USING CDIO TO DEVELOP PROJECT LEARNING ACTIVITIES FOR YOUNGER STUDENTS

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ABSTRACT

A persistent misconception about technology as an education field and the work of the engineer exists with younger students (13-16-year-olds). These young students need to determine at this age their own interests in pursuing future studies. To better support their choices, initiatives have been undertaken in collaboration with primary and secondary school science educators to develop learning activities promoting technology and discovery by mobilizing students around an open-ended project with project-based learning (PBL) approach. The project's goal is to provide a learning activity during which young students (boys and girls) could experience in teams the design-build-test project development cycle through an open exploration mindset, anchored with a socially significant goal. During the project definition, it was found that science educators need better support to teach technology using more interactive and open methods. This paper presents the multiple activities that were combined to achieve this goal. The project started by building upon the knowledge acquired with undergraduate students through the development of active learning projects. The next step was to adapt those projects to younger student's interests and motivations, such as social and environmental issues. To this end, a co-creation process was implemented; secondary school educators from the school board, Commission scolaire Marguerite-Bourgeoys, undergraduate engineering students, engineering professors, and Fablab personnel from École Polytechnique Montréal were involved in the development of hands-on activity for younger students. The open-ended social design challenge -a hydroponic system-, based on plant growth, motivated the students to conduct their own experiments while respecting the educational program requirements. The activity has been tested, with positive but also mixed results. Open-ended projects increase motivation with young students. However, the link between the project realization and a better understanding of the work of engineers could not be confirmed. More experiences are needed to better manage personnel and material resources to provide a long term sustainable initiative.

KEYWORDS

Technology education, young students, open-ended project, PBL, Standards 4, 7, 8, 10

STATE OF TECHNOLOGY EDUCATION IN QUEBEC

The state of science and technology education in Canada appears to be very good, Québec's schools scored 7th overall in PISA 2018. Nevertheless, the science and technology curriculum has some strongly documented criticisms for the way problem-solving is implemented. Educators involved in teaching sciences with better integration of concepts from several STEM (Science, Technology, Engineering, and Mathematics) fields into one coherent learning sequence. In nation-wide studies on student's motivations for STEM (DeCoito, 2016, and Parkin, 2018), students strongly reaffirm their preference for meaningful hands-on project learning environments.

Another issue is the male-female imbalance observed in technology education and careers. Authors report that for technology education, males have more positive attitudes and confidence than females for using technology in learning (Yau, 2012) or learning about technology (Kulturel-Konak, 2011). If the context and methods used to learn technology were modified (active learning, significant context, creative thinking), could this socially constructed imbalance (Yau, 2012) be changed?

A project-based learning (PBL) context seemed well adapted to promote technology learning. PBL has been found to promote learning in STEM students at all performance levels and individual factors such as gender, ethnicity, and language proficiency (Han, 2015).

Pedagogical support personnel's experience indicates that science education is easier for educators to teach, as compared to technology - which is viewed as the practical application of science. Educator's lack of resources and practical knowledge prevent them from being fully comfortable to teach technology, and consequently, teachers stick to the textbook. This is problematic considering that the Quebec educational system pushes 13-14-year-old students to decide between two profiles for secondary 3: a pure science approach to concepts or an applied science approach. At 14-16 years old (secondary 4 and 5), students are making a choice of math and science courses that can restrict or require extra courses to have access to certain disciplines in their future studies. At this age, the exact knowledge of the possibilities available in technical careers are sometimes biased or not well known.

In an effort to improve this situation by providing a better understanding of the technical careers, an experiential learning project in the development and application of technologies for society was found to be an interesting opportunity.

CREATING AN OPEN-ENDED TECHNOLOGY SUPPORTED SOCIAL PROJECT

Partners

The initiative is based on past experiences of teaching undergraduate engineering students at ÉPM and bring experiences developed in project work to younger students. The motivation was to foster the curiosity of 13-15-year-olds to experience the link between technology and society. Representatives from a Montreal school board, Commission scolaire Marguerite-Bourgeoys, confirmed their interest in the project. Through them, interested professors and classes were identified to integrate this co-developed activity in their program.

Requirements

Following the first team meetings, it was decided a CDIO inspired methodology would be applied to the development of the learning activities as well as in their delivery to the students. Many outreach programs exist at ÉPM, some as short single activities (2-3 hours) but also in a long summer camp format (1-2 weeks). A short activity creates interest but does not give an outlet for the long term involvement of students, and curiosity rapidly disappears in the weekly flow of school activities. The summer camp attracts mostly students with already close contact with people involved in technology (parents, close friends, and family). The search for a different format of activity was felt necessary to develop and improve the link between the people who develop technologies and their impact on society.

Based on the science and technology course content defined by the provincial education ministry, it was found an open-ended social design challenge based on plant growth on a green wall covered a significant number of poorly contextualized content objectives (Table 1).

Table 1. Science and Technology course content

Required subjects in the program	
Matter and solutions	History of life
Energy	Biotechnology
Fluids and waves	Technical drawing
Cells and genes	Mechanical engineering
Human systems	

Furthermore, the exploration and iteration around a core of achievable functioning prototype elements ensured, at a minimum, a positive but still challenging outcome. This contributes greatly to student motivation (Viau, 2000). The cost of the project was significantly higher than what an ordinary school can afford. The cost of the machines and materials was greatly simplified by the stakeholders, but it was not the main constraint.

Activity Goal

The important goal defined by the stakeholders was to bring students to see technology as an accessible and interesting field where they can contribute to help society in solving important and significant problems, not just science for science's sake. To achieve this, a more active approach to teaching technology was chosen.

Project Definition

A group of undergraduate engineering students and Fablab personnel designed and built the project as well as the in-class activities. Iterations with the pedagogical experts and in-class teachers followed to improve the activity further in multiple co-creation cycles.

The project was constructed to be able to follow different paths and outcomes depending on the class response and motivation during the activity. A completed student team project contains a structure, container, computer-controlled light source, and pump (Figure 1). Some elements were supplied but required assembly, soldering, programming, or other activities to complete the project. Needs research, design iterations, and exploration were the main components of the activities in class.

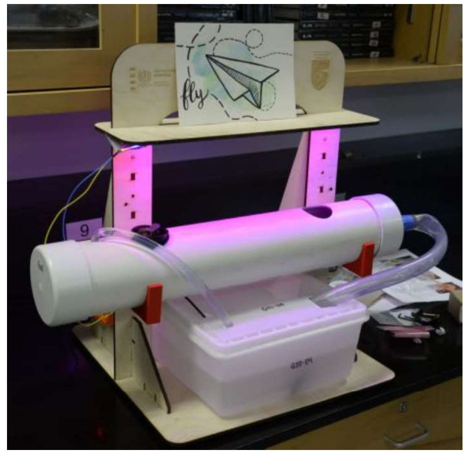

Figure 1. Completed student project

For this first trial experience, the objective was to plan positive outcomes in many alternative project paths to be able to modulate: complexity, outcomes, and technical subjects explored. During the project, students will go through a complete product design cycle (Figure 2).

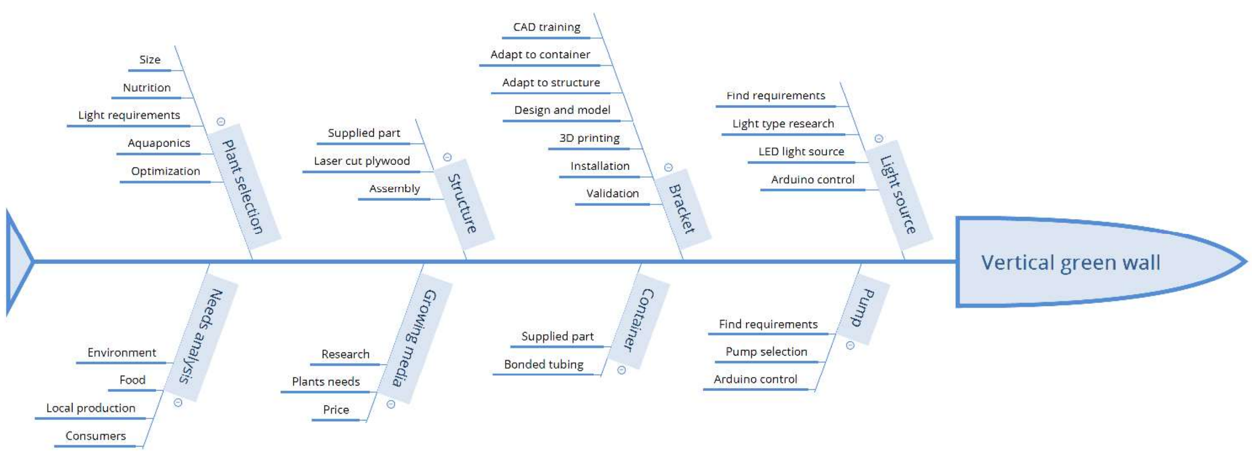

Figure 2. Activity planning

Engineering students (student mentors) are in class to give formal content but, more importantly, to provide mentor figures and role models closer to the young students than an engineering professor. The activity spans over 12 weeks, with one 75 minutes period every week. A CDIO design process is applied where young students research needs, design a product or service, implement the design, and operate it. All fabrication equipment required is brought to the school where the young students use the equipment themselves to manufacture or assemble their parts.

Developed Documentation and Materials

To support the activity, an important effort in creating documentation and providing design tools for the different stakeholders in the project was created or adapted from existing efforts (Figure 3).

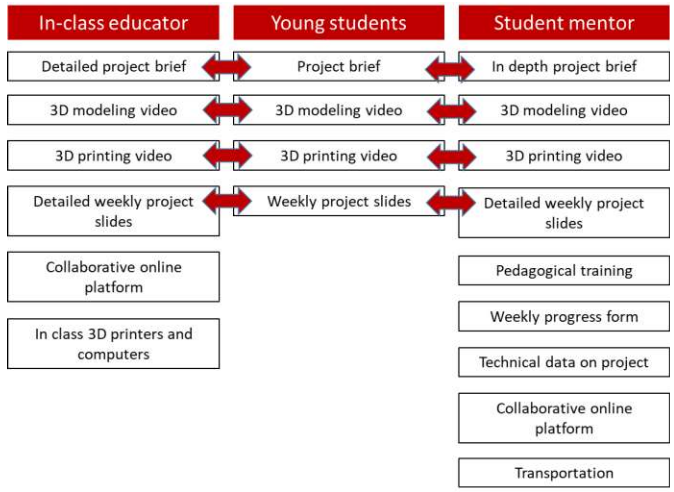

Figure 3. Developed materials and support

THE PROJECT IN CLASS

The project was presented to two classes of 24 students from January to March 2019. For this pilot project, the activity was optional and was added to the traditional content that was still given to the young students. Each project prototype will be built by teams of 4-5 young students. A team of two engineering student mentors will be in class for each class period.

Training of In-Class Engineering Student Mentors

Engineering students were trained to have basic knowledge about student-mentor relationships and a few pedagogical skills to interact with teenagers. Extended in a few training sessions, the course contained basic etiquette (punctuality, dress code, professionalism), relational aspects (sharing personal experiences, being a role model, adapting quickly to diverse situations, leading in-class discussions, asking open-ended questions, connecting with students, respecting students' rhythm, etc.), and finally an introduction to technology (basic programming skills, demystifying concepts, simplifying, generating curiosity, and questions to be explored). It was presented to the student mentors in various forms, amongst which: formal training, technical exercises, and role-playing. The team of 8 student mentors included male and female students, from diverse engineering fields and levels of study. About half of them already had some experience of interacting with young students in shorter activities.

Activities in Class

From the initial technical activity planning, a weekly in-class plan was detailed (Figure 4). The main items chosen to develop were: design process, design software tools, 3D printing, Arduino programming, assembly, and fabrication techniques.

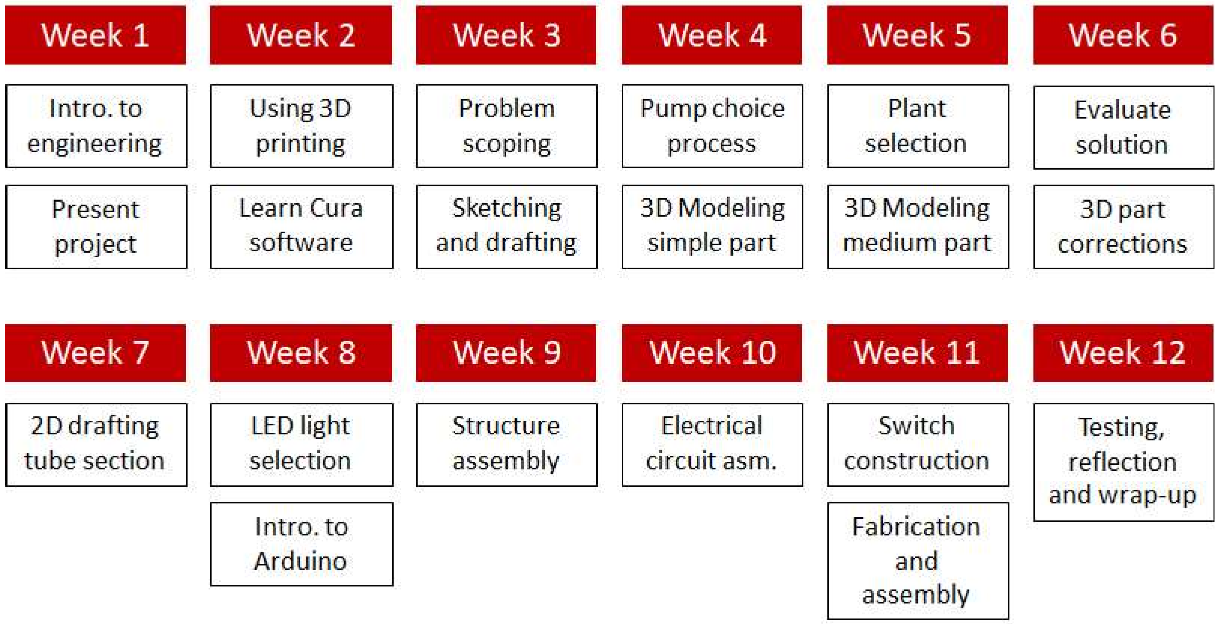

Figure 4. In-class activities

The task intensity can seem quite high, but a process-oriented approach was favored in place of results only approach to manage project difficulties. An incomplete result will be managed by student mentor support to coach the young student to find a quick win solution by himself or understand the origins of the incomplete result.

Logistics

The project required intense logistics and project planning. Student mentor availability, material sourcing, design, sub-assembly construction, budget burn rate, project progress, and transportation were all closely followed by a senior project manager.

RESULTS

Student Projects

All student teams completed the hydroponic system project with a functional prototype. All prototypes subsystems worked: all structures were correctly assembled, and some were improved, custom-designed brackets supported the main tank, the pump system circulated water, the Arduino controlled lighting followed programmed durations. The level of quality varied from one team to another and from one subsystem to another. Again the objective of the activity was processing and not prototype performance per se for this first 12-week design cycle.

One of the open-ended design elements student teams had to develop was the main tank support brackets. The different geometries generated hands-on opportunities to discuss optimal material use and structural integrity with student teams. Some student teams had structural failures for which they designed new versions to correct the situation. Multiple design variations of the tank brackets from the two groups can be seen in Figure 5.

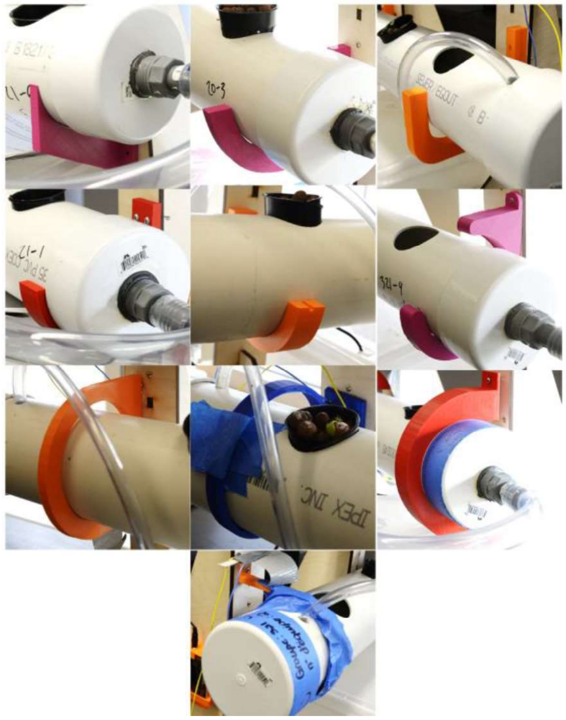

Figure 5. Main tank support bracket variations

Stakeholder Perception of Results

After the project completion, multiple feedback activities were completed:

- Young students completed a project survey at the end of the activity
- Student mentors wrote a reflexive essay at the end of the activity
- School board stakeholders wrote a complete activity report
- Polytechnique Montreal wrote an internal process and activity review

The critical learning points extracted from all this information can be found in Table 2.

Table 2. Critical learning points

School board project review excerpts	Impact on young students ● Project learning has an impact on student autonomy, not on content (Prince, 2004) ● Good introduction to "grit," does not always work the first time ● Can work for students with manual or theoretical preferences ● Ambitious complexity level is well received by students for its diversity and in context competencies ● Imperfection of student mentors makes their charm ● Young students want even more liberty in the project process Impact on administration ● Good alignment with program requirements essential ● Project brings context to traditional content ● Requires time investment from the in-class teacher, not all are ready ● Need better training for teachers on the tools used

	● Existing school system makes challenging the integration of PBL ● Teacher must consider evaluation from a different perspective ● Surprised by the co-construction process of the activity Content and format ● Online video training is not sufficient for learning 3D modeling tools ● Improve support documentation ● Look into Shorter 2-day activity to experience the design process ● Multiple other project subjects and contexts could be explored for future development
Student mentors reflexive essay excerpts	Impact on young students ● Amazing to see the eyes of the young students twinkle when they first start their prototype, priceless! ● Time given builds closer relationships with young students ● Kids are fascinated by 3d printers ● Need a more weekly reflexive review of activities with young students Personal gain ● Sentiment of implication and applied grit to make the project work ● Supplied training (mentorship, process, tools) was sufficient ● I would do it again, anytime (by all student mentors involved) Content and format ● More important to be good in animation than good technically (technology easier to learn in this context) ● Match experienced student mentor with new mentors ● Use a better week to week process progress documentation ● Involve the in-class teacher more in the first weeks ● Software needs were too simple, and students could do more ● With more task flexibility in the project, a more complex project could be completed ● Give more flexibility in materials supplied for the design ● Complete project view needed to accompany young students ● Need better support from project leaders and designers ● Slack tool helped manage communications between stakeholders
Polytechnique Montréal project review excerpts	Impact on young students ● Take into account the socio-cultural context of the young students ● Better demystify the engineering profession by tagging the activities in the project and presenting in the context ● Plan project so all young students must contribute at all times ● Same student mentor must go in the same class to build confidence ● Varied learning materials and formats worked very well Impact on administration ● Continue to adapt to the teacher's planning and evaluation (Conseil supérieur de l'éducation, 2018) ● Better train the educators before the activity (8h minimum) ● Need to build better links to co-construct future projects Content and format ● Build student-mentor teams in advance ● Train student mentors very closely and in a structured way ● Insist on the need for iteration in problem-solving ● Plan closely on what elements young students have control over ● Software, tools, machines must be functional! ● Must have a single point resource identified to manage problems ● Real-time project resource planning is essential

Young student's self-reported survey analysis	● Students would appreciate the project even if they did not show interest in engineering ● Links between project and engineering were not clear for students ● 3D modeling and printing is a hit ● Satisfaction of designing, assembling an efficient, functional and robust product ● Project proposals of interest to young students: robotics to help humans, technologies to save fauna, renewable energies, sound or visual pollution, universal access

Looking more closely at the young student self-reported survey using technical, social, and professional segmenting of data, the following trends can be seen (Figures 6, 7, and 8). The interest was looking at the opinions of boys and girls on the activity.

In Figure 6, the number of students still feeling at a very beginner level after the 12-week activity remains high. The group has shifted to a higher perceived competence level, but more reflection on the training material supplied is needed to increase this shift incompetence further.

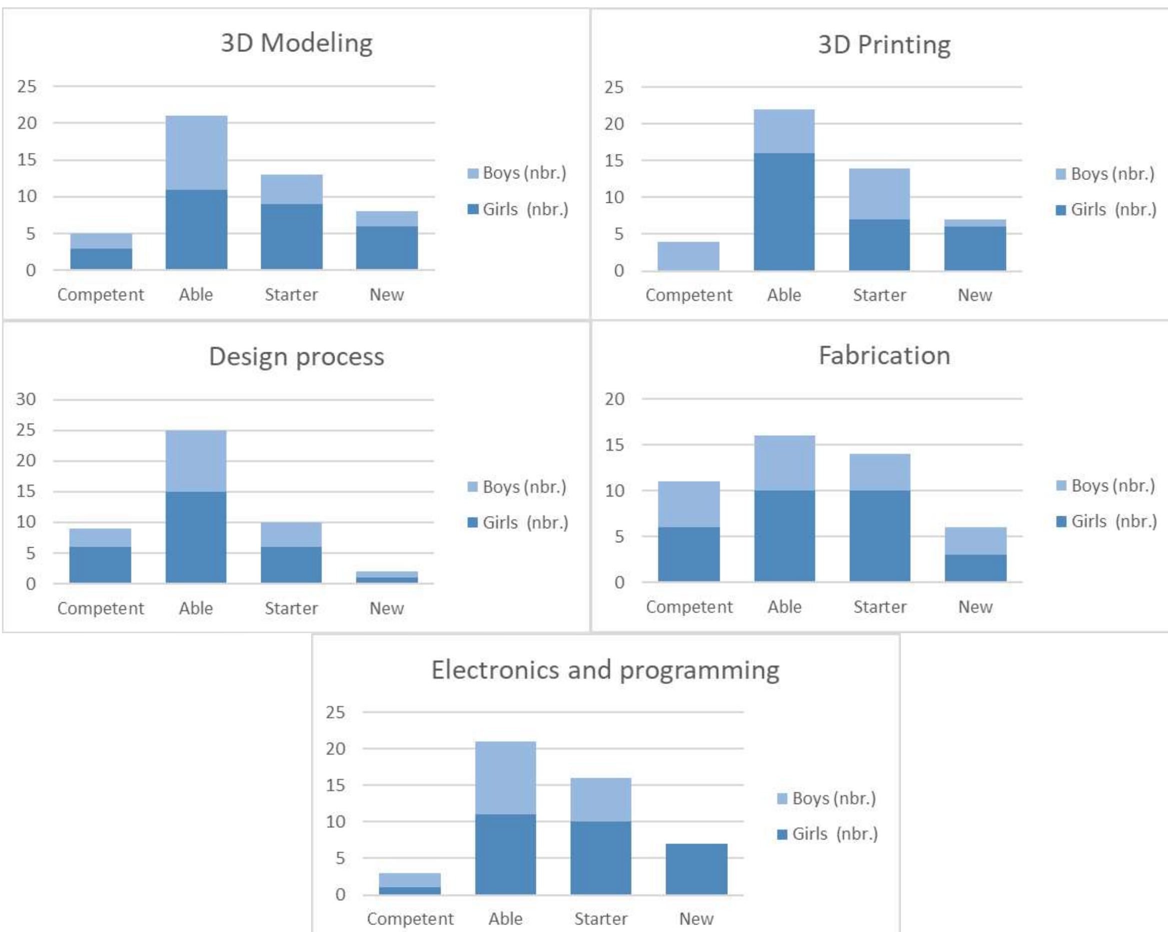

Figure 6. Technical aspects in survey

The disparity between boys and girls found in Figure 7 is interesting. With similar teamwork mentoring, the perceived competence has increased more with girls than boys. The one on one long term mentoring might be one of the positive actions that favours this result.

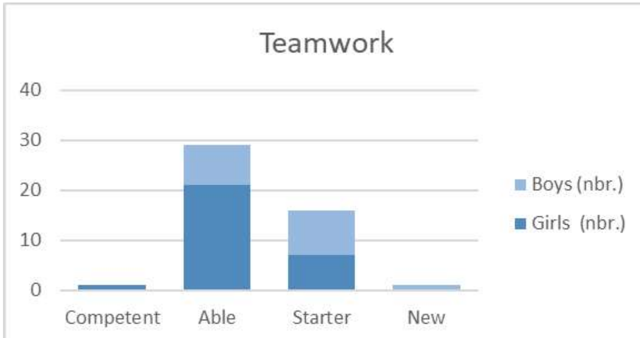

Figure 7. Social aspect in survey

While project appreciation is high, as seen in Figure 8, the transfer to the interest and knowledge of engineering is not as good. More work is needed to better highlight the links between the content given in class during the project and specific engineering practice and fields of study.

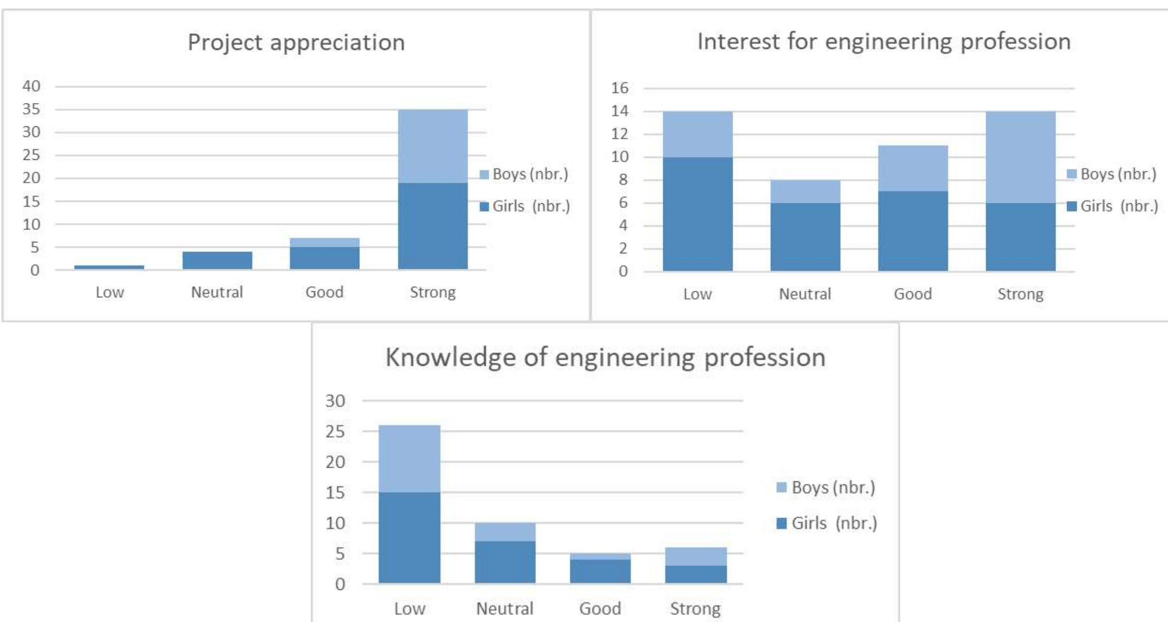

Figure 8. Professional aspects in survey

CONCLUSION

In review, the project subject and context was a success. Students appreciated working on a hands-on project but also demonstrated to their educators their understanding of what they were working at a surprisingly detailed level. The in-class educator found the PBL experience challenging but very rewarding. The level of confidence of the in-class educator with the content increased over the 12 weeks to the point that when faced with technical problems with the 3D printing machine, the educator debugged the machine herself. However, some difficult issues remain.

Providing a sustainable long term project-based learning platform is difficult. In this experience, the level of coordination of the resources needed required huge amounts of energy from the already busy staff. Financing this initiative can also become difficult since right now, it is very dependent on specific, highly motivated individuals in place at the different institutions. Figure 9 highlights the important aspects and challenges faced during this project experience.

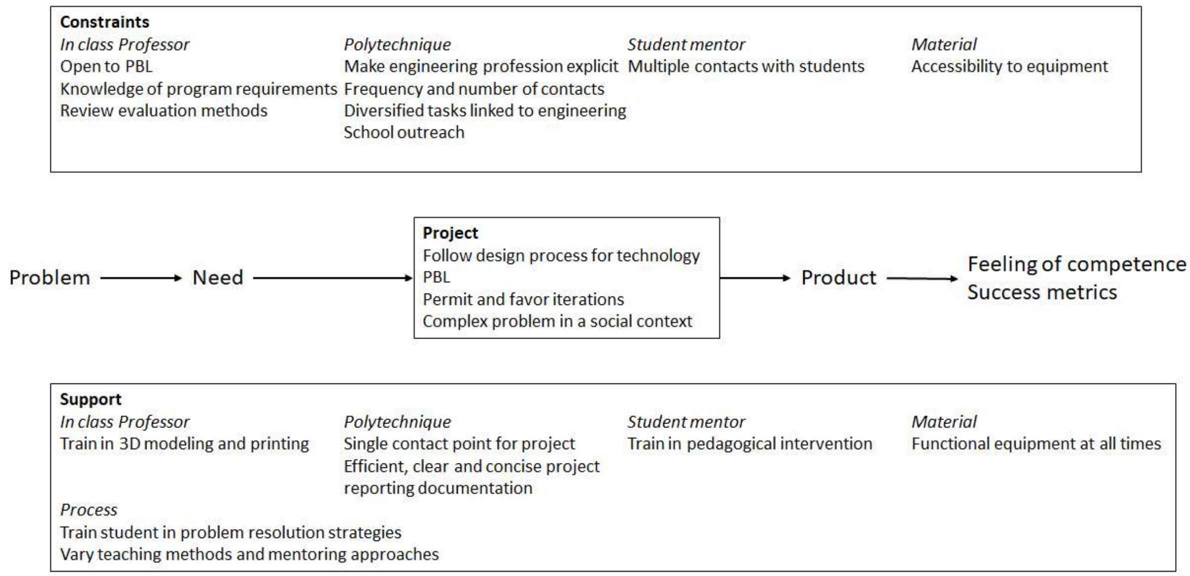

Figure 9. Project highlights and lessons learned

At the last stakeholder review meeting, the conclusion was that although the project in its present form provided motivation and hands-on experience of the design process, a shorter and less intensive approach might bring similar results. The reflection on how to better define the problem-solving activities will act as steps to realize a better open-ended project. Already, some new activities have been influenced by the work done.

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REFERENCES

Conseil supérieur de l'éducation (2018), *Évaluer pour que ça compte vraiment*, https://www.cse.gouv.qc.ca/wp-content/uploads/2019/02/2019-02-evaluer-pour-que-ca-compte-vraiment-rapport-2016-2018-etat-et-besoins-50-0508.pdf, accessed 8 November 2019.

DeCoito, I. (2016). *STEM education in Canada: A Knowledge Synthesis*, Canadian journal of science, mathematics and technology education, Routledge, Vol. 16, No.2, P. 114-118.

Han, S. Capraro, R., Capraro, MM. (2015). *How science, technology, engineering, and mathematics (STEM) project-based learning (PBL) affects high, middle and low achievers differently: the impact of student factors on achievement*, International Journal of Science and Mathematics Education, p. 1089-1113.

Kulturel-Konak, S. D'Allegro, ML. Dickinson, S. (2011). *Review of gender differences in learning styles: Suggestion for STEM education.* Contemporary Issues in Education Research, Vol. 4, No. 3, p. 9-18.

Parkin, P. (2018). *Supporting education transformation in Canada*, Let's talk Science, https://canada2067.ca/app/uploads/2018/11/Canada-2067-Supporting-Education-Transformation-in-Canada_Final.pdf, accessed 25 October 2019.

Prince, M. (2004 July). *Does active learning work? A review of the research*, Journal of Engineering Education, p.223-231.

Viau, R. (2000). *Des conditions à respecter pour susciter la motivation des élèves*, Correspondance, Centre collégial de développement didactique, Vol. 5, No.3, http://correspo.ccdmd.qc.ca/index.php/document/connaitre-les-regles-grammaticales-necessaire-mais-insuffisant/des-conditions-a-respecter-pour-susciter-la-motivation-des-eleves/, accessed 8 November 2019.

Yau, HK. Cheng, ALF. (2012) *Gender difference of confidence in using technology for learning.*

Journal of Technology Studies, 2012, p.74-79

BIOGRAPHICAL INFORMATION

Daniel Spooner is a professor of engineering practice at École Polytechnique Montréal (ÉPM). He also teaches at Université de Montréal's School of Industrial Design. In the last 20 years, he has lead multidisciplinary development teams for more than 70 products in the transport, consumer, medical, and telecommunication industries. He is responsible for the CDIO introductory and interdisciplinary capstone projects for mechanical engineering at ÉPM since 2006 (www.wecollaborate.ca). Daniel is a founding member of Polyfab, ÉPM's growing community accessible Fablab and holder of a Chair in project-based learning.

Évelyne Lussier is currently a student recruitment advisor and project coordinator at École Polytechnique Montréal (ÉPM). Her background as a highschool teacher leads her to contribute to the development of contextualized pedagogical projects aimed at helping young students discover engineering through hands-on activities.

Laurence Martel is currently Operations coordinator at PolyFab (Fablab), École Polytechnique Montréal (ÉPM). She aims at providing primary and secondary school students with successful design activities which integrate a transdisciplinary, experimental, and human-centered approach, involving the use of new digital manufacturing technologies.

Mathieu Dubreuil-Cousineau is currently a K12 STEM advisor at Commission scolaire Marguerite-Bourgeoys, a public school district providing services to 7500 students. He is the founder of Fab Lab CSMB, which became a node for 8 high school fab Labs. His current focus is on the development of a community of pedagogical competent science and technology teachers. He acts as co-president of Fab Lab Québec, a cooperative devoted to sharing best practices between digital fabrication labs in Québec.

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