From PBL to innovation: a decennial case-study from an HPV student team

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Abstract

Purpose - The implementation of Project Based Learning (PBL) activities in the curricula of engineering students has become a consolidated method to improve their skills. The purpose of this article is to share the experience acquired by the authors from a decennial case-study on a student team PBL activity focused on design and development of Human Powered Vehicles. A review of the project evolution, boundary constraints and management choices could provide inspiration and suggestions to faculty staff that would like to set-up similar experiences for engineering students in their universities.

Design/methodology/approach - A student team was funded by the authors in 2008 in order to gather engineering students interested in design and construction of Human Powered Vehicles (HPVs). In the last decade, the team has grown from 10 up to 60 students enrolled per year and stimulated to develop a range of HPV designs for sports and mobility. The project management evolved as a consequence in order to comply with the growing ambitions of the group and complexity of the goals.

Findings - A thorough analysis of factors contributing to the success of the project led to identification of the key factors to increase student participation: persistence of the faculty staff is essential, attending competitions and challenges increases students recruitment, formal recognition of the activity through credits and the implementation of intermediate assessment steps increases the active participation rate. Bigger teams reduce the negative impact of recruits eventually abandoning the project in a early stage. Ambitious goals keep motivated students for longer periods and enable a virtuous circle by transferring enthusiasm and knowledge to new members.

Research limitations/implications - The activity is analysed starting from a subjective experience perspective and some of the findings/conclusions may be not applicable in a different context. However such review can suggest strategies on the long term period in order to create similar conditions elsewhere.

Social implications - In the last part of the paper, it is pointed out how PBL projects can provide a fertile ground for innovation and lead to patents and development of new products aiming at the market.

Originality/value - This study contributes to provide an insight view of how a student team PBL activity can grow over a decade if guided by faculty staff.

Keywords: Project Based Learning; Education practices; Design team management; Innovation; Human Powered Vehicles.

1 Introduction

Project Based Learning (PBL) in university educational path is a widely explored approach "*based on the constructivist finding that students gain a deeper understanding about a certain topic when they are asked to build their knowledge working with and using ideas*", Krajcik & Blumenfeld (2005). The roots of this methodology are ascribed to educator and philosopher John Dewey (1959), arguing that students are prone to make a personal investment on a subject if they are engaged in real, meaningful tasks and problems. This approach to education has been widely applied and analysed in the last decades and example of PBL projects can be easily found all around the world. Extensive literature reviews about the PBL approach were published by Helle et al. (2006) and, recently, by Kokotsaki et al. (2016). Interesting arguments in support of the PBL approach were published by Blumenfeld et al. (1991), with particular focus on the motivational aspects although mainly referred to children students. Lehmann et al. (2008) highlight the needs for interplay, mix and diversity in engineering education and suggest the problem-oriented and project-based learning approaches as possible answers. An analysis carried out by Johnson et al. (2015) indicates that PBL experiences significantly increase the self-efficacy of engineering students, together with the goal orientation of their learning. Other interesting perspectives on both problem-based and project-based learning can be found in Gülbahar & Tinmaz (2006), Perrenet et al. (2000), Kolmos (1996), Bell (2010), Markham (2011) and DeFillippi (2001).

A specific form of engineering PBL involves the integration of an heterogeneous group of students within a team which is oriented towards design and building of a product (often a vehicle), in order to attend regional, national or international competitions. Ifenthaler et al. (2014) explored how students learn in a team-based graduate course using a theoretical framework that focuses on the cognitive functions of team-based processes and team performance. Knight et al. (2007) report an increased student retention rate when hands-on team-based design projects are introduced since the 1st year of engineering. Denton (1997) examine planning and practice aspects of multidisciplinary team based design project at undergraduate level. The interdisciplinarity plays a key role in strengthening the student curricula and experience, as discussed in Carla et al. (2018). Borrego et al. (2013) analyse a range of team-based approaches trying to identify good and bad practices while pointing out great opportunities to apply industrial and organizational psychology research to engineering education. The implementation of Moylan (2008) proposes a review of several PBL endeavours and addresses the successes of these programs in improving student learning. According to McLening et al. (2018) and to Burnik & Košir (2017), team-based projects have a positive impact on graduate employability and career futures of the participating students. Implementation of PBL in student curricula is being explored worldwide in many different engineering areas: an example in the field of electrical engineering and renewable energy is presented by Leite (2017), while in Fini et al. (2018) a PBL in the field of transportation engineering is discussed. Moreover, team-based PBL can be specifically organized in order to provide a “global dimension” in engineering curricula for students not having opportunity to travel abroad, as pointed out in Sanger et al. (2018). Other interesting perspectives with focus on team-based PBL in engineering education are provided in Weloa et al. (2013), Jensen et al. (2003) and Seidel & Godfrey (2005).

A fundamental aspect to build a team-based PBL over years is to set up a fair evaluation of student contribution to the project. This can rely on the supervising teacher or can be achieved through peer assessment among team members. An insight about the last option is provided by Devlin et al. (2016), where two methodology for peer assessment within a software design PBL are presented, discussed and compared.

The Student Team PBL (ST-PBL) approach is specifically suitable for engineering students due to three main reasons:

- to provide a hands-on experience where students can find practical application (and thus deeper understanding) of theoretical concepts taught in traditional lectures;
- to stimulate their curiosity on physical phenomena that needs to be deeply understood by engineers in order to achieve successful design;
- to let students develop soft skills of primary importance in real world industry, where their career is likely to develop.

The last point is of particular importance since, in design teams, the capability to communicate effectively within members is a key for success. All products, even those aiming at a very specific goal, are always the result of an intelligent compromise among contrasting design factors. Such a compromise must be achieved through communication between the different sub-section of a design team. Moreover, dealing with deadlines in design, construction and testing for a race, makes the students aware of the importance of planning in advance their activities, and they will learn that whether they succeed or fail.

In this paper, a decennial ST-PBL case-study carried out by the authors is presented. After summarizing the context and the project evolution over years, the main factors that contributed to increase both enrolment and active participation of students in the PBL will be analysed and the learning outcomes will be summarized. In the final part of the article the path that led from the PBL to a potentially innovative product will be discussed, trying to highlight the key aspects that made this result possible.

2 Case-study: HPV student team at Politecnico di Torino

2.1 The context

ST-PBL at Politecnico di Torino started from SAE Formula team (2005) and then gradually expanded with the creation of a Shell-Eco Marathon team (2007), human-powered vehicle design team [OMITTED TEAM NAME] (late 2008) and many others up to the current number of about 15 stable teams plus other 25-30 occasional ST-PBL activities. At least 7 of the 15 stable teams are focused on design and construction of vehicles, including cars for different purposes, motorcycles, boats, drones, aircraft and bicycles.

Student teams are economically supported by Politecnico di Torino through an internal panel in charge for evaluating project proposals according to defined rules. The panel is headed by the Vice Rector for Education and is composed by a mixed group of faculty, technical and administrative staff plus a student delegate. The panel provides 5-6 calendar deadline for the teams to send their proposals, requiring to explain in detail the scope, the time-line and the provisional cost of each project. Then, a small representative of each applicant team is required to held a short presentation in front of the commission that will finally approve (or reject) a full or partial budget.

After this process, the team receives funds under management of the Department to which belong the Academic Responsible (a mandatory figure) and the group is required to spend all the budget within the planned time-line (usually 1 year). Before submitting a new financial support request, a detailed final report of the previous project must be presented. For any change in the planned use of the money the team is required to ask approval to the panel by email.

Internal organization of the team and level of interaction with the Academic Responsible and/or other supervisors is not subject to any specific rule. The supervisor activity is a form of volunteering, totally unrelated to their lecture duties and with no rewards in terms of career, although a reduction of their lecture duties is currently being discussed. No laboratory or workshop space is formally assigned to the teams by the panel and is up to the hosting Department to eventually provide a space. This is a critical point in the overall management of ST-PBL and the University is currently evaluating a solution for all the teams.

Starting from 2012, the active participation to ST-PBL is recognized with credits in almost all engineering courses at Politecnico di Torino. In particular, students from mechanical, aerospace and automotive engineering can obtain 6 credits in their bachelor and 6 or 12 credits in their master careers, depending on the level of dedication (i.e. 12 credits are typically recognized to the team leader and/or to section managers).

Within this general framework, the decennial history of [OMITTED TEAM NAME] Team PBL has developed as summarized in the next section.

2.2 Foundation and evolution of [OMITTED TEAM NAME]

Human Powered Vehicles is an expression used to indicate a wide range of machines, including the most popular safety-bicycle as a sub-category. In fact, HPVs can be intended for use on land, water (on surface or submersed) and even for flight purposes, all representing an opportunity to create valuable PBL projects as demonstrated by the existence of a significant number of student challenges and competitions that can be easily found all around the world. However, the experience developed at Politecnico di Torino through Team [OMITTED TEAM NAME] has been strictly focused on laid-back pedalling vehicles for land use, up to now.

In late 2008, the authors proposed to a small group of 4 BS and 2 MS students in Mechanical Engineering to work on a HPV project by constituting what is now referred as Team #1. The Team #1 enrolled few additional members and received approval for economical support in June 2009 to start building his first recumbent prototype. The racing debut was in May 2010 at the WHPVA World Championship in Jersey Island (JE) with no significant results in the competition, but a huge injection of enthusiasm and learning-by-errors experience. Since then, the Team has been annually renewed with new members, but letting "veterans" free to continue their experience, up to the current Team#10 (academic year 2018/19). This approach granted a progressive building of the team identity and technical knowledge. New HPV projects were realized in the following years with a progressive evolution of goals and complexity level, as summarized in Figure 1.

2.3 Learning outcomes

With few exceptions, the students approaching the team are quite unaware of what an HPV is. They are familiar with the bicycle in its most popular forms: road racing, commuting, mountain bikes and few other categories. Obviously, being involved in such specific PBL, most of them will acquire a wider perception of HPV technologies and market, however this is not the most interesting learning outcome. Developing projects in the field of HPVs allows engineering students to internalize and consolidate some important concepts that are listed in the following.

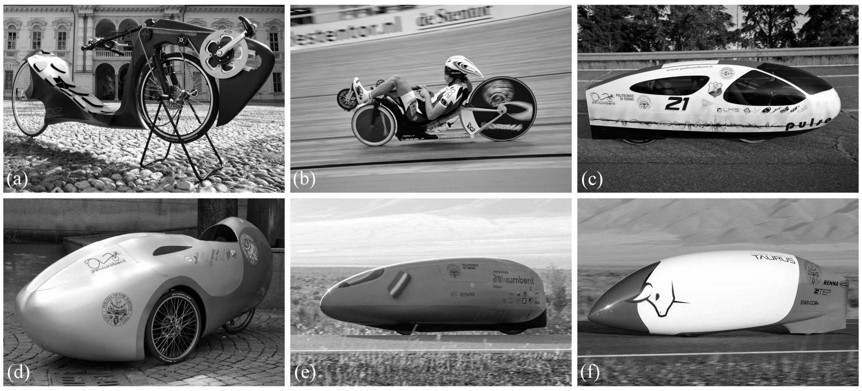

Figure 1: HPV projects realized by the Team: (a) CORA 2010, (b) Cor-Al13 2011, (c) Pulse 2012, (d) S-Trike 2014, (e) PulsaR 2015, (f) Taurus 2017.

The relativity of "perfection" - The most popular design and shape of a vehicle (i.e. the safety bicycle among HPVs) is not an absolute optimal with respect to all specific requirements. Many cycling enthusiasts often refer to the safety bicycle as "the perfect machine". However, this definition can be wrong depending on the premises: perfect for what? Not for comfort and ergonomics since the recumbent position is more naturally accepted by the human body and prevents many typical cycling pathologies. Not for speed and efficiency on flat and smooth roads, as other HPVs can reach much higher speeds for the same amount of power input in these conditions. Maybe for climbing roads with high slope, although not proven by any scientific comparison. Maybe as a practical vehicle for everyday commuting, despite conflicting cohabitation with motorized vehicles in many contexts.

Another popular sentence states that "bicycle design naturally evolved toward the optimal solution", ignoring that such a technical evolution was strongly driven by design rules imposed by a sport federation, the UCI (Unione Cycliste Internationale). Those rules not only affected the evolution of road racing bicycles, but, by conditioning the popular perception of what a bicycle is, they defined the technical solution for all other kind of bicycles, including those intended for everyday commuting.

Students entering an HPV Team will be more cautious with respect to popular sentences about "perfection" of a machine and they will have new perspectives about historical evolution of technology which is not always strictly related to a technical point of view.

The central role of compromise - The compromise plays a fundamental role in every project, even for the most specialized machine such as a world record aiming HPV. For sure, aerodynamics, rolling resistance and transmission efficiency are the leading design features. However, the rider has to fit inside the shell, to reach the pedals with physiological knee angles and to have a good perception of safety to deliver all his power. In addition, the steering must be sufficient for the assisted start and stop, the vehicle weight is not to be neglected, the shell needs a split for the entrance and a safe locking system operable from the external in case of crash. All these additional aspects challenge the group to find a compromise with respect to the three initial leading features.

The importance of data-driven decisions - In HPV competitions, the rider feedback plays an important role to fix and tune the vehicle, but it can be sometime misleading due to its subjective nature. During the year of activity, the students learn to process and analyse the rider feedback with a critical approach by taking into account the context. As an example, if the rider feels new tires are "rolling better", the information is stored as "opinion" and critically analysed when back from testing: was really the tire or the road was smoother? Or the bike lighter than previous test? Or the better wheel rim where the tire is mounted? Then, objective measurements are defined to collect data before classifying new tires as "faster".

A human-centred perspective in machine design - With the end goal to teach future engineers for a greener way to deal with transportation, we have to ensure that they truly comprehend the meaning of physical quantities and develop a practical perception about their order of magnitude. Power and energy amounts tends to lose their human-focused reference point when they are exclusively taught from a motorized point of view. Although most young engineers are familiar with power and energy concept for a variety of motorized vehicles, they are often unable to relate these quantities to themselves. The effort needed to generate power with our own muscles is the most basic, direct and practical experience we can have, as humans, about power and energy. If the next generation of engineer and technicians will be asked to develop more sustainable transportation systems, it is desirable for them to have a clear human-centred perception of these quantities.

2.4 Factors affecting student enrolment

The attractiveness of an HPV project for engineering students is quite trivial to explain: a sport related topic, with a competition promising unusually high speeds for a bicycle on flat (far over 100 km/h). What a young hopeful engineer can ask more? From the first overview of the project by means of pictures and videos, the idea of achieving such a speed on human legs is able to trigger curiosity and emotional involvement in most of the students. Figure 2 shows the team growth from the foundation up to the current group, including a distinction among new members, veterans (students remaining in team from the previous year) and occasional "Erasmus guest" students that were hosted by the project.

The team evolution can be divided in two distinct phases:

- phase 1 including two sub-phases:

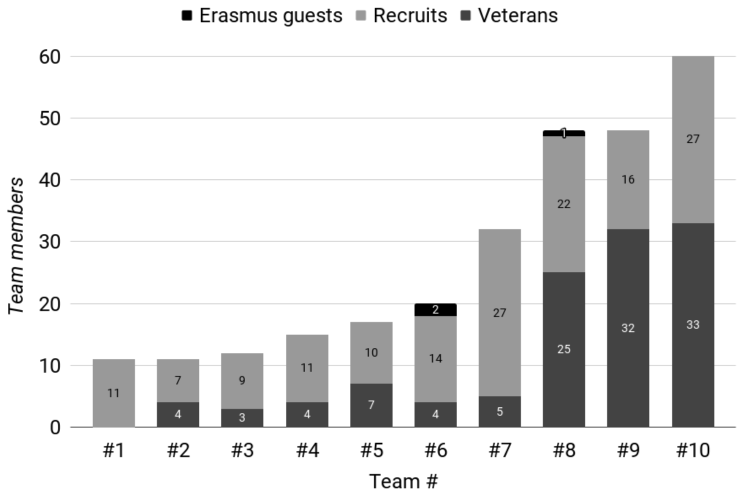

Figure 2: Team members evolution from Team #1 (2008/09/10) to Team #10 (2018/19).

[1.1] teams #1 and #2 (2008-2011): relatively small teams with 11 nominal members with a good active involvement rate (around 60%);

[1.2] teams #3 to #5 (2012-2014), slow growing teams up to 17 students, but a lower active involvement rate (less than 40%);

- phase 2 - teams #6 to #10 (2015-2019): rapid growth from 20 to 60 nominal members and higher involvement rate (around 70%).

This progress, involving an overall number of 157 students through 10 years, was possible thanks to a combination of factors. It is clear from the above described path that in the 1st phase the overall project suffered by the lack of experience (both technical and managerial) and, even more, by the lack of an ambitious goal (such as a world record). However, phase 1 helped the faculty staff to develop managerial skills and to reshape the project up to its current organization. Two key factors surely contributed to make this evolution possible: a significant time investment from the faculty staff, driven by passion for the PBL approach in engineering education, and the persistence of a cyclist-student, that has been deeply involved since team #2 (except a temporary suspension during team #4 and #5).

The previously mentioned attractiveness of "speed" is clearly emerging from the jump in recruitments for team #7 (Figure 2). The first WHPSC participation in September 2015 (team #6) had a boosting effect on this ST-PBL attractiveness thanks to an increased local and national media coverage and to the fascination of challenging a world speed record. Indeed, while the recruitment from Team #1 to #6 was totally open, with a dozen of candidates per year and without any selection process, starting from team #7 the recruitment had to face with almost 100 applicants per year. As a consequence, the selection process started to be accurately defined and limited to specific positions within the project. Also, the percentage of veterans opting for a continuation of their experience was increased after the WHPSC participation, in particular from team #7 to #8 where 78% of the previous members opted to prosecute. There is a specific reason for this trend: team #7 has worked in parallel to the upgrade of a previous prototype (PulsaR) and to the design of a new one (Taurus) for the next year. As a consequence, almost all students that had a role in the new design were strongly motivated to stay and see their idea taking shape. Moreover, the sub-group of team #7 that went to Nevada in 2016 was so excited by the experience that they wanted definitely see the project improving and it was natural for them to become each one responsible of a team section.

An overview of the project evolution is summarized in Figure 3, where each team has an attribution title that can be explained as follow:

- *foundation and continuation*: team #1 was in fact prolonged over a couple of academic years in order to start from scratch a totally new activity without any background;
- *confirmation*: recruiting team #2 and realizing a 2nd project confirmed the capability to renew and prosecute over years;
- *evolution*: team #3 started aiming at ambitious goals and more complex design by switching towards fully faired vehicles, but with poor results due to inexperience;
- *pause*: team #4 suffered the pressure to develop two separated projects (sport records and green mobility), resulting in a slower development process, difficult organization and unclear goals;
- *restart*: team #5 focused on the green mobility project and succeeded in making a new vehicle, although the final result was not remarkable from a technical point of view;
- *now or never*: team #6 choosing to finalize a speed-bike project to attend the World Human Powered Speed Challenge (WHPSC) yearly organized in Nevada (US) by the IHPVA (International Human Powered Vehicle Association). That was perceived as a dream target since the beginning of the whole team experience and the team felt that more delay would have been detrimental to the entire project;
- *enthusiasm*: the visibility gained by the previous team attracted more students and provided strong motivations for team #7 to improve the existing HPV and to start designing a new one;

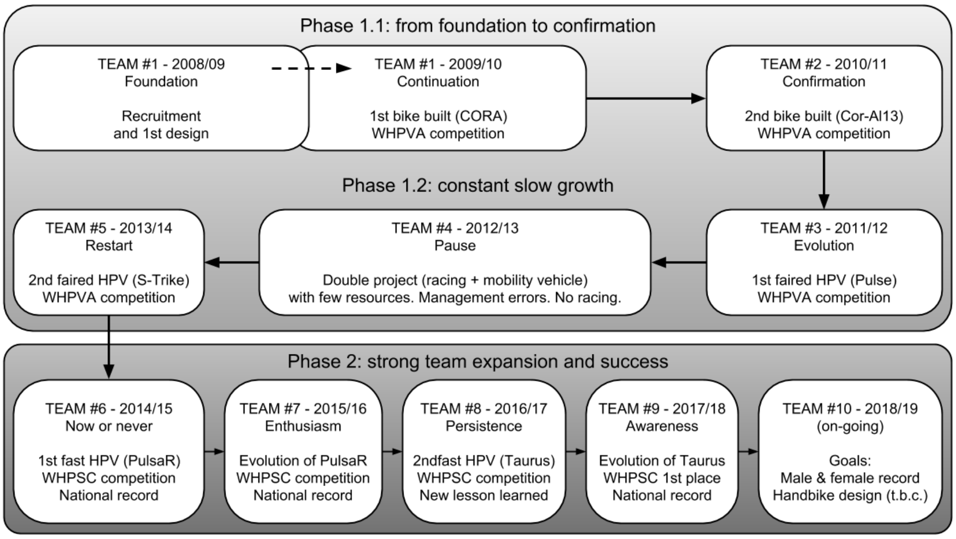

Figure 3: Project evolution overview.

- *persistence*: team #8 demonstrated to be persistent in working for improvements, despite the world record was pushed at a discouraging level in the previous WHPSC edition by a Canadian private team;
- *awareness*: by working on important details to evolve the previous project, team #9 reached a new technical level that was rewarded by victory at the WHPSC. Team #10, the largest group up to now, is now working on a double goal for male and female speed records and is starting a third parallel project for a speed-handbike to build in 2021.

The previous analysis clearly shows a key factor for the ability to attract students to this type of project: to propose an exciting and well-defined challenge (i.e. a world speed record) in an international competitive context.

2.5 Factors affecting student active participation

The recruitment of new members in an ST-PBL is a necessary first step that can be nullified by a lack of real involvement of the students themselves. As mentioned above, the numerical growth of the team was followed by different rates of active involvement. In particular, there was a decrease in active involvement during phase 1.2 of slow progressive growth (Team #3 to #5) and a subsequent recovery in phase 2 of numerical boom (Team #6 to #10). In this section, the factors that contributed to these changes will be analysed.

The main braking force for new students to get deeply involved is the lack of self-awareness about their potential contribution to the project. Therefore, it is important to provide them an overview of the expected (ideal) progression, as in the following example list:

- within 1 month: all recruits will explore previous team vehicles to gain knowledge about technical vocabulary, issues, potential improvements, successful sub-systems to be preserved;
- within 3 months: all recruits will be able to classify design features and related activities by importance and by logical sequence. Then they will define a specific team sub-group to be involved in and a sub-topic to develop their expertise;
- within 6 months: recruits will show a robust knowledge in their sub-topic and will be able to propose strategies and technical solutions to improve the existing or to develop a new vehicle.

However, such an ideal progression is a reference model and, in most cases, the activity is already ongoing when new members are selected. As a consequence, they are directly addressed to a specific sub-group and gradually introduced to their tasks with a learning-while-doing approach. This approach raises the risk for less skilled recruits to feel inadequate and potentially abandon the project or to become passive. The active involvement rate is affected by two typical phenomena in ST-PBL experiences:

1. some veterans stay in the group because of their emotional connection to the project, but then eventually become inactive since focused on other study deadlines when is time to conclude their educational path;
2. new members approaching the team for the fascination of the challenge, but then becoming inactive since they underestimated the required time investment or think to be unable to contribute or had difficult to integrate within the pre-existing group, etc. Obviously in this case, students abandoning the project do not get any credit.

In general, it is interesting to observe how the percentage of inactive students dropped with the recent member increase starting from Team #7. This trend is ascribed by the authors to a combination of factors:

- the introduction of a recruitment process based on curricula and a short interview (held by veteran members), allows to identify the most reliable and motivated profiles among candidates;
- a more structured organization (as necessary for a large group) of the whole activity with sub-groups, clear roles, detailed responsibilities for some of the veterans gives to new members a better perception of their role and of the overall framework;

- a flywheel effect. It has been observed that most of the team members behave as followers. Within a small group of 10 students, if 2 members are really involved and 3 become inactive, the remaining 5 followers tends to loose interest and to become inactive. However, within a large team of 50 students, with a base group of 10-12 strongly motivated members (i.e. 6-7 veterans plus 4-5 well selected recruits), even when 10-15 members become inactive, the remaining followers tend to actively participate and this enables a virtuous circle;
- during each year, around March, team members can (optionally) apply for the upcoming trip to the WHPSC in Nevada, which is held in September (overlapping one exam session). The budget usually allows for 12 to 15 participants, including the rider and a staff member. Then, a selection is made by the technical advisor, giving priority to the level of active participation, to the "usefulness" of each member and applying a ratio of about 3:7 between veterans and recruits.

The last point may look critical in the overall management since an "evaluation" in the middle of such an yearly project could potentially change the group equilibrium. However, the authors were positively surprised, up to now, by the student reaction to that. Firstly, the optionality of such application implies a self-assessment of the students and, with few exceptions, members that were inactive during the first semester usually abstained from applying. Then, although the authors expected a raise in participation for the selected sub-group and, eventually, some defection among the non-selected, this did not happened in general. Beside very few exceptions, an increased participation was noticed also for the non-selected students, that probably became aware of their under-average contribution until that moment. In any case, after the selection, a detailed follow-up explaining all the factors that ruled the choice is always made and eventually discussed with the entire group.

In conclusion, the previous analysis highlighted three important factors to keep alive the active involvement in the team: a well-defined filter during recruitment, an intermediate assessment to make students aware of their contribution and the presence of a strongly motivated subgroup able to involve the followers with a flywheel effect.

3 From PBL to innovation

Thompson (2012) already highlighted how the boundaries between engineering design and business are increasingly blurring and the demand of imaginative, pioneering engineers is growing in modern societies. Creativity is a natural resource among young engineering students, but they often needs to be guided towards maturity in order to not "reinvent the wheel" and to achieve effective innovation. As pointed out by Elizondo et al. (2010), creativity and innovative thinking are difficult to teach in the classroom, but their inception can be achieved through practice and experience. This observation is true for individuals, but can be extended to teams and small companies from a wider perspective (and to the history of technology in our society, from an even wider point of view). Even though most team members change every year, it is possible to preserve, transmit and thus increase competence and knowledge. This transfer of inheritance takes place mainly in four ways: through those who remain over the medium term (veteran students active over 2-3 years), through who oversees the long-term project (university staff), through technical documentation and through built prototypes that remain available to new members.

Beyond the primarily educational purpose of team [OMITTED TEAM NAME], designing and implementing something new has been an intrinsic secondary objective from the very beginning. However, considering the recumbent niche market, there were no expectations in terms of market-oriented innovation. Despite that, the growth of technical level in the 2nd phase of the team evolution led to the filing of three patents. Starting from very specific needs of the project, some sub-sections of the team were able to develop original ideas with a potential impact on the bicycle market. Therefore, Politecnico di Torino decided to protect those potential innovations through patents and to promote further development.

3.1 Technical details of the patented solutions

The 1st patent application was deposited in 2017 and concerned a variable length bicycle crank designed to recover the radial component of the pedal force that is usually lost in traditional pedalling systems. In this case, the initial enthusiasm rapidly vanished due to lack of real interest from the group of inventors towards prototyping and experimental validation. The students from this group were spread away for different reasons (started working in companies or a master program in a different university or stopped their educational path, etc.) and there was no chance to create a sustainable path for the project to evolve.

The 2nd and 3rd patents (2017 and 2018) concerned two similar but different systems for realizing an electronic gear shift with moving cassette (Figure 4). Although developed and prototyped in relation to a very specific and unconventional transmission design, the involved students were interested in developing a derived version for conventional bicycles. As a consequence, with the help of the authors, the project was presented to a proof-of-concept call funded by the university and won the economical support to develop a marketable version of the product. Moreover, the project is now being considered to become part of a spin-off company together with other bicycle-related ideas.

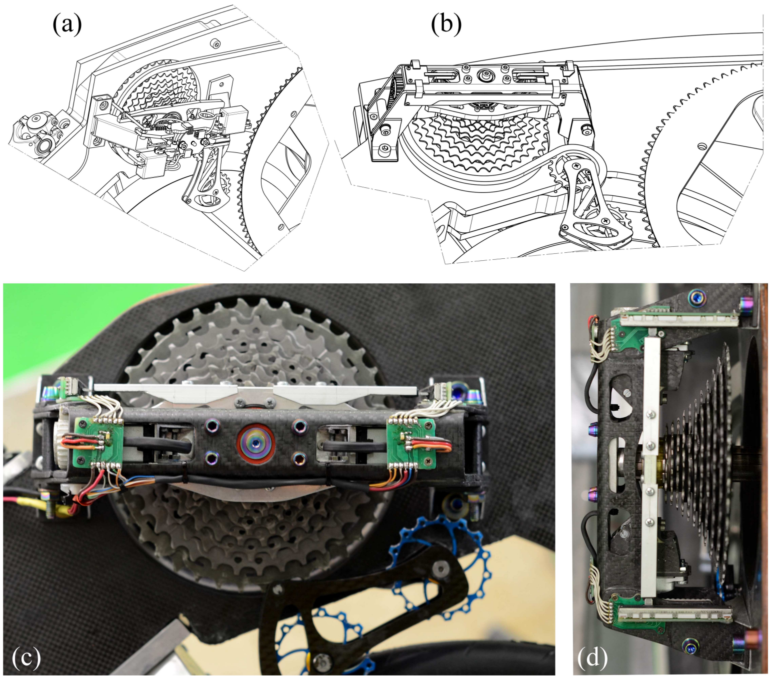

Figure 4: Electronic shift with moving cassette: (a) version 2017 drawing, (b) version 2018 drawing, 2018 prototype (c) lateral view and (d) top view.

The patented transmission allows to keep the chain always in perfect line with a single chainring while shifting up to 11 (potentially 13) gears on the cassette. Instead of moving the chain tensioner, as it happens in conventional bicycle transmissions, the cassette is mounted on a sleeve that can slide on the transmission shaft thanks to a prismatic coupling. In the 1st version (2017), the servo-motors were fixed on the external support and the motion was imposed through a non-linear leverage system. In the 2nd version (2018) the servo-motors are connected to the moving sleeve, allowing them to act linearly on the cassette position by means of a gear rack and pinion. Moreover, a sensor (potentiometer) is placed on the frame to detect the effective position of the cassette and to provide a feedback signal to the control unit. In the speed-bike Taurus, the shifting system is mounted on the frame, at an intermediate stage of the whole transmission, and a second chain is transmitting power from the shaft to the wheel on the left side of the vehicle. The cyclist is selecting the gear ratio through simple up/down buttons on the handlebar.

While the project started from an advanced TRL (Technology Readiness Level) close to 8, with the 2018 version successfully used in the WHPSC competition, its development towards a marketable version has to go far back in TRL (down to 2-3) to reshape the entire system and to respect additional constraints. Indeed, the cassette will need to slide into a custom hollow hub at the rear wheel, the weight has to be reduced, protection from water and mud needs to be taken into account and it is not yet clear if the system will fit on a standard frame or it will require a custom one. The potential target application is for triathlon and time-trial bicycles, where a single chainring is used and where even a marginal gain from the improved efficiency of a perfectly aligned chain can play a significant role. As in every research-to-market project, it is hard to predict success or failure in this early stage, but the inventors are strongly determined to develop the product and to try finding a place for it in the bicycle market.

3.2 Accidental innovation?

The development of patents and a potentially innovative technology for the traditional bicycle market, starting from an ST-PBL context and a very specialized speed-bike project, could appear to be a fruit of chance. However, this outcome is actually the fruit of a fertile background without which it would hardly have matured. It has often happened in history: scientific discoveries and technological innovations arise from a push towards a limit to be crossed and develop in contexts where this driving force is collected and developed by a group of people with available time and budget. It matters little whether these people are highly specialized scientists and technicians who aspire to space exploration or a small group of young students in a garage that wants to win a sporting challenge: both represents fertile ground for innovation and in both cases the fallout can be well outside the specific context in which the idea was born.

Therefore, the answer to the section title question is “no”: it is the context itself that has created the premises (the thrust and the boundary conditions) necessary for the birth of technical innovations. The times have been longer than can be expected in a company context, but this is due to the peculiarities of the project: the continuous turnover of students involved and the initial difficulty in orientating oneself towards a sufficiently ambitious and stimulating challenge.

4 Conclusions

The decennial experience of a student team PBL focused on HPV design at Politecnico di Torino was presented in this article in order to provide inspiration and suggestions to teachers interested in providing a similar experience to engineering students.

The PBL evolution and growth has been analysed by identifying boundary conditions and key factors that determined the project path through years. In particular, it has emerged as a key factor for attracting students to the project the identification of an exciting and clearly defined challenge within an international framework. Therefore, three main factors have been identified that favour the active involvement of the participants: a careful selection during the recruitment phase, the introduction of an intermediate individual assessment to stimulate in the students a critical review of their contribution, and the creation of a motivated subgroup of veterans who can drag less proactive members.

Finally, we discussed the recent development within the ST-PBL of patents and innovative technologies for the cycling market, highlighting how these were not born fortuitously, but were a natural maturation of the project in the fertile ground where it has developed.

As typical in every successful project, it emerges that good results are just the tip of an iceberg underlying a remarkable time investment, trial and errors and persistence.

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