessment sends messages about the standard and amount of work required, and what aspects of the syllabus are most important. (pp. 187-8)

Furthermore, research supports the view that students choose their approaches to learning rather than these being the result of innate characteristics or dispositions. For example, Prosser and Trigwell (1998) argue:

> …approaches to learning are not stable characteristics of students. Students *approaches* to learning do change with changes in perception of their learning situation and their perception of it can be changed by…teachers. (p.83)

This is particularly significant if we accept the view that some approaches to learning are qualitatively better than others. Again to quote Prosser and Trigwell (1998) in this context:

> …there are better and worse ways for students to approach their learning – a deep approach being better than a surface approach. (p.7)

The approach to learning advocated in this paper invariably seeks to promote a deep learning approach, focusing on conceptual understanding and complex real world application, involving a range of competencies. However, this poses significant challenges to learner assessment as a result of higher inference assessment. There is much greater subjectivity involved in assessing creative thinking, teamwork and ethical reasoning than more objectively based content knowledge.

Assessment of a range of performance areas within the context of a complex project requires the deriving of clear assessment criteria for of the assessed areas. To reduce subjectivity and improve reliability in the assessment process, rubrics and checklists are drawn up and publicized to students ahead of assessments. Often, all the teaching staff are involved in the assessment of each student.

STUDENT & STAFF FEEDBACK ON THE INTEGRATED ROBOTICS CURRICULUM

Feedback was obtained from both academic staff and students after the first run of the Integrated Robotics Curriculum. For academic staff, sharing sessions were used as a forum for them to share their experiences and highlight areas for concern and future improvement. The following were some key issues highlighted:

a) It is necessary to explain both the "what" as well as the "why" of each learning activity for the students to benefit fully from them
b) It is important to scope each learning activity more tightly rather than to leave it open-ended. Much anxiety and increased workload was created by the open-endedness of original projects and assignments because students tended to over produce
c) The learning outcomes of each activity must be properly articulated and documented, and be made known to both students and teaching staff. It is easy to get lost amidst all the active learning activities. Debriefing sessions after each activity are vital.
d) Teaching is enriched by the many ad-hoc teachable moments which naturally emerge in the course of the semester

For students, feedback was obtained from a survey conducted at the end of Term 1 and an informal discussion forum organised at the end of Term 2. The data is collated and analysed in order to ascertain student's experiences in a range of areas, as identified in Table 3. The Term 1 survey consisted of 3 parts which asked students about the following:

- Whether our option and course aims have been achieved (Outcome Based Questions)
- Whether there were any logistics & administrative issues (Administrative Questions)
- What they taught of this new way of Teaching and Learning

The first 2 parts used the Likert Scale, while the 3rd comprise open response items. A summary of the survey results is shown below:

Table 3. Survey of Robotics Option - Outcome Based Questions (n=15)
(Strongly Agree (SA), Agree (A), Neutral (N), Disagree (D), Strongly Disagree (SD))

	SA	A	N	D	SD	
	5	4	3	2	1	**Mean**
I am clear about how each of the 3 courses is relevant to the area of robotics	3	12	0	0	0	**4.200**
I see a strong link between the 3 courses	5	9	1	0	0	**4.267**
I am better able to retain the knowledge learnt	4	9	2	0	0	**4.133**
Learning is now more interesting	6	7	2	0	0	**4.267**

I have been given opportunities to work in teams	6	7	2	0	0	**4.267**
I have been given opportunities to improve in my interpersonal skills	5	7	3	0	0	**4.133**
I have been given opportunities to communicate my learning, ideas and thoughts	5	8	2	0	0	**4.200**
I have been given opportunities to work in a multi-disciplinary environment	4	9	2	0	0	**4.133**
I am now more confident in taking up challenges	2	12	0	1	0	**4.000**

Table 3. Survey of Robotics Option - Administrative Based Questions (n=15)
(Strongly Agree (SA), Agree (A), Neutral (N), Disagree (D), Strongly Disagree (SD))

	SA	A	N	D	SD	
	5	4	3	2	1	**Average**
I am clear about the purpose of each teaching block	3	7	4	1	0	**3.800**
The robots and tasks assigned makes sense to me	1	9	4	1	0	**3.667**
I am clear about the instructions given for each exercise/assessment	3	6	5	0	1	**3.667**
I understand clearly what is expected of me during assessments	2	7	5	1	0	**3.667**
The teaching of the 3 courses is well organised	2	9	4	0	0	**3.867**
The teaching materials available for each of the 3 courses is satisfactory	1	12	1	1	0	**3.867**
The teaching sequence makes sense to me	2	11	2	0	0	**4.000**

The open response section of the survey asked the following questions:

1. What do you like best about this method of teaching?
2. What do you like least about this method of teaching?
3. What can be done to improve your learning experience?

Typical responses to the first question about what they liked best included “More hands-on experiences make learning interesting”, “Able to see application”, “Able to work in groups and gain hands-on experience”, “A lot of practical work”, “We are able to communicate our learning, thoughts and ideas”. An active and experiential learning approach featured strongly in the responses.

The responses to the second question about what they liked least included “Too little time given for project”, “Too little information given in some projects”, “Some projects were too difficult”, “No clear direction set”. Many of these comments squared with the need to better define what is required from each project rather to leave it open-ended as articulated by teaching staff.

Responses to the third question about what can be done to improve the learning experience were more varied. They included “Plan out the course map more clearly to show how projects link to course syllabus”, “Give more time for projects”, “Allocate more lessons on Robot Programming”, “spend more time on other robots rather than BIOLOID” etc.

It is heartening to note that students scored most of the outcome based questions favourably, hence supporting the essential purpose and approach underlying the curriculum initiative. However, it is clear that a number of administrative issues addressing to enhance the learning experience for more students in future. In particular, issues like giving clear instructions, being clear about the assessments and organisation of each course needs to be addressed promptly.

SUMMARY: OPTIMISM WITH CAUTION

In summary, based on the overall feedback obtained, we are optimistic that the pilot run was worthwhile from a pedagogic perspective. It has certainly gone some way to meeting student learning preferences for a more hands on or authentic learning. Our experiences are consistent with Chickering and Gamson’s (1987) frame, when they argued:

> Learning is not a spectator sport. Students do not learn much just by sitting in class listening to teachers, memorizing pre-packaged assignments, and spitting out answers. They must talk about what they are learning, write about it, relate it to past experiences, apply it to their daily lives. They must make what they learn part of themselves (p.3)

It remains to be ascertained as to what extent these graduates actually demonstrate a notable higher level of proficiency in such skills as critical thinking, communication and teamwork, etc., in other contexts (e.g., work, university, etc.). This would require further research at some later time.

On a more cautionary note, the approach has been more resource intensive, both in terms of faculty time and learning support facilities. Also, it is challenging to ensure full coverage of curriculum learning outcomes as well as giving all students adequate time for project completion. It requires the curriculum designers to be very clear about the core knowledge required (key concepts, principles, procedures, etc.); the must know rather than the “good to know”.

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