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SUPERCHARGING RESULTS THROUGH SELF-MOTIVATION

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ABSTRACT

The 3rd year Electrical Engineering Design Studio (EEDS) course is a project-based learning (PBL) course that gives students hands-on experience with putting engineering principles into practice. It is found that learning outcomes are improved by enhancing student motivation using a number of diverse techniques. Improved student outcomes are shown both anecdotally and measurably.

NOMENCLATURE

CNC	computer numeric controlled
DOF	degrees-of-freedom
EC	electronically commutated
ECE	Electrical & Computer Engineering
EEDS	Electrical Engineering Design Studio
FDM	fused deposition modeling
IC	integrated circuit
LCR	inductance / capacitance / resistance
MEMS	micro-electro-mechanical systems
OTS	off-the-shelf
PBL	project-based learning
PCB	printed circuit board
PID	proportional, integral, derivative
RCG	requirements, constraints and goals
SLA	stereo lithography
TA	teaching assistant

INTRODUCTION

It is widely accepted that student performance depends as much on effort as it does on ability. According to Thomas Edison, “Genius is one percent inspiration, ninety nine percent perspiration”. It follows that effective motivation can unlock a significant portion of a student’s potential.

One techniques that is fast becoming a mainstay of modern engineering eduction is Project-Based-Learning (PBL) [1][2]. PBL is a departure from conventional lecture-based instruction [3] that involves the practical application of knowledge and skills to an open-ended task. It is often performed in teams and includes a substantial hands-on component that is absent from conventional assignments and examinations.

This work is motivated by the hypothesis that student outcomes in a 3rd year PBL Electrical Engineering Design Studio (EEDS) course may be improved increasing self-motivation using a variety of techniques that include project definition, student empowerment, timely instruction and project evaluation.

BACKGROUND

EEDS is a required 3rd year course in the Electrical Engineering program at the University of British Columbia. The course takes place in the Spring term (January - April) and runs for 14 weeks, including a 1 week Spring break. It includes 2 lecture hours and 6 lab hours per week. The Spring 2015 course had a total of 154 students while the Spring 2016 course had a total of 122 students. Students work in teams of 4 and the course accounts for 6 of 15-18 credits in the standard term. Lectures focus on prototyping skills with some technical content to fill any gaps in the 3rd year curriculum.

In Spring 2015, the project was a 2-DOF robot arm driven by a PID controller, a mechanically commutated DC motor and a position sensor. In Spring 2016, the project was a 2-DOF helicopter driven by a PID controller, an electronically commutated DC motor and a velocity sensor. A conceptual drawing of the 2016 project is shown in Fig. 1. The task was to perform a take-off, *180°* rotation, and landing.

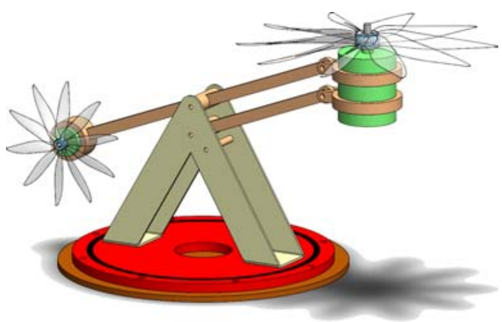

Fig. 1: Spring 2016 design project: 2-DOF Helicopter

The mechanical prototyping capabilities available to ECE students include a supervised machine shop and 3D printing lab. The supervised shop has drill presses, sanders, band saws, shears, brakes, powder-coating, spot welding, bench vices, punches, sand blasting and other equipment. The 3D printing lab has 7 FDM printers and 3 SLA printers. More complex parts may also be produced by a machinist using a CNC mill / lathe, a waterjet cutter and a wood shop.

Electrical prototyping is done in a semi-supervised electronics lab that provides 24/7 access to power supplies, signal generators, multi-meters, oscilloscopes, soldering stations, an LCR meter, a precision scale and a laser tachometer. PCB production is outsourced to a local manufacturing facility.

The available software tools include SolidWorks™ for solid modeling and simulation, Altium Designer™ for circuit design, simulation and PCB development, and Matlab™ / Simulink™ for modeling and simulating dynamic and control systems.

PROJECT DEFINITION

A common practice in PBL courses is for students to define their own project. It is argued that this allows students to select a topic they are passionate about but this practice comes at a price. Students routinely define projects which are:

- Perceived to be easily achievable
- Ill-defined

Vygotsky [5] showed that children learn best when assigned a task that they cannot complete unless provided with help. This particular subset of tasks was termed the “Zone of Proximal Development”. The same holds true for university students who are well equipped to fill gaps in their own knowledge through readings, collaborations with colleagues, and personal or in-class conversations with professors. A sufficiently challenging task initiates these activities and leads to a much richer learning experience than the mere execution of an easier task.

When progress is made on a task that is initially perceived as un-doable, a sense of satisfaction is experienced which leaves the subject wanting more, motivating continued or even accelerated effort. Each new accomplishment leaves the student feeling more greatly invested and less willing to accept an unsuccessful conclusion. Although there are exceptions, even strong students are inclined to select conservative projects to minimize the chance of failure and the associated impact on other courses they are taking. These projects that may be completed without help, lie outside the zone of proximal development and do not enjoy the same motivational benefits.

Adequately defining a project is a task that takes years of experience to master. Student defined projects are often vague and overly open-ended. They may require materials that are dangerous, unavailable or beyond budgetary constraints. They may have serious legal, safety or policy implications. They may be difficult to separate into defined tasks and are unlikely to encompass all of the necessary teaching elements.

Electrical Engineering is a very broad area and EEDS is expected to incorporate the diverse range of technical skills that are taught in 3rd year, which includes the following:

- Circuit analysis and design
- Electro-magnetics
- Electrical devices
- Control theory
- Machines and power systems
- Embedded systems
- Real-time programming

EEDS should also incorporate the following practical skills:

- Circuit design & simulation
- System modeling & simulation
- Physical parts & assembly design
- 3D printing
- Water-jet cutting
- PCB layout
- Soldering

Identifying a project that incorporates all of these elements is well beyond the scope of any student enrolled in the course. Instead, the project is defined by the instructor who also ensures the following:

- the project is somewhat familiar due to the students' theoretical knowledge but relates to a system they have little experience with
- the project is initially perceived to be overly enthusiastic and somewhat unrealistic given the associated time and experience constraints
- the project is not possible to complete single-handedly and requires the combined and coordinated effort of a team
- the project has clearly defined milestones, requirements and constraints
- the project does not require any unavailable or dangerous products or facilities
- any associated dangers are mitigated by safety precautions that are prepared ahead of time and strictly enforced
- the project is easily separated into sub-tasks

STUDENT EMPOWERMENT

Even a well defined project does not motivate unless students feels personally responsible for its success. This is accomplished by putting maximum decision making power into the hands of students.

Design Constraints

Design studio courses often have artificial design constraints such as components or software products that are declared off-limits. This is as common in academia as it is uncommon in industry where anything that makes a job easier is welcome. The industrial philosophy is adopted here.

A sufficiently challenging project eliminates the need for any such constraints and places the onus onto students to decide how best to solve the problem. The variety of potential solutions is expanded and a sense of ownership is felt by students for their particular solution. The project feels less like an academic exercise and more like a practical, real-life project.

Fiscal Constraints

In spring 2015, students were provided with separate budgets for 3D printed parts, PCBs, electronics and mechanical components and were not charged for waterjet parts. The following behaviour was noted.

- Costly SLA printing was used to produce large and/or simple parts due to the availability of an SLA budget but not because of a need for high resolution or accuracy.
- Waterjet parts were ordered with little discretion.
- Spare components were stockpiled near end of term when there was available budget to be used up.

The wasteful use of resources resulted in backlogs and empty parts bins which impacted other groups and programs which all share departmental resources. In 2016, 2 FDM 3D printers were reserved for large print jobs, 5 were provided during lab hours free of charge, and an integrated budget of *$1,000* was provided to each team. This had the following side-effects.

- Wasteful orders in all categories dropped noticeably.
- SLA and waterjet parts requests dropped to a small fraction of 2015 levels.
- Parts were specifically designed to fit the time constraints of the free FDM printing resource.
- No-cost, rough, hand-machined proof-of-concept parts were more common.

The total jobs submitted by each team were tracked for each prototyping service and are tabulated in Table 1.

Tab. 1: Total number of jobs submitted

	Min	Max	Mode	Mean
Waterjet	1	5	3	3.3
FDM	0	14	0	2.7
FDM(self)	n/a	n/a	n/a	17.4
SLA	0	4	0	0.4

Students were surveyed to identify the prototyping activities that were avoided as a result of budgetary constraints. The number of used (a) and avoided (b) prototyping services is shown in Fig. 2. Not surprisingly, the most avoided service, SLA 3D printing, was also the most costly service.

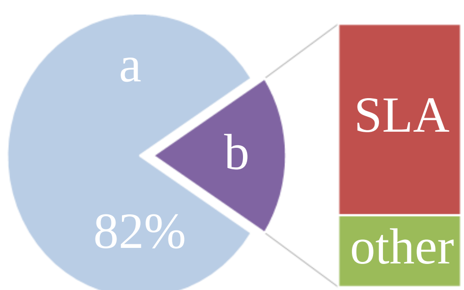

Fig. 2: Used (a) and avoided (b) prototyping services

The most heavily used services were free 3D printing, waterjet cutting, billed FDM printing, and SLA 3D printing, in that order. A student survey revealed that *242* out of a total of *539* parts (45%) were specifically designed to fit within the free 3 hour, FDM time window. Waterjet material was not billed and in one example, expensive acrylic was used as a platform, strictly for aesthetic appeal when plywood would have sufficed. This is an opportunity for future improvement.

TIMELY INSTRUCTION

The improved outcomes proposed by Vygotsky [5] requires that students receive the help they need when taking on a task from the zone of proximal development. If that assistance is absent, either little progress or low quality progress results. This was observed in EEDS 2015 when the need to perform a task preceded the lecture that was scheduled to introduce it. Table 2 identifies each topic and when it was delivered in 2015 and 2016.

Tab. 2: Spring 2015 & 2016 lecture schedule

	Topic	2015	2016
	Overhead: Course info	1	1a
A	Design & RCGs	1	1a
B	How to get started	2	1b
C	3D printing & waterjet	3	2a
D	SolidWorks I: Solid & Sheet	4	2b
E	Electrical Prototyping	5	3a
F	Altium I: Circuit Design & Sim	6	3b
	Overhead: Progress	n/a	5a
	Overhead: Component Demo	8	10
G	Mechanical Prototyping	9	4a
H	SolidWorks II: Assemblies	10	4b
I	Altium II: PCB Layout	11	5a
	PCB Production	12	11
	Overhead: Final Demo	14	14

Technical topics (A-I) were arranged in perceived order of importance. For example, getting started and SolidWorks are scheduled early since they are common early obstacles for Electrical Engineering students. According to the student survey, in 2015 students began work on proof-of-concept prototypes in week 2 but SolidWorks was not presented until week 4 so many were required to learn it on their own.

In 2016, additional 2-hour time slots were added in the first 6 weeks. The result is shown in Fig. 3 where the right tick corresponds to the 2015 delivery date, the left tick corresponds to the 2016 delivery date, and each “x” denotes when the students began using the associated lecture material.

The new lecture schedule had the following side-effects.

- Software tools were used more effectively since students learned them in context and prior to needing them.
- Quality increased in component-level evaluations since students had time to practice skills taught in class.

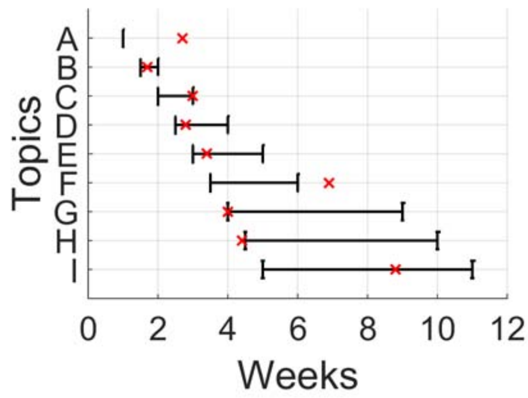

Fig. 3: Graphic comparison of subject delivery dates

- Quality increased in system-level evaluations since higher quality work was accomplished earlier with less re-work.

In 2015, students worked inefficiently for up to 5 weeks (G, H). Topic C (3D printing) is not useful until after topic D (SolidWorks I) is presented and Topics G (Mechanical Prototyping) and H (SolidWorks II) are more time sensitive than Topic F (Altium).

EVALUATION TECHNIQUE

Students are motivated to start early by a series of assessments that demand both an early start and continual progress. The initial formative assessment takes place in the 5th week. The grading rubric is non-specific and evaluates the likelihood that a group will complete on time if they continue working at the same pace. Students provide a checklist of what has been completed and an estimate of whether or not they are on schedule. This has the following positive side-effects.

- Unsolicited feedback identifies underestimated tasks in time for students to react.
- Students are motivated to have something substantial to demonstrate early in the term.
- Overly optimistic self-assessments are identified.

The second formative/summative assessment takes place in the 10th week. Each group is graded individually on their component. This has the following positive side-effects.

- A milestone is set where two complex sub-components must be simultaneously ready for integration.
- Proper design processes such as defining RCGs are required to coordinate parallel efforts.

The third summative assessment takes place in the 14th and final week. Teams are graded as a whole on their system. This has the following positive side-effects.

- Student groups are obliged to converge and function as a cohesive team.
- Students learn to appreciate the magnitude and difficulty of system integration.

Students were surveyed to estimate their combined effort during each week. The average hours (per team) are shown in Fig. 4 with each evaluation week indicated by a red line.

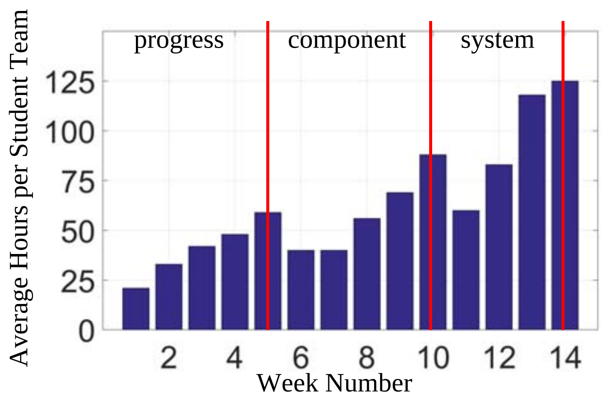

Fig. 4: Average hours per student team per week

There is an increase in time spent as the term progresses. Small peaks occur during the weeks that precede an evaluation and large peaks occur in the final 2 weeks. This suggests that periodic evaluations do motivate students to devote additional time and that the integration phase is commonly underestimated.

Fig. 5 shows a motor that was presented by one team during the progress and component demonstrations. The first motor is made from a bottle and screws while the second is made from the 3D printers and waterjet cutter. This is a representative example of the progress that was made by most teams in the time spanning the first two evaluations.

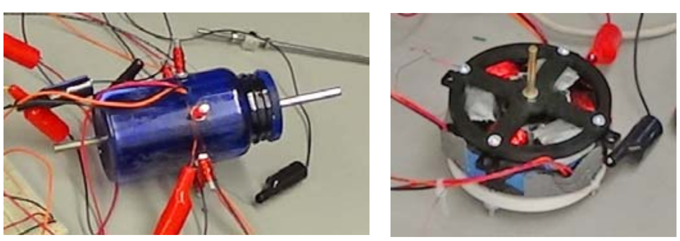

Fig. 5: Sample proof-of-concept and finished motor

CONCLUSIONS

A strong correlation is demonstrated between PBL learning outcomes and motivation which is developed by various techniques. A challenging, well defined project is provided. Students are empowered both technically and fiscally to solve it. Instruction and facilities are provided in a timely manner to transform a seemingly impossible task into a personal victory. And an aggressive schedule motivates constant progress that starts early. Fig. 6 shows one example of the high quality output that was produced by a team that participated in EEDS 2016.

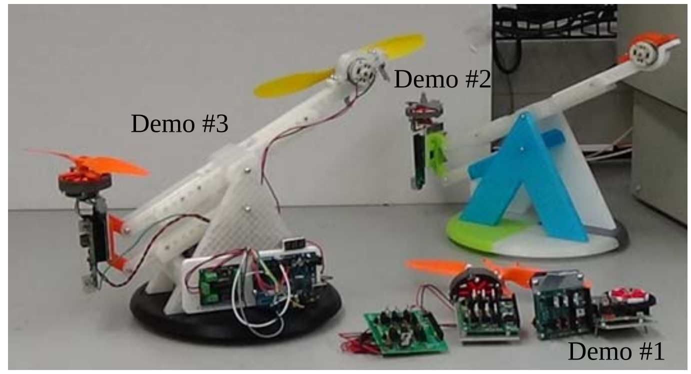

Fig. 6: Progression of demonstrated results

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