Integrating Activities-, Project- and Problem-Based (APPB) Learning into Introductory Undergraduate Electronics Coursework

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Abstract

Traditional freshmen-level electronics courses cover a broad range of topics frequently interweaving theory and practical applications. As part of classroom and laboratory activities, it is important to provide students with opportunities for integrating their skills within a meaningful context. In this paper, we illustrate how concepts drawn from the Project Lead the Way (PLTW) curriculum can be integrated into introductory electronics courses for strengthening student learning. PLTW courses are based on an activities-, project- and problem-based (APPB) learning model. This enables students to make effective connections between various sections of a course. The APPB learning strategies were adapted for developing a personalized mini-project in an introductory undergraduate electronics course. Following various in-class and laboratory activities regarding various electronics topics, students worked in groups for construction and customizing a split voltage power supply project. The project also included elements of specific real-world problems: adding custom safety interlocks and personalized displays in the design. This made constructing the supplies fun for the students and judging consistent for the instructor. Anonymous surveys of the project experience indicated that the students had ample opportunities for making important decisions about their project and that their confidence regarding working with electronic systems grew significantly. Integrating the APPB learning approach strengthened students' understanding of the core content and essentials skills by building a tangible electronic device. Students used the completed power supply in subsequent portions of the course. Some students also used the power supply in other electronics courses, and for outside electronics hobbyist projects. Students continued to build on their understanding through the semester. The personal stake that students had in the project was a motivating factor in its success. The paper also discusses the challenges faced in adopting the APPB approach. These challenges include finding the time needed for completing student projects, while covering the topics required in a typical electronics course. Suggestions for addressing these challenges and organizing classroom materials around projects and problem solving are provided.

Introduction

Instruction in engineering- and technology-oriented fields is aimed at developing problem solving, critical thinking, technical, and communication skills. In-class and laboratory

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activities, as well as course projects, should be used for developing students' abilities to design, implement, experiment, test, and troubleshoot systems. Alberts [1] points to the acute need for redefining science education, stating, "Rather than learning how to think scientifically, students are generally being told about science and asked to remember facts." The ASEE Engineering K12 Center [2] report suggests ways for improving education in schools and in outreach, including

- an increased emphasis on hands-on (context based) learning activities
- adding an interdisciplinary flavor in all subjects by including technology components
- developing math and science curriculum based on state standards

Bybee, adapting the National Research Council framework elaborating on science and engineering practices, states that there is a need for "Asking questions and defining problems; Developing and using models; Planning and carrying out investigations; Analyzing and interpreting data; Using mathematics and computational thinking; Constructing explanations and designing solutions; Engaging in argument about evidence; and Obtaining, evaluating, and communicating information" [3].

Geeter, Golder, and Nordin [4] regard development of "problem solving skills, critical thinking skills, interpersonal skills, personal responsibility, time management, and creativity," through team participation in hands-on projects as being important for engineers of the future. By encouraging students to develop their own theories and solutions, this approach attempts to harness the inherent curiosity, imagination, and creativity of students and thereby enable them to visualize alternatives and solutions. Making the learning process more meaningful to the students is a challenge. Students also need to learn about different criteria, such as safety, benchmark testing, costing, and other standards that are needed while determining the optimal solution for a technical problem. At the same time, instructors are faced with a dilemma about covering the content without sacrificing student interest.

Wiggings & McTighe [5] in their groundbreaking work, use a "backward design" process for actively engaging the students, so that they might discover ideas for themselves. This starts out by identifying the results or competencies instructors want to students to have, then determining the evidence that will indicate that the competency has been achieved. After setting the goals, the instructor plans the lectures and classroom activities that will steadily build necessary student competencies. For demonstrating true understanding of the subject, Meier [6] elaborates on the backward design strategy. She states that students should be able to explain, interpret, apply, have perspective, empathize, and exhibit self-knowledge. Addressing core questions of a subject will move students towards increasing competency and enduring understanding. In a related work, Bransford, Brown, and Cocking [7] state that significant transfer of learning has been observed by first having students work on sample scaled down problems, supplemented by lecture, prior to working on more complex problems. Alper, Fendel, Fraser and Resek [8] underscore the importance of having students see "mathematical structure in real-life" situations.

Project Lead the Way [9, 10] brings together several of these ideas in strengthening students critical thinking, technical and communication skills. PLTW is a non-profit organization that has pioneered a unique science, technology, engineering, and mathematics (STEM) curriculum for middle and high schools in the United States. Over three thousand schools and half a million students participate in the PTLW program, providing a launching pad for future engineers and technologists. Johnson [11] points to successful partnerships that have been forged between public schools, institutions of higher education, and the private sector. PLTW uses the APPB approach for making STEM content more relevant from the students' perspective. Students perform activities while building the essential knowledge and skills needed for solving class projects derived from real-world devices and systems. Students synthesize knowledge for dealing with the complexity the problem presents. They develop their own solutions for problems that arise while working on their projects. This requires students to form new connections between the materials they have learned through prior activities, and apply these in a relevant context. The positive impact of problem-based learning (PBL) on the conceptual understanding of electrical engineering students has been studied empirically by Yadav, Subedi, Lundeberg, and Bunting [12]. Goncher and Johri [13] introduced constraints into the learning environment and studied the impact the context of the project had on the design process. The relationship of project design parameters such as functionality, safety, innovativeness, and educational/entertainment on the design process students chose and the actual design practices used was evaluated. They identified impediments to students' achievement of specified learning objectives for design: projects being treated as isolated entities, linear design phases, cognitive inertia due to rigid timelines limiting redesign, and focus only on explicit constraints. They recommended use of content from other courses as part of a design project and permitting sufficient time to allow for iteration of design phases making transitions between phases smoother. Projects that include open-ended problem elements can provide ample opportunity for students to expand their understanding within the context of on a given project.

Instructional Strategy for Using APPB Learning

PLTW uses small, multi-day mini-projects. Rushton, Cyr, Gravel, and Prouty [14] emphasize that often course projects can be rather overwhelming, since one has to design a solution to a problem with no fixed parameters, no fixed list of equipment to use, limited information if any about constraints, and no specified problem solving methodology. Using a mini-project or linking multiple mini-projects can make this process more manageable. It also prepares students for larger projects further along in the curriculum, culminating in the capstone project experience.

Using mini-projects in the course provides opportunities for personalizing and inter-linking several lectures and laboratory activities together by Chandra and Reese [15]. These and similar activities allow students opportunities to personalize their projects by drawing on individual or group specialties and inter-link related information and skills while doing so. The course then is viewed largely as a cohesive whole rather than a mixture of disconnected topics. Using mini-projects shifts emphasis to student learning rather than to coverage of content. Extended time is spent on one theme or problem, and content coverage is interwoven in a natural way. Performance assessments related to the project require working designs, functional programs, and portfolio items. Collaboration is encouraged. Students design and showcase devices or systems that reflect their unique interests. Development of the projects requires that students conduct online research, interact with peers, and learn new problem solving strategies. When possible, they create simulations prior to actual construction of the device or system. From our experience, the mini-projects should be designed around interconnected essential topics of a course, or indeed across the curriculum, enabling students to see the broad utility of the device they are designing and implementing. For example, an electronic power supply constructed in an analog electronics course could be used for future laboratory activities within the same course or in related courses, such as digital electronics.

Prior to implementing the projects, students need a background of associated knowledge and laboratory skills. They should know certain facts, theorems, notation, rules, and principles, etc., as well as, be able to do certain things like perform specific hands-on activities and procedures. In addition, the project should require group work, communication, initiative, and creativity on part of the students. The course project should be complex but personalized, and student groups should be able to complete it within the specified time.

Implementing APPB Learning in an Introductory Electronics Course

The APPB learning techniques integral to the PLTW instructional methodology were adapted for use in an Electronic Devices and Circuits course. This freshman-level course is taken by different majors across campus and is not restricted to those pursuing electronics, computer systems, or networking undergraduate specializations. The prerequisite for this course is a fundamental electricity course. The initial portion of the Electronic Devices and Circuits course is related to rectification and power control. The latter section of the course deals with transistors for switching and amplification. The transition between the two major sections was chosen as a location for implementing a power supply mini-project requiring design, customization, implementation, troubleshooting, and documentation. The pre-APPB version of the power supply project required its construction with a limited opportunity design customization based on student research into commercially available power supplies with regards to safety, ease-of-use, or personalization needs.

Students taking the Electronic Devices and Circuits are already familiar with the basic functioning of bench power supplies that they have used in the prerequisite course for performing various laboratory experiments. In order to build interest about the topic, students considered sample power supplies in systems they use on a daily basis, such as those in computer systems. The significance of power ratings can be readily conveyed by examining the power requirements of high-end video cards needed for online gaming, a topic that is likely to be of interest to students. Sample power supplies from different computer systems, along with laboratory power supplies, were used to motivate the construction and subsequent customization of a split variable voltage regulated power supply.

Safety considerations regarding the power supply are paramount. Rather than provide specific guidelines for the safety interlocks that each power supply required, students were asked to brainstorm ideas in groups. Groups examined what they considered would be the safety features of commercially available power supplies, along with the safety features used in automated systems. This interaction helped to internalize safety concepts and made them more aware of why certain functions are added in devices. The instructor was watchful to ensure no important safety concepts were overlooked.

In a study for establishing links between learning activities and outcomes in problem-based learning, verbal interactions by students were studied by Yew and Schmidt [16]. They identified a concept articulation phase and a concept repetition phase. By increasing verbalization of concepts during the different phases of the problem-solving process, students were found to improve learning outcomes. In the context of the electronics power supply project construction and extension activities for including safety interlocks, encouraging verbalization of the knowledge, skills, and professional practices being used can be helpful for students working in teams. This type of collaborative interaction can allow students with widely varying skills to teach and learn electronics concepts in a group setting.

After the power supply was built and tested, it was used by different groups in subsequent portions of the course and also for other courses in the electronics area. The dual voltage power supply is particularly helpful for various transistor amplifiers. The power supply provided students insight into solving realistic problems that span multiple content areas. The practical applications of course content helped to deepen students' understanding. Troubleshooting and problem solving were integral to successfully completing the project, with students trying to apply what they had learned through structured classroom discussions and activities for solving the problems that arose. Addressing real-world problems such as safety hazards within the context of their power supply, informed by their online research and class discussions, can increase student involvement and ownership of their learning process.

Results

All student groups successfully implemented the dual voltage power supply project including construction, customization, troubleshooting, and documentation. Considerations for the project evaluation were based on power supply design and safety interlocks, group number display, outside and inside appearance (casing), soldering quality, demonstration of the variable voltage of the dual regulated power supply within specifications, and the project report.

Figure 1 shows representative power supplies built by students as part of the mini-project.

(a)
(b)

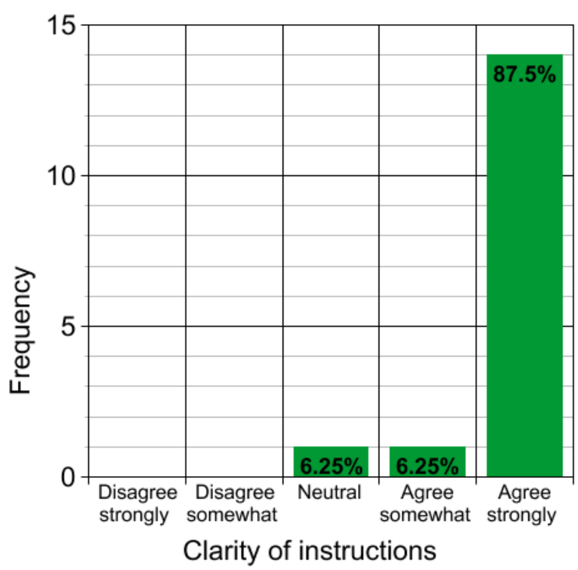
Figure 1. Sample power supply projects with safety interlocks designed by students

The safety interlocks that students added to their project following group discussions included activation of buzzer alarms and flashing LEDs when the supply casing was opened, along with deactivation of the unit, key locks, cooling fans along with appropriate ventilation, digital voltage level indicators, external quick acting switches, a spring "hammock" for the power supply PCB for protecting it against excessive vibrations, transparent enclosures for immediate visual information about components, multiple types of interconnected switches monitoring conditions inside the power supply.

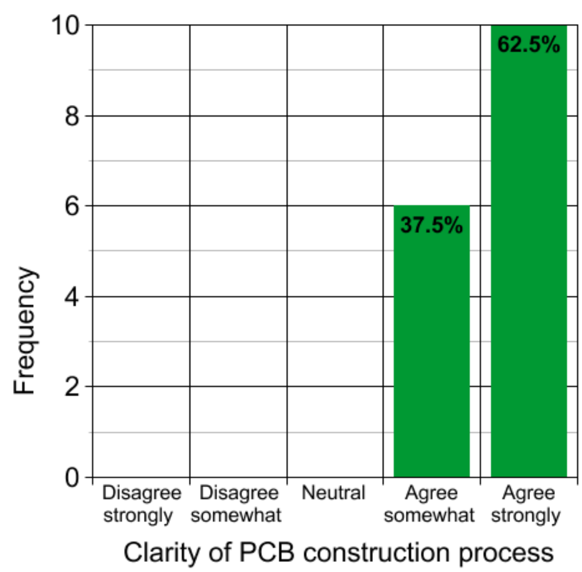
The report for the mini-project was similar to an expanded laboratory report, with prompts requiring students to provide their ideas from brainstorming sessions, along with the completed designs. It also included the implementation steps, observations, troubleshooting procedures, results, conclusions, directions for use of their power supply, activity logs, list of references uses, and digital photos of the project. A project report template was available online for the students. While a majority of the project reports met all the requirements, it was observed that students had difficulty in developing appropriate diagrams for the customization portion of the project. This was in part due to the different types of sensors used, as well as the mechanical safety interlocks added by some groups. Also, many students seemed to rely on their recollection of the activities performed while filling out the activity log portion rather than filling it out right away.

After completing the power supply project, students completed an anonymous 10-item survey. Five-level Likert items were used for determining student reactions regarding different aspects of the power supply project. The responses of the 16 students who took the survey are summarized in Table 1 (a-j).

Table 1. Power supply survey results



(a)



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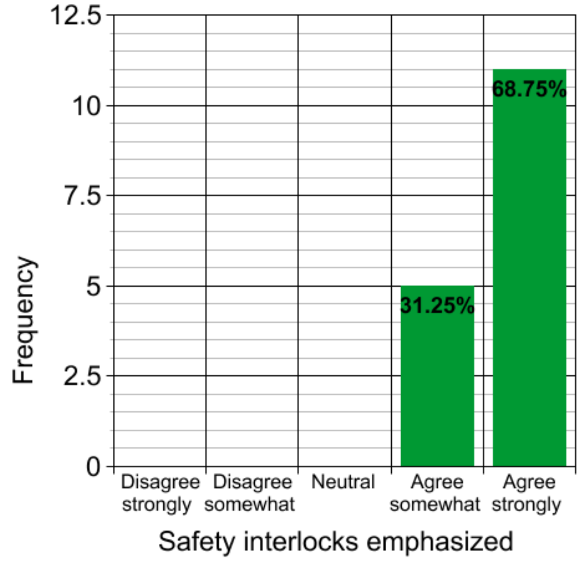
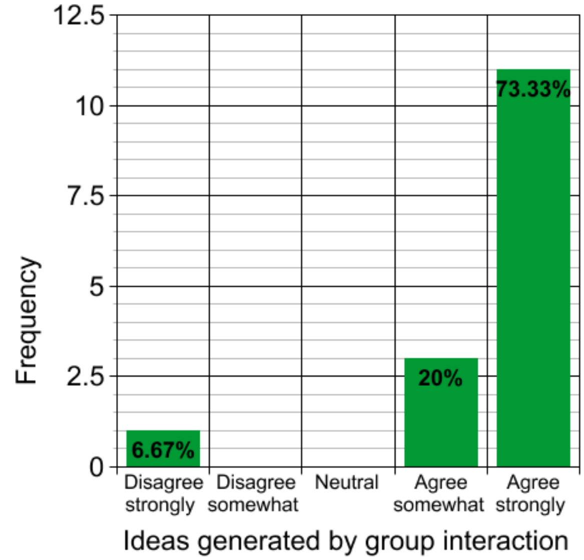


(c)



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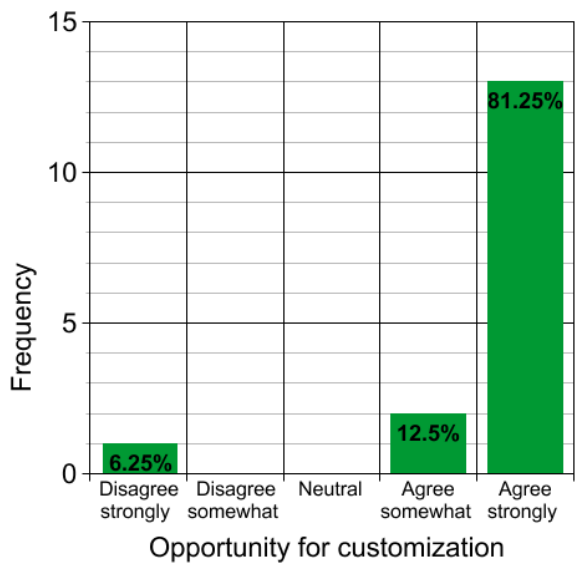
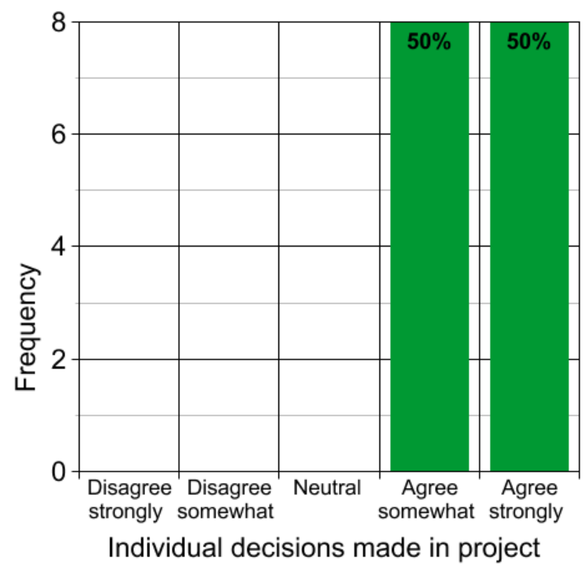


(e)



(f)

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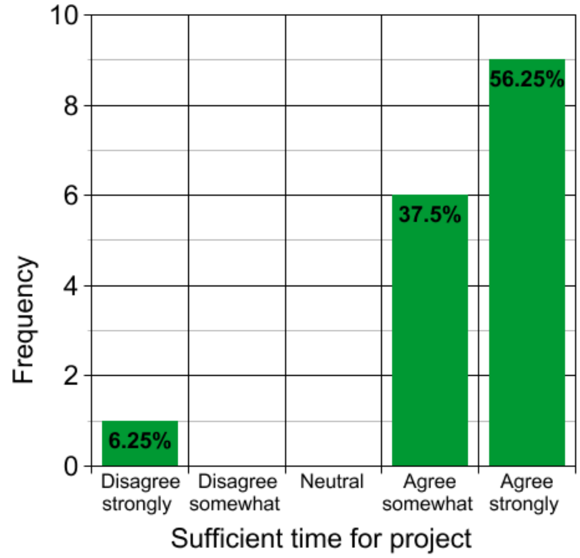
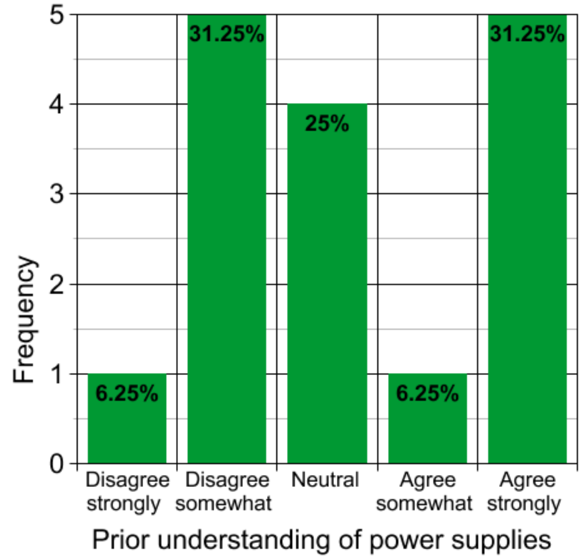
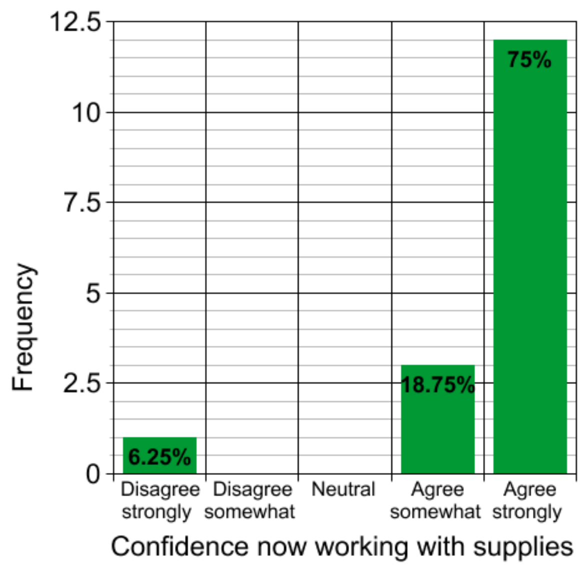


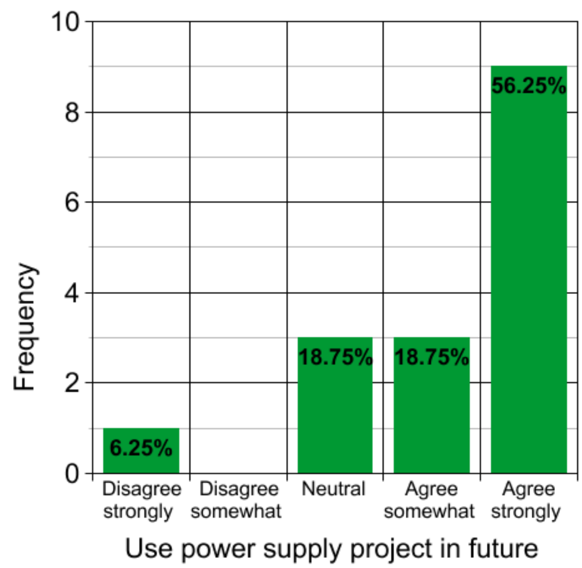
(g)



(h)



(i)



(j)

Almost all (93.75%) the students indicated that the instructions for the mini-project were clear and that they understood the steps involved in constructing the power supply, as well as the importance of safety. Almost all members of the different groups interacted closely while participating in the project. While the class was split evenly about their perception of the prior understanding they had about power supplies, most of the students (93.75%) agreed that their personal experience while working on the power supply increased their confidence about working with power supplies, with 75% agreeing strongly to this survey item. Students gained a better appreciation for the compact and efficient design of commercially available power supplies with multiple regulated outputs. Students used practical and innovative ideas for integrating safety into their power supply units.

Some of the student comments regarding the power supply project are listed below:

> "The power supply project was an excellent learning opportunity. Not only did it teach about the electronic operation of power supplies, it also taught about the various processes involved in electronic circuit construction. There was also the challenge of design and layout."
>
> "I loved working on the power supply project! I found myself always wanting to add things to it, and I always looked forward to tweaking things on it."
>
> "The power supply significantly improved my understanding of electronics and of how power supplies functioned and made me feel much more confident in my knowledge of electronics. I think it would be terrible idea to drop the power supply project in future semesters of this course!"

Some of the challenges associated with the project:

> "[Group] partner didn't want to help outside of class."
>
> "Personally I did not have much time out of class to spend on the power supply."

Some of the suggestions provided by students for future improvement of the project included

> "I think it might be better to have to do the project later in the class. Everyone seems to drop everything else as we worked on the project."
>
> "I would like to see more check points and deadlines to show a gradual build of the supply over time and possibly 1 week more to complete the supply."

Challenges and Implications for Learning

The different phases of the power supply mini-project presented several logistical issues. With a full-class working on the project, equipment such as drills and miscellaneous tools were is short supply, especially during the PCB etching process and power supply assembly. While the project was intended to be completed within five class periods, reworking and troubleshooting of circuit boards took more time than planned. Several of the groups had to work outside of class time to get the project completed. There were also delays associated with ideas needed for the safety interlocks and customization needed through group brainstorming sessions.

The biggest challenge was providing sufficient time for the project while moving ahead to subsequent topics in the course. Additional class time was allocated during the semester for completion of the project. Content coverage of other areas of the course was reduced owing to extended time spent on the project. Assignment of online Web readings or videos is planned for supplementing classroom instruction, particularly on advanced topics. Also, assessments in class are to include an open-book section. By assigning project-related homework, students will be able to complete part of the work outside of class time. Instructors can also choose to use comprehensive exams that include content from the project so that students use these as opportunities for reviewing the essentials of the entire course. Instructors can help students with organizers that identify underlying themes. Block diagrams and concept maps can graphically illustrate key ideas and linkages. These can be referred to time and again, especially while transitioning to different sections, so that students view the course as a coherent whole.

Balancing the contribution of individual group members is another important challenge. Rubrics that show students what is expected in professional interactions can be used for this purpose. These could include criteria for collaboration, sharing of responsibilities, or the roles of different group members. Reducing group sizes to two or three students and requiring self-reflection statements on the contributions to the group objective may be used. It is essential that adequate resources are available for all groups/students, and this may require separating essential equipment for the project from that shared with other classes.

It was observed that the activity log for the power supply project was not updated regularly, as students were absorbed in the actual project activities. In future offerings of the course, there are plans for including project management software that will enable students to track progress and allocate time and other resources optimally.

We continue to make adaptations in our approach. If time permits, the use of multiple, interlinked projects in the same course will provide students with practice developing additional topics. It may be possible to modify or upgrade the mini-project developed in an earlier portion of the course for use in the subsequent sections. Similarly, using projects created in prior classes will show students linkages across curriculum. Requiring submission of the final project report later in the semester, but with an interim version, is being considered.

Overall, even considering all its challenges, the use of APPB-based learning in the Electronic Devices and Circuits course turned out to be a rewarding experience. Students enjoyed working on a realistic and relevant project that they could use for other electronics laboratory activities, and even outside of class. Accessorizing the power supply required creative and critical thinking on the part of the students, while they developed technical solutions that could be applied in a personalized context.

Conclusions

Using carefully selected projects that lend themselves to personalization by students increases their grasp of technical material and enables faculty members to convey key concepts effectively. The theoretical underpinnings of problem-based learning as identified by Marra, Jonassen, Palmer, and Luft [17] include constructing knowledge stimulated by a question, need or desire by interacting with the environment; and embedding learning within a context similar to one in which it will be applied. They note that working on an authentic problem improves metacognitive skills and helps students construct knowledge, make meaning, and learn. Any foundational project used in the technology curriculum, such as constructing an electronic power supply in an electronics course, can, with relatively minor changes, include open-ended problems in its design. Improving safety, functionality, efficiency, aesthetics, and accessorizing it based on online research of commercially available equivalents allows students the opportunity to actively engage in the learning process. The opportunity for using and re-using a tangible product students have created and customized in a freshmen-level course all the way through their senior-level capstone makes it possible to embed learning that lasts into the fabric of the course. Student survey data from the course indicate that students are eager to build practical applications blending relevant theory with practice. By structuring the classroom activity so that thinking and action go hand-in-hand, students get prompt reinforcement about whether their designs or suggested solutions will indeed work. Our next steps will be to create comparison groups for measuring differences in performance outcomes in APPB and non-APPB.

The APPB learning that is an integral part of the Project Lead the Way PTLW curriculum can be used as illustrated in this paper to integrate topics in meaningful ways at the introductory undergraduate level. Successful completion of individual stages of the project gives students confidence for seeing a task through and encourages them for taking on complex projects in subsequent classes. This, in turn, may spark and sustain interest in the electronics field and aid student retention in technology and engineering fields. The relative ease with which almost any technology project in the curriculum can include elements of the APPB model—specifically open-ended problems requiring customization based on online research, discussion and experimentation—has the potential to personalize learning and thus make it more enduring.

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