STUDENTS' LEARNING STRATEGIES, MOTIVATION AND PROJECT-MANAGEMENT SKILLS DURING INTERDISCIPLINARY PROJECTS IN COVID TIMES

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ABSTRACT

In this study, we investigated an interdisciplinary project-based learning program. Students were confronted with interdisciplinary challenges in the form of complex and authentic problems, like building a racing car or making a mobile laboratory for genetic analysis. These hands-on educational formats had a clear aim to develop skills required in students' future careers, as well as bridge the gap between theory and practice. In this paper, we show preliminary results of an on-going mixed-method study where the students' learning strategies, motivation, and project-management skills were measured through a survey using a pre and post-test approach. Quantitative results were contrasted with qualitative input from interviews

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with projects' coaches and students' focus groups. The results provided evidence of gains regarding professional skills (e.g. risk assessment in projects), but also shed light on difficulties and needs to implement meaningful experiential learning content within engineering education (e.g. collaboration). On top of this, the research took place during COVID-19 lockdown, hence both students' and coaches' reflections accounted for ways in which this situation did impact the projects.

1 INTRODUCTION

The challenges that students will be confronted with once they graduate are becoming increasingly complex. Besides requiring solid background in a core discipline, they demand an ability to work at the intersection among many fields. At Ecole Polytechnique Fédérale de Lausanne (EPFL), there is a program of interdisciplinary projects called "MAKE" that aims to close this gap in its students' education. The goal of this Project-Based Learning (PBL) initiative we studied was to give students an opportunity to confront themselves with the challenges posed by interdisciplinarity during their training, giving them a head start in developing the necessary skills they will need in their professional future. By participating in one of these projects, students were expected to acquire solid team-working and project management skills and get a first hands-on experience in a real-world project at the same time. Students engaged in one interdisciplinary project either enrolling formally (i.e., earning some credits to their Bachelor's or Master's degree), or engaging on a voluntary, *ad-honorem* basis. Each project involved one or more teams where interdisciplinarity could be seen within one team (it included students from different faculties) or across teams (each team typically included students from one area of expertise). Students and coaches all worked together towards the creation of products through prototyping cycles (designing, prototyping and testing) that required the input of all the team members.

The aim of this research was to inform curriculum development about student's engagement and learning not only in terms of disciplinary learning but also transversal competences. To this end, this study investigated the evolution of student motivation, learning strategies, and transversal competences like project-management skills in the course of PBL. Both student and teacher perspectives were considered. As a consequence, feedback and results were provided to the teachers and managing staff at the end of the experience.

To achieve the research objectives, the study was guided by the following questions:

- Are there any significant changes from pre to post-test in terms of student motivation, student learning strategies (i.e., critical thinking, peer learning, metacognitive self-regulation, effort regulation), or project-management skills (i.e., project planning, risk assessment, ethical sensitivity, team communication, interdisciplinary competence)?
- Are there any contextual factors that are associated with such changes according to students and coaches (e.g., instructional design of projects,

learning activities, coaches' and teachers' feedback, COVID-related restrictions, use of technology)?

2. LITERATURE

Experiential learning is the base of project-based educational models and their potential advantage is projected through narrowing the gap between academia and the "real world" (Condliffe et al., 2017). PBL has reported positive results in mathematics, natural sciences and technology, with a medium positive effect size on average (Chen & Yang, 2019). The 2018 MIT Engineering Education Report suggested that "a move towards socially-relevant and outward thinking engineering curricula" is a strongly anticipated trend, which quite directly connects to rethinking higher education and its pedagogical approaches (Graham, 2018, p. iii).

Interdisciplinary learning is seen as another potential advantage in the overall higher education curriculum. Interdisciplinarity offers the so-called boundary-crossing skills which enhance "the ability to change perspectives, to synthesize knowledge of different disciplines, and to cope with complexity" (Spelt et al., 2009, p. 366). This educational approach is in contrast with traditional academic pedagogy which often focuses on subject and domain-specific knowledge. Spelt et al. (2009) pointed out that, unlike multidisciplinarity, interdisciplinary education is integrative, hence it creates the capacity to synthesize and integrate different knowledge and modes of thinking from a variety of disciplines.

There is a great variety of aspects and approaches when dealing with PBL, and this is oftentimes difficult to synthesize. Thomas (2000) defined PBL according to these five criteria:

1. Centrality: PBL projects are central, not peripheral to the curriculum.
2. Driving questions: PBL projects are focused on questions or problems that drive students to encounter (and struggle with) the central concepts and principles of a discipline.
3. Constructive investigations: projects involve students in a constructive investigation.
4. Autonomy: projects are student-driven to a significant degree.
5. Realism: projects are realistic, not school-like.

However, transferring from traditional learning methods into PBL methods is quite a challenge, both for institutions, teachers and students (Chen, Kolmos & Du, 2021). Despite the high expectations created over interdisciplinary PBL, at this stage we've had few rigorous studies on its impact on student learning (Lafuente, 2019) which showed only a small positive effect size on student's academic achievement (i.e., content-based learning) on average. This points to the difficulty of achieving highly effective environments where teachers from different disciplines get to coordinate their designs, teach, and assess student's learning, which requires a great deal of effort and time. Although the scientific community holds high expectations on PBL's impact on student engagement and motivation, meta-analyses have shown a very weak positive effect size (Lafuente, 2019). So far, we have seen that PBL is very likely to produce a very positive and appreciative opinion in students (i.e., they often prefer PBL over traditional lecturing); however, studies produced thus far showed that this does not translate into a significant increase of their intrinsic motivation towards learning. In the same vein, we lack rigorous studies to document the impact of project-based scenarios on student's transversal competences (Condliffe et al., 2017; Lafuente, 2019) like collaborative learning skills, critical thinking, metacognitive self-regulation, or project-management skills.

3. Methodology

In this study we used a mixed-methods approach, gathering data both from a quantitative and qualitative approach. The sample included all five PBL projects starting in the autumn semester 2020/2021 in which 85 students (74 males and 11 females) and five coaches were involved:

- *Genorobotics*: students develop a miniaturized tool to automatically extract and sequence DNA samples from expeditions with the objective of identifying and protecting biodiversity.
- *Procam*: students build a low-cost camera that combines infrared and visible light sensors to track individuals with a fever while preserving their privacy on all captured footage.
- *Lab in a tube*: students design and experimentally validate flexible microsensors via manufacturing, electronics and modelling to finally have a smart catheter equipped with temperature and liquid flow sensing.
- *Racing Team*: distributed in different teams (e.g. chassis, aerodynamics, electronics, business), students design and build a single-seater and electric car.
- *Student Kreativity and Innovation Laboratory*: without any predefined topic or assignment, students work together in small and interdisciplinary groups on their own ideas, with access to a wide range of tools, materials, software, etc. and assisted by specialized coaches.

On the quantitative side, we developed a pre-post-test design to measure student motivation, learning strategies and project-management skills. The pre-test was launched at the start of their project (September/October 2020), and the post-test at the end of it (January/February 2021). A total of 36 answers from students to both the pre and post-test (33 male and three female students) were collected and analysed running a paired t-test of students' scores and calculating effect sizes through Cohen's d estimator.

Two main questionnaires were used for this purpose:

1. Motivation Strategies for Learning Questionnaire (MSLQ) (Pintrich, Smith, Garcia & McKeachie, 1993, 1991). We used a 5 point-Likert scale and an abridged and adapted form of this questionnaire selecting four or five items per each subscale, namely:
    a. Intrinsic goal orientation (i.e., intrinsic motivation)
    b. Extrinsic goal orientation (i.e., extrinsic motivation)
    c. Critical thinking

  d. Effort regulation
  e. Metacognition for self-regulation of learning
  f. Peer learning
2. Interdisciplinary Project Management Questionnaire (IPMQ) (Tormey and Laperrouza, forthcoming). We used a 5 point-Likert scale and the following subscales were included in this questionnaire:
  g. Team communication
  h. Ethical sensitivity
  i. Interdisciplinary competence
  j. Project planning
  k. Risk assessment

Items were answered on a Likert scale: 0: strongly disagree, 1: disagree, 2: neither agree nor disagree, 3: agree, 4: strongly agree.

Furthermore, one question to gauge student's satisfaction with the project was included in the study. Also, the survey included an open-ended question where students had to mention their main challenges in the project.

The qualitative part of the research gathered data from coaches and from students. With coaches we used a semi-structured interview to explore their experiences with curriculum design, organisation of resources, implementation difficulties and interventions, and learning outcomes for students. A total of eight coaches were interviewed, representing all projects (three coaches were involved in more than one project simultaneously). As for the students, we had individual and group interviews (with six students) exploring the themes emerging from the pre-test survey at a deeper level. Specifically, the interviews had four main blocks of questions, including:

- Why students joined the project: the motivation behind student participation.
- Experience of PBL: the specific learning strategies, time-management, collaboration, and difficulties.
- Impact on future choices: the learning outcomes, benefits and dimensions of project management.
- What works: the elements that are important for students engaged in PBL.

4. Main findings

We first present an overview of the quantitative data (pre and post-test), followed by the survey outcomes and qualitative results which we structured in three sections: (1) motivation, (2) learning strategies, and (3) interdisciplinary project-management skills.

Differences between the pre and post-test are explored in Table 1. Qualitative data were analysed using a targeted thematic approach in order to distil deeper understanding of some trends in the survey charts.

Table 1. Pre and post-test scores of all dependent variables (mean and standard deviation) , t statistic and p-value from a paired t-test (two-tailed), and effect sizes calculated through Cohen's d estimator. Values in bold are statistically significant at CI=95%.

	Mean pre-test	SD pre-test	Mean post-test	SD post-test	T stat.	P value	Effect size

Intrinsic mot.	3.35	0.45	3.23	0.44	-1.95	0.06	-0.32
Extrinsic mot.	2.48	0.60	2.18	0.80	-3.16	**0.00**	**-0.53**
Critical thinking	3.07	0.39	3.12	0.45	0.91	0.37	0.15
Effort regulation	3.46	0.41	3.17	0.48	-3.03	**0.00**	**-0.50**
Metacognition	3.32	0.34	3.23	0.40	-1.12	0.27	-0.19
Peer learning	3.49	0.49	3.27	0.50	-2.87	**0.01**	**-0.48**
Satisfaction	3.75	0.44	3.47	0.61	-2.94	**0.01**	**-0.49**
Team communic.	3.05	0.48	2.97	0.50	-1.07	0.29	-0.18
Ethical sensitivity	2.51	0.83	2.59	0.83	0.77	0.45	0.13
Interdisciplinary comp.	2.97	0.52	3.04	0.43	1.06	0.30	0.18
Project planning	3.04	0.63	3.06	0.62	0.31	0.76	0.05
Risk assessment	2.63	0.63	2.84	0.53	2.61	**0.01**	**0.44**

4.1 Motivation

Intrinsic motivation, which reflects the degree to which students perceive themselves to be participating in the project for reasons such as challenge, curiosity, mastery, decreased from pre to post-test, $t(35)=-1.95$, $p=.06$, $d=-.32$ (see Figure 1). Extrinsic motivation, which reflects the degree to which students perceive themselves to be participating in the project for reasons such as grades, performance, evaluation by others, competition, or job-related goals, also decreased with a moderate effect size, $t(35)=-3.16$, $p=.003$, $d=-.53$. In both the pre-test and the post-test, intrinsic motivation scores were significantly higher than extrinsic motivation scores. The responses on the question on student satisfaction with the project also evolved negatively, $t(35)=-.2.94$, $p=.01$, $d=-.49$.

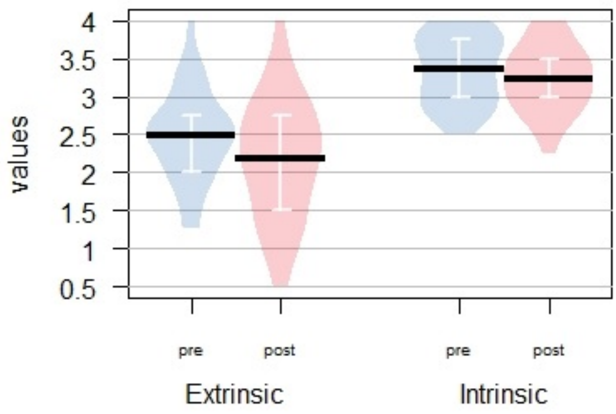

Fig 2. Pre and post-test scores of intrinsic and extrinsic motivational orientations.

Student qualitative input confirmed high levels of motivation, and they were willing to engage for long hours in order to work on their projects.

Coaches reported in the interviews that students were aware about the potential benefits of their engagement in the project, especially on the level of preparedness for future jobs as well as a more complete CV.

> *"Too much work, but they are happy because the work is exciting" (C1)*

Motivation was potentially connected to the fact that students gained practical skills which complemented the theoretical knowledge the school provides.

> *"One good thing is you can try out what you want" (S03)*

> *"This kind of project allows us to get practice. The school is very theoretical and we don't get much practice in our courses (…) this kind of projects really helps us to put into motion the theory we get in the courses" (S05)*

> *"The benefit is that you should work on a topic that is so wide that no one is an expert and we need to know where you are relevant on this topic and also know when you need to seek help. And this is really something that is not learnt [through classes]" (S07)*

4.2 Learning strategies

Two of four learning strategies decreased significantly (see Figure 2). First, peer learning, which means to what extent students see themselves as engaged in collaborative endeavours in the project, $t(35)= -2.87$, $p= .01$, $d=-.48$. There was also a decrease in effort regulation, which reflects the student's perceived ability to control their effort and attention in the face of distractions, difficulties and uninteresting tasks, $t(35)= -3.03$, $p=.004$, $d=-.5$. Critical thinking and metacognition did not change significantly between pre and post-test.

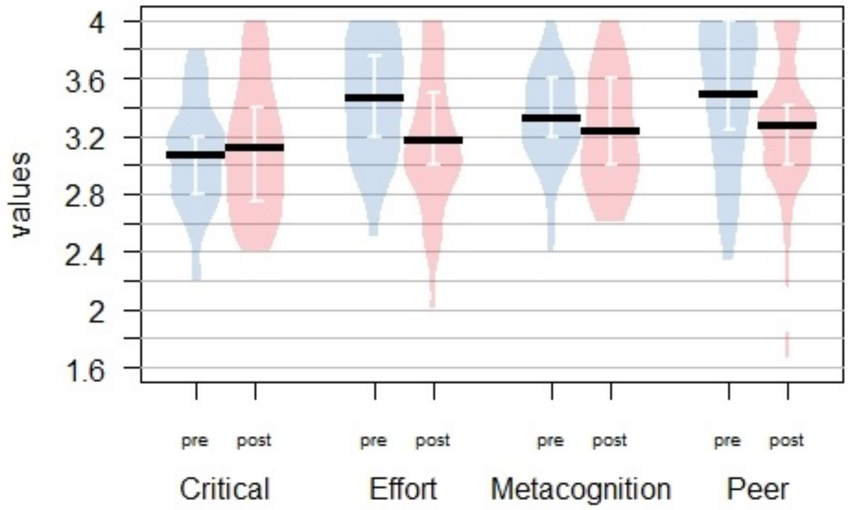

Fig 2. Pre and post-test scores of the learning strategies critical thinking, effort regulation, metacognition for self-regulation of learning, and peer learning.

From the open-ended questions in the surveys, students did anticipate difficulties connected with learning new skills as well as using their generated knowledge in project-related tasks. The answers included: learning new skills, learning engineering software, learning from transversal teams, not understanding other fields of expertise, catching up with the lacking theoretical background, as well as working in French. Coaches noticed a steep learning curve for the students, and they pointed out that hands-on, experiential learning on the project helped students to use their theoretical knowledge. Furthermore, three out of seven interviewed coaches also mentioned that PBL complements theoretical acquisition and that students involved in the projects were more capable to identify gaps in their theoretical knowledge and hence returned to the classes more attentive and prepared to learn.

4.3 Interdisciplinary project management skills

Only one project-management skill showed relevant change from pre to post-test (see Figure 3). After the project, students saw themselves as more capable of assessing risks in their projects (i.e., managing uncertainty when carrying out a project), compared to before, $t(35)= 2.61$, $p=.01$, $d=.44$. No significant changes were observed for team communication, ethical sensitivity, interdisciplinary competence, and project planning.

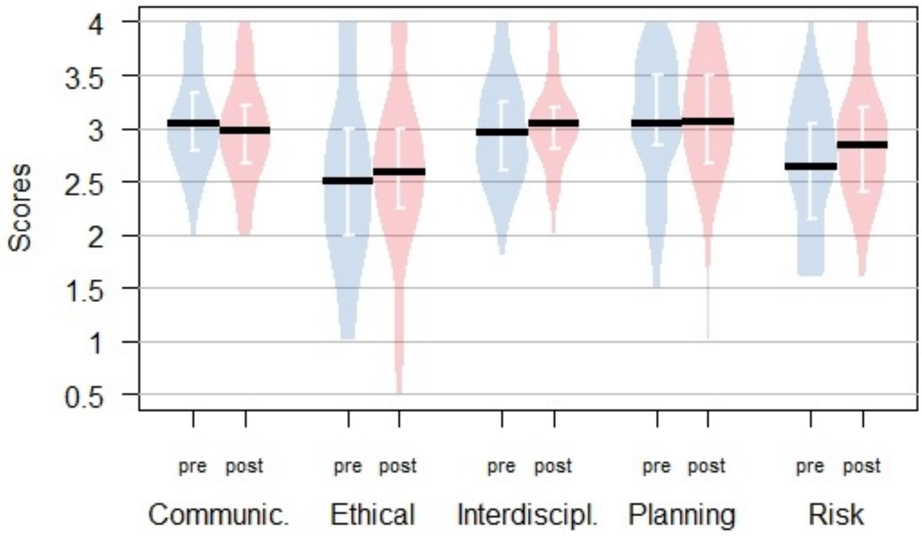

Figure 3. Pre and post-test scores of interdisciplinary project-management skills: team communication, ethical sensitivity, interdisciplinary competence, project planning, and risk assessment.

In the interviews, students expressed difficulties with project coordination, communication and planning, and most profoundly time management. Indeed, this confirms the perspective of coaches who agreed that time management is a difficulty for students; in their opinions, students tend to like investing time in projects and this is sometimes costly in terms of their course work. Furthermore, this confirms also the larger intrinsic motivation, since if students were only motivated to get the credits, they would have other options (i.e., semester projects) that are way less costly in terms of time and energy invested. With regards to the communication skills, all coaches shared their observations that students have difficulties in communicating or coordinating within the teams.

On the other hand, the interviewed students recognized the difficulty of acquiring professional skills, including team management, internal and external communication and resource allocation, but throughout the course of their engagement with the projects they realized how important these skills are for the engineering profession.

> *“What I learned from these projects is that technical barrier is not the toughest barrier. Yes, you need to find the engineering solution, but usually what needs to work is not engineering but all the rest, it is the fundraising, management, dealing with the people in the team, resource allocation” (S06)*

The problematic issue raised by students is that project-management skills are not frequently part of the regular curriculum.

In some teams, COVID-19 impact was felt particularly with the newcomers, as it was a bit difficult to motivate the new members. Team building lacked the element of physical contact, as the teams would regularly meet between the classes which was not possible during the lockdown. Interviewed students reported few positive sides, for instance the fact that the lessons are recorded meant that the students could more flexibly navigate through their project work.

> *"Especially during COVID-19, it is great to be part of a team. [...] during lockdown, I would not see anyone and they (the team) are the ones I can see now and I'm very happy and always talking about the team and it is very rewarding" (S04)*

As students have confirmed in their interviews, being part of the team that works on something was emotionally rewarding, despite COVID-19 limitations for working and meeting face to face on a daily basis.

5. DISCUSSION AND CONCLUSIONS

Throughout the projects, the students' intrinsic motivational scores were always above those of extrinsic motivation. This highlights that students valued the interdisciplinary project-based learning program for the learning opportunities it provided. Students aimed to achieve learning outcomes that they can't achieve through other ordinary courses like the mastery of practical skills, and working in interdisciplinary teams where they can try new things. However, extrinsic motivation was also an important ingredient of their goals, as students appreciated the importance of having these interdisciplinary projects in their CVs, and contacting stakeholders from private corporations that may give them an opportunity to be hired in the future, highlighting the fact the PBL may be also a way for them of narrowing the gap between the 'real world' and academia (Condliffe et al., 2017).

Motivation decreased throughout the projects. It is possible that, given that the pre-test was run at the very beginning of their projects, this captured their prior expectations on the project, which went up in the pre-test due to hyper excitement about the project. The decrease was especially true for extrinsic motivation. We speculate that while the students may have strong learning-unrelated reasons for joining the project, once they develop the project, they realize that these may not be the most important goals. Another reason for decreasing motivation may be that the students realize that working in interdisciplinary projects is harder than they thought it would be, experiencing difficulties that range from coordination and collaboration, to time-management, to resource allocation. Overall, our results confirm the difficulty of improving students' intrinsic motivation suggested by previous reviews of the literature (Lafuente, 2019).

As the projects unfolded, students perceived that collaboration was not as required and frequent as they thought it would be. While students generally realize the importance of learning soft-skills like collaboration and communication, they also acknowledged that this was one of the major challenges they had to face in their projects: students struggled to learn in interdisciplinary teams and to understand other fields of expertise. While PBL presents a tremendous opportunity for encouraging such skills, in the literature we find scarce examples as to how to do that (Condliffe et al., 2017).

The reported decrease in collaboration may also be related to the fact that students find it harder to keep focused and productive despite having obstacles in their projects. This is what the variable 'effort regulation' seems to reflect, and we cannot rule out that some of these obstacles they encounter (e.g., not being able to work and coordinate appropriately) are directly related with limitations due to COVID-19 restrictions in the school that impede face-to-face working in large teams.

Regarding interdisciplinary project-management skills, we saw that the only significant change is an increase in risk-assessment skills. Students perceived themselves as more capable of assessing the risks involved in the project and dealing with the uncertainty of it. While coaches assert that project-management skills are not part of the common engineering curriculum, it seems that escaping the well-defined environment of regular theoretical classes and directly participating in these kinds of projects, students feel more comfortable over time to deal with the unpredictability arising from many factors, from misunderstandings in the team, to lack of resources and funds.

As for the main take-aways and recommendations for the future, we propose the following:

- Make sure the students have an operational working environment at all times. Operational and organizational issues are not to be underestimated and they can erode students' motivation if all their energies are focused on overcoming issues related to, say, infrastructures, IT, resources, legal and financial needs, administrative support, etc.
- It is important to more tightly follow students' endeavours and provide support to remediate difficulties encountered throughout the project, which may help to better sustain high levels of intrinsic motivation and effort regulation.
- Students don't learn collaborative and communicative skills spontaneously: it is important to have explicit practices to promote these skills and save some time for scaffolding them and to give some feedback on them.
- As metacognition did not improve throughout the projects and students convey issues with time management, we suggest to model project schedules for students and to provide explicit opportunities for them to write their own plans and schedules to prepare working sessions and distribute roles.
- As critical thinking skills seem to stagnate over time, it is important to provide better opportunities for the students to criticize the ideas and proposals presented in the projects and come up with their own solutions. Coaches should engage in critical conversation with students so they can identify potential drawbacks and areas of improvement.
- As only one of the five project management skills improved, it seems relevant to implement explicit programs to promote the conscious acquisition of those skills (Picard et al., 2021).

This study has some important limitations. First, the survey response rate (36 out of 85) poses a threat to generalization of these results to all students and we cannot deny that the results may be biased in relation to the whole population of students. We hope to have more responses as the rest of the projects finish. Second, we lack a control group with which to compare our results, so without a counterfactual our evidence is purely correlational and far from the realm of causality. We recommend future studies where evidence goes beyond self-reported data. Likewise, future studies could explore more in detail the evolution of the students' motivation and learning strategies. This study puts forward the need to unravel how much of those changes in students' motivation and learning strategies are due to their prior expectations, and how much of them are due to adaptive reactions to succeeding or struggling with their projects.

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