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Advancements in Using a Machine Design Project for Teaching Introductory Electrical Engineering

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Abstract—Project-based learning is commonly used in teaching electrical/electronic engineering content. This paper analyses a proposed course that used a Rube Goldberg machine design project for introductory electrical engineering teaching. To facilitate students’ learning, two main enhancements of the original course development are described: i) a refurnished project vehicle and new curriculum-framing questions have been proposed to assist students achieving the course’s learning outcomes, and ii) tools for idea cultivation, design progress monitoring and design/learning collaboration technologies have been proposed to assist students to direct their learning.

Keywords—Rube Goldberg Machine; electrical engineering education; project-based learning; curriculum-framing questions; checklists; introductory engineering; e-learning

I. INTRODUCTION

Recently, design training, student learning process and technologies have been introduced to reshape the scope of engineering education [1], [2]. Because of the reformulation, project-based learning has been proposed to assess students’ competence in multiple perspectives, as well as to encourage students participation [3]–[5]. In other words, through project based learning, students learn to acquire technical knowledge, collaborate with peers, solve open-ended problems, without clear definitions, and apply new content understanding with greater flexibility. For example, CDIO (Conceive-Design-Implement-Operate) framework has been proposed to integrate the learning of a comprehensive set of personal and interpersonal skills, in addition to technical design skills with disciplinary knowledge [5]. At the same time, project based learning has also been adopted in different electrical engineering courses [4], [6]–[8].

Recently, because of the innovative, humorous and unconventional project vehicle, an introductory electrical engineering course with a Rube Goldberg Machine design project was introduced [9]. It proved to trigger and retain student motivations to learn engineering concepts. It also showed that through the project, students had acquired technical knowledge and also had developed generic skills. However, various aspects of the project vehicle as well as tools for guidance of students’ learning have not been investigated thoroughly. As a result, instructors cannot direct students to the appropriate pedagogical steps for achieving the desired learning outcomes. Thus, teaching effectiveness can be undermined in the student centered learning process.

In this paper, we present a panoramic view of this recently proposed course in relation to past work and some of the recent developments. In particular, a refurnished project vehicle (Section II) and curriculum-framing/probing questions (Section III) have been proposed to assist students achieving the intended learning outcomes. Meanwhile, tools for design/learning collaboration (Section IV-A), idea cultivation (Section IV-B) and design progress monitoring (Section IV-C) have been proposed to assist students in directing their learning and hence to learn effectively and efficiently. The purpose and process of each adopted technique are explained in each section, and are elaborated by evaluations and further discussions (Section V).

II. FACILITATION VIA THE PROJECT VEHICLE

Broadly speaking, the Rube Goldberg Machine can be defined as “a machine designed to perform a very simple task in an overly complex way” or “a comically involved, complicated invention, laboriously contrived to perform a simple operation” [10]. Technically speaking, the Rube Goldberg Machine can be defined as an intuitive and loosely conceived engineering system. In particular, the Rube Goldberg Machine is a device that has at least four distinct stages with its own triggering mechanisms. In addition, the machine begins when a button/switch is pushed, and ends when a balloon pops. At any particular stage, an electrical sensor is triggered by an external mechanical input. The sensor then switches on the electrical actuator(s) through relay buffers. Finally, the electrical actuator moves some mechanical parts, which trigger the electrical sensor in the next stage.

Pedagogically speaking, the Rube Goldberg Machine design project can be used to trigger and maintain students’ motivations in learning because of its innovative, humorous and unconventional nature. Furthermore, Rube Goldberg Machines are usually constituted of daily life objects, and thus the design project creates a friendly environment that encourages intellectual engagement of students. Moreover, the Rube Goldberg Machine project contributes to two primary learning events: i) to gain students attention, and ii) to stimulate students’ recall of prior learning. According to Gagnes instructional theory [11], for learning to take place (i.e. learning to design their machines efficiently), primary learning events must be accomplished first. Therefore, the Rube Goldberg Machine is a suitable project vehicle for teaching introductory engineering concepts.
III. FACILITATION VIA CURRICULUM-FRAMING QUESTIONS

Engineering students should be able to apply technical knowledge, design a system to meet desired needs within realistic constraints, and function on multi-disciplinary teams. Besides setting learning outcomes, asking critical probing questions is an effective way to promote students' interest, high order thinking, self-motivation and understanding, as well as to assist students in achieving some intended learning outcomes. Thus, a Curriculum-Framing Questions framework [12] has been adopted to formulate probing questions.

A Curriculum-Framing Questions framework is usually made up by an essential question, a few unit questions and a few content questions. By exploring those constructed questions throughout the project, students can address concepts at different levels, from general engineering ideas to specific technical knowledge.

An essential question is open-ended and usually explores concepts throughout the project. It often helps students see how different topics in the project are related. In this project, one essential question has been prepared:

- How to design an (complicated) electrical system?

Unit questions are also open-ended but frame a particular concept and essential questions. They can help students demonstrate how well they understand the core technical concepts they learned, and build understanding for the essential question. In this project, one unit question has been prepared:

- How do we (as a team) build a multi-stage Rube Goldberg Machine that is functional and creative?

Content questions are those that convey factual information, and support the essential question and also the unit question(s) by providing a focus of learning. In this project, six content questions have been prepared:

- How do you describe the stages that are involved in the machine?
- How do you describe the electrical components (e.g. sensors and actuators) in the machine?
- How do you demonstrate your skills of technical design and implementation?
- How do you frame, analyze and synthesize information in order to solve problems?
- How do you demonstrate your ability to work effectively with diverse teams?
- How do you demonstrate your originality and inventiveness?

IV. FACILITATION VIA NEW LEARNING ACTIVITIES

A. Collaborations through Social Networks

In order to facilitate teacher-student communications within the class, a friendly and interactive student learning community has been created in a dedicated course profile within a social networking site (i.e., Facebook (FB) Page) [13]. It provides a prompt and convenient channel for course announcements, giving feedback and provoking discussions. Furthermore, it is also convenient and free to share videos, photos and teaching materials using the platform and its inbuilt open RSS feed. In addition, it is convenient for students to see updates which show up on news feed that they check often. Meanwhile, because of the open nature of the platform, students can observe progress of other groups’ projects, thus encouraging project participation.

B. Idea Cultivation

This activity can also be classified as a self-directed learning and product-oriented learning. Through it, students can creatively connect prior knowledge and new possibilities to formulate the project theme and triggering mechanisms, before the project implementation, and with their groupmates.

In the first stage, students were asked to include outrageous ideas or ideas that expand on their past daily and technological experience without restrictions. In the second stage, in order to formulate the thinking process in a comprehensive perspective and inspire innovative triggering mechanisms, the following instructions have been given to students:

- Collaboration (i.e., demonstrating ability to work effectively within teams)
  - Develop a project theme: Christmas? Theme park? Dragon adventure?
  - Set a common goal: Distinction? Credit? Pass?
  - Hold a weekly group working session
  - Set a schedule and milestones

- Creativity (i.e., developing and implementing original ideas)
  - How to push/pull/rotate the object?
  - How to trigger the sensor? What is the consequence of triggering the sensor?
  - How to pop up the balloon? When the balloon is popped?

- Problem solving (i.e., framing, analyzing and synthesizing information in order to solve problems)
  - Identify allowed resources: Components, time, skills, number of stages
  - Design and evaluate some triggering mechanisms: Robust? Fancy? Difficult to implement? Difficult to connect with other stages?
  - Is the design practical?
  - Any (easier) alternatives if the proposed triggering mechanism fails?

At the end of the session, students were asked to report some ideas that discussed.

C. Progress Monitoring

Checklists can continuously assist students to systematically record the design process and efficiently identify thinking processes by type, location and cause. It can help students to view problems as stages of challenges/tasks and desires of changing, as well as to promote self-directed learning by maintaining students' attention. Through the self-
In the project, six checklists have been designed. They have been used to assess generic skills (i.e. collaboration, creativity and problem solving), as well as project design process (i.e. project planning and project implementation). An example of a checklist for assessing project implementation is shown in Table I. Checklists are distributed to students who are instructed to repeatedly consult the checklist throughout the experiment process, so that they can understand the criteria for an effective and successful design. In other words, students use checklists to systematically reflect on how well they use thinking skills (creativity, problem solving and collaboration) in the project, and eventually apply these skills in the later design stage. Furthermore, students can efficiently monitor their project planning and implementation.

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<th>Action</th>
<th>Consistently/ Usually/ Rarely</th>
<th>Dates</th>
<th>Observed Details</th>
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<tr>
<td>I identify the situation of the project.</td>
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<td></td>
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<tr>
<td>I formulate the problem with assumptions and constraints.</td>
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<tr>
<td>I propose more than one strategy to solve the problem with different tradeoff.</td>
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<tr>
<td>I choose an appropriate strategy according to the situation and resources.</td>
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<tr>
<td>I show work clearly and skillfully.</td>
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<tr>
<td>I justify the solution with adequate testing.</td>
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<tr>
<td>I plan and revise for improvements.</td>
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<tr>
<td>I see relationships among different engineering concepts.</td>
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<tr>
<td>I generalize processes to other design situations.</td>
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V. EVALUATIONS AND DISCUSSIONS

A survey analysis is used to evaluate the integration of the project. Open-ended feedback comments from students and instructors have been collected. The enrollment for the course was 140 students in the investigated semester. Among these students, 108 students have returned the survey; therefore the response rate was about 77%.

A. Student Works

An example of student works is shown in Fig. 1. Students have used “Christmas Tree” as the project theme. In this machine, contact switch, button switch, reed contact switch and other sensors have been used for stage sensing. In particular, students have used a rotary potentiometer as a rotation sensor to control the motor. Meanwhile, an electrical fan, solenoids, electrical motors have been used as actuators in the project. In order to perform delay/timer functions in the project, students have used reed relays to construct a timer circuit, based on the experiences gained from a pre-project laboratory exercise. A close up of the project is shown in Fig. 2. The figure shows that the circuit is neatly and skillfully implemented. For example, students have labeled the most critical project components and have firmly assembled the structure of the machine by joints. In summary, the work demonstrates the creativity, problem solving, and implementation skills of students in the group.

Fig. 1. A Rube Goldberg machine designed and implemented by students.

Fig. 2. A close up of a Rube Goldberg machine designed and implemented by students.

B. Enthusiasm of Students

From what we have seen from the feedback in the laboratory, more than half of the students were enthusiastic with the project, and thought that the project was full of fun, challenging and able to give students a great sense of achievement after they have built the Rube Goldberg Machine. On the other hand, a number of students felt that the project was time-consuming and the workload was heavy, and thought negatively towards the project. The disagreement between these two groups of students is quite serious. Therefore, the project should be reconstructed to encourage further students participation. In addition, we believe it is important to continue to use the social networking technologies as facilitation tools to arouse students enthusiasm of designing the machine and studying the course.
C. A Priori Technical Knowledge, Generic Skills and Self-Reflection of Students

Although pre-project laboratories and tutorials for students have been provided, from what we have seen in experiments, students often broke electronic components down. This may be because students’ knowledge on the components was not thorough enough, or they were not familiar with the mechanisms of how the components work. Although breaking of components is inevitable, a large amount of unwanted accidents can be avoided if they know the working principles of the components. Therefore, we need to raise students’ awareness through tutorials. Furthermore, most students did not have skills of design and collaboration in the beginning of the course, because this instructional method was new to them. Therefore, we will provide mini-lessons for them before the project in the future. Furthermore, we can reveal students a prior knowledge and create students learning atmosphere through pre-project and post-project assessments. Examples of probing questions are shown as follow:

- What do you already know about electrical systems? (Pre-project)
- What do you wonder about the design of electrical systems? (Pre-project)
- How will you demonstrate problem solving, creativity and collaboration skills in your project? (Pre-project)
- What have you learned in the Rube Goldberg Machine design project? (Post-project)
- How have you learned in the Rube Goldberg Machine design project? (Post-project)

Besides probing questions, examples of new self-reflection questions can be proposed:

- What was the most important concept you learned about i) systems, and ii) timer circuits? How did you learn those concepts in the project?
- What problem solving and collaboration strategies did you try? What worked well and what did not work so well?
- Based on your learning and experiences from your previous work, please list out three problem solving strategies that you will try in future design processes?

For each answer, students will have to give specific examples to illustrate their thoughts.

D. Technology Facilitation

We have also evaluated the effectiveness of the Facebook (FB) Page (the social networking platform) [13]. Results show that FB Page promoted a strong communication and collaboration environment. In particular, not only students and teaching staffs visited the project site, but also friends of the community and observers from other faculties. Therefore, it has developed a virtual space for collaboration and learning. Furthermore, we can observe that social objects, such as tagged photos and videos as well as “Like”s and comments from the peers, can encourage students to participate activities.

In the near future, we will explore more technologies that can enhance student learning experience. For example, we will fully adopt a wiki-based forum to develop virtual spaces for the increased involvement of students, potential employers and community partners in the learning process. Furthermore, a cyber-physical system has been developed recently to be installed for laboratory environment regulation [15], in order to improve the efficiency, reliability, comfortability and safety of the project implementation process.

VI. CONCLUSION

In this paper, we have reshaped the project-based teaching component in an introductory electrical engineering course. In particular, a variety of new teaching instruments, such as curriculum framing questions, idea cultivation sessions, process checklists and Internet technologies have been introduced to the existing course, in order to improve the effectiveness of achieving its learning outcomes.

REFERENCES