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Innovative and multidisciplinary teaching to design a low consumption vehicle

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Abstract
The paper presents an innovative and multidisciplinary method for teaching how to design a low consumption vehicle point out at the Politecnico of Torino thanks to the application cases of the Team H_2politO.
The interdisciplinary Team, made by students, give an opportunity to tackle a "new teaching", different from that of the traditional classroom lesson given by the teacher, but innovative with the students who are able to tackle complex technical problems, such as those they will face in the world of work.
The challenge of the Team is design, build, assembly and test on track a real vehicle prototype with an important goal: reduce the consumption and increase the distance obtained with the equivalent of 1 L of gasoline. The final global efficiency challenge is the Shell Eco-marathon race, an International student's competition where the vehicle with the lowest consumption wins.
Every year new students managers of the different areas "grow up" training students who, year by year, change roles, realizing a non-traditional and innovative training, from student to student and learning by doing. In this way, the University is able to develop a new generation of engineers, able to solve complex technical problems but who also have managerial skills, more ready to enter the world of work.

Keywords: SDG4, SDG5, SDG7, SDG12
CAD & FEM analysis, Vehicle Dynamics, Multi-body Simulation, Aerodynamics, energy optimization, low consumption vehicle, Education, Research.

1. The Team H_2politO

The Team H_2politO was born in 2007 with 15 students and then year after year it has grown to have until 80 students.

The Politecnico of Torino missions was to create an interdisciplinary Team made by student (bachelor and master degree) which come from different engineering fields (mechanical, automotive, aerospace material science, electronic, informatics, mechatronic, management, etc) with a goal: design, build, assembly, test on track ad finally participate at the Shell Eco-Marathon (defined also SEM) competition.

The 1st participation at the SEM of the Team H_2politO was in 2008 in Nogarò (France) with the vehicle IDRA08, a fuel cell prototype.

The Team 2021 is composed by 60 students, approximatelly 40 from bachelor and 20 from master degree, organized and followed by a Team Leader, that is the firt contact with the Faculty Advisor. Each Vehicle has a Vehicle Manager, that organize the different area: Mechanics, Electronics, Fuel cell, Combustion Engine, Aerodynamics, Dynamics and Strategy, Management and Communication.

2. The Technical Challenge

The European SEM is an International competition organized by Shell from more than 30 years. It is, first of all, an educative project that brings together the values of: sustainable mobility, low consumption, emission reduction, alternative energy use.

Following a certain number of phases every year more than 200 Teams (made by students of University and high schools) are selected to take part at the competition involving more than 3000 students arriving from all over Europe.

The vehicles must be designed considering the technical and safety competition rules [1] that are relative to: maximum dimensions and mass, mechanical and electronic safety, safety belts, roll bar, powertrain etc. In fact the judges, during the "Technical and Safety Inspections" (Figure 1 left) make a detailed analysis of each vehicle to give the mandatory stickers (Figure 1 right) that allow to run.

The SEM has two different vehicle categories:

- Prototype (three wheels vehicle),
- Urban Concept (four wheels vehicle).

And different propulsion system:

- battery-electric,
- hydrogen (fuel cell),
- combustion engine (gasoline, diesel, ethanol).

The last SEM was in 2019 in London (Mercedes-Benz World Track Weybridge – London) and the competition rules were to complete 11 laps of the track, for a total distance of about 15.6 km in a maximum time of 39 min, with a "Start & Stop" phase at each laps for the Urban Vehicle Category. Each Team has 4 tentative of run available, and for the final ranking the best one is considered to evaluate the consumption in kWh, kg/m^3 of energy or km/L that can be traveled with the equivalent of a liter of fuel.

Fig. 1. Technical Inspection (left) and Technical and Safety stickers (right)

3. The innovative path

However, despite the SEM has existed for more than 30 years, as well as other student competitions (for example the Formula Student or Moto Student), there are no standard for the management methodologies (as a function of University) or scientific literature about it. When a Faculty Advisor begins to follow a team sets the rules related to his experience or from the comparison with colleagues.

From the beginning, the Team H_2politO was organized as a Business Team (Figure 2) where instead of the Product and the Market there are the Vehicle Prototype and the Competition, with two fundamental common aspects:

- deadlines,
- budget.

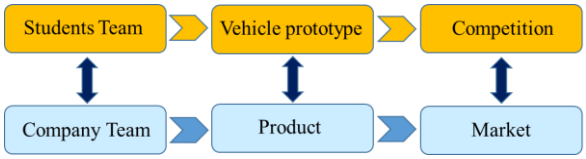

Fig. 2. Organization comparison between Student and Company Team

Observing Figure 3 it is possible to explain the connection between the Innovative knowledge and the Traditional Didactic knowledge. The students thanks to the knowledge and skills acquired during their academic career (Traditional Didactic) have the opportunity to learn more competencies, also multidisciplinary, managing a real project from A to Z, working together and not individually, solving real problems, typical of the workplace (Innovative knowledges). The blue narrows explain the work flow while the red narrows explain the closed loop of the path, in particular take into account the competition results obtained of the Team it is possible to change, year by year, the innovative and the didactic path. [2]

The Team H_2politO is a different, innovative and somehow unique project, is not just a Team but also something more: it is a new type of conceiving educational, professional and personal growth.

Team members aim at being perceived as an experimental laboratory where competences, capabilities and potentialities of future's engineers are fostered. Students strive to become not only solid and advanced technical experts but also, equally important, down-to-earth managers having excellent communication, leadership and teamwork skills.

Practical and hands-on experiences are doubtlessly a complementary and enriching form of educational path. Therefore, H_2politO firmly believes that learning by doing represents an absolute advantage Team members can count on.

Figure 4 explains the methodology used for the transfer of know-how between students year by year, in particular the *New Team* formation, that maintain the *Remaining students* come from the *Old Team* and involve a certain number on *Training students* (selected by the *Student manager/Leaders* after an *Advertising campaign* and a *Recruitment* phase). The *Student manager/Leaders* are some students of the *Remaining students* group that have particular *leadership* and are able to be the Responsible of each technical area (Mechanics, Electronics, Aerodynamics, Vehicle dynamics/Race strategy, Fuel cell, Combustion engine, Management, Social Media) or/and the Team Leader.

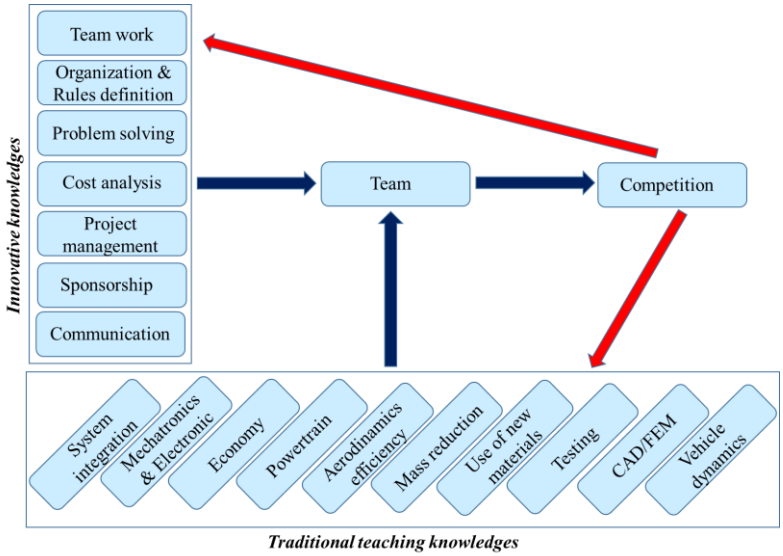

Fig. 3. Team path

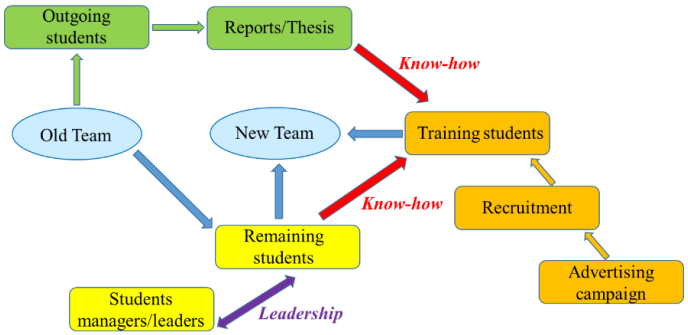

Fig.4. The passage of knowledge and the formation of a new Team

The *know-how* passage is possible thanks to the use of Reports that all the students have to do to describe the technical activity during the stay inside the Team, but also thanks to the *Thesis* (Bachelor and/or Master) that the *Team Members* develop inside the Team itself (from the beginning until now 200 thesis has been developed).

4. The application's method to design a vehicle

Starting from a "white sheet", the students, under the technical supervision of a Faculty Advisor, design the vehicle. Partner companies (if not commercial) make the components, then the student's assembly all the subsystems, testing all in laboratory and complete the assembly of the vehicle. Finally, the tests on the track, before the competition, allow validating the vehicle dynamics and strategy models.

Fig. 5. The vehicles of Team H_2politO

All the vehicles realized by the Team H_2politO has shown in Figure 5.

From 2007 to now, for the SEM competition, 6 different vehicles have been made:

- 4 hydrogen fuel cell prototypes (IDRA08 - 2008, IDRA09 - 2009, IDRApegasus - 2012, IDRAkronos - 2016),
- 1 parallel hybrid urban concept (XAM - 2011),
- 1 combustion engine urban concept (JUNO - 2019).

While in 2012 the Team has been developed an electric with range extender heavy quadricycle (XAM 2.0) for a "normal road" competition from Brighton to London.

Table 1 shows the technical characteristics of the actual vehicles that participate at the race: IDRAkronos (middle of Figure 5) and JUNO (lower-right in Figure 5).

When the Team starts to design a new vehicle (usually one year before the competition) a lot of parameter, financial and technical, have to take into account (Figure 6).

The steps of the activity to design a new vehicle are:

1. Analysis of the rules and constrains of the competition (maximum dimensions and mass, safety aspect for mechanical and electronics,…) [1].
2. Parallel activities of: internal layout study; CAS of the external shape of vehicle and aerodynamics simulation; CAD of all mechanical components; FEM model and simulation of the body and mechanical components; vehicle dynamics simulation to evaluate force/moment (i.e. in suspension system or hub/bearing); powertrain modelling for fuel cell and combustion engine motor; electronic boards simulations. The phase design take into account new technical solution and material to reduce mass and guarantee the safety; some iterations are necessary and mandatory among the different activity.
3. Budget analysis and partner/sponsor research to have technical and financial support. This phase, also if it not "technical" is very important and need the strictly interaction between management and technical areas.
4. Final control of all the virtual models and "Freezing" of the vehicle, parallel identification of the companies for vehicle and sub system construction, when it is not possible to realize the components inside the University.
5. Components construction.

6. Sub system assembling (electronic control board, powertrain, mechanical transmission, etc.) and testing in laboratory, if possible.
7. Vehicle assembling.
8. First vehicle "functionality" tests on track to obtain a reliable vehicle with a double purpose: make consumption tests to validate the developed models and training news drivers and race strategy students.
9. Participation at the competition and application of the race strategy model to obtain the best results.

If the vehicle is not a new one similar steps are followed to re-design and implement new component and sub-system.

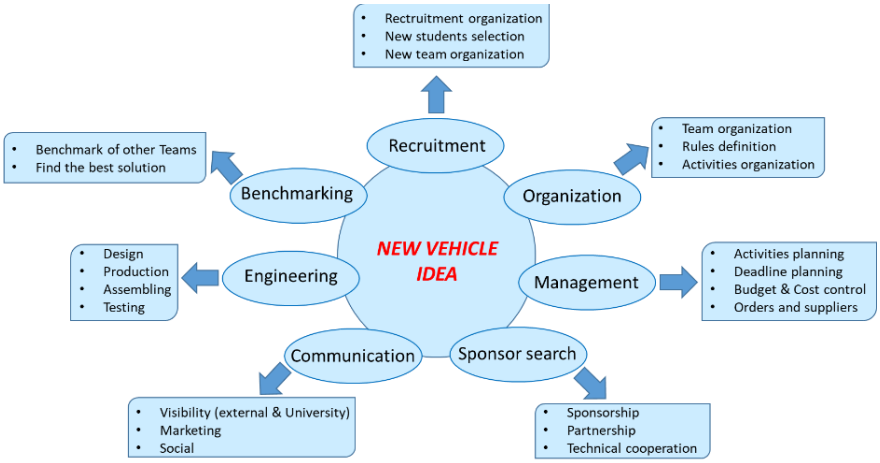

Figure 6: Activity around a New Vehicle

Table 1 – Main characteristics of JUNO and IDRAkronos

JUNO	**IDRAkronos**
One seater Urban Concept	One seater Prototype
Internal Combustion Engine 50 cc port fuel injection	Fuel Cell PEM 500 W (customized)
Fuel: bio-ethanol	Electric Motor 250 W (brushed DC)
Chassis: carbon fiber monocoque	Fuel: Hydrogen
Front Steering wheels	Chassis: carbon fiber monocoque
Transmission: spur gears (straight teeth) + planetary reduction gear	Front Steering wheels
Brakes: X connection with separate circuits	Transmission; single spur gear directed connected to the wheel
Cone clutch	Brakes: front and rear separate circuits
Suspensions: Push rod and Double wishbone	-
Tyres: Michelin 90/80 R16	No suspension system
Length/Height/Width: 2875/1165/1217 mm (respectively)	-
Track Width/Wheelbase: 1000/1660 mm respectively)	Tyres: Michelin 45/75 R16
Total mass: 130 kg	Length/Height/Width: 3341/807/561mm (respectively)
Max speed: 50 km/h (limited)	Track Width/Wheelbase: 568.5/1403 mm (respectively)
Cx = 0,28	Total mass: 42 kg

Best Fuel consumption: 240 km/L	Max speed: 30 km/h (limited) Cx = 0,1 Best Fuel consumption: 3445 km/L

5. The results for the students on track

The results obtained during the last competition 2019 with the vehicle IDRAkronos are:

- 1st place hydrogen category SEM Netherlands– 1027 km/m^3 (3129 km/L)
- 2nd place hydrogen category SEM Europe London– 1058 km/m^3 (3445 km/L)

However, during the SEM it is possible to win some off track awards and from 2007 to now the Team H_2politO has been obtained:

- 5 Communication Award: 2009, 2010, 2012, 2014, 2017.
- 3 Design Award: 2010 (with IDRA), 2011 (with XAM) and 2016 (with IDRAkronos).

For the Team, winning a Design Award means having done a good project from an overall point of view (from vehicle dynamics to aerodynamics, from mechanical to electronic design).While to win the Communication Award does it mean to have made a very good work to involve other students and companies.

However, the most important victory is obtained on track during the race, where the students must be able to solve the problems that arise even in stressful conditions, it may be in their future career.

6. The results for the students at the Politecnico

The Politecnico of Torino is the only University in Italy that recognize the Team activity in terms of credits. In fact, after a period of work inside the Team (approximately 1 years) for the students, in agreement with the Faculty Advisor, is possible to obtain:

- 6 ECTS credit with “Team learning activities in student” instead of a choice exam during the bachelor or master degree.

However, if the student stays inside the Team more than one year has the possibility to “transform” their work in a thesis, to obtain the important passage of knowledge “student by student”. Until now inside the Team 200 thesis have been developed, and this is a very innovative educational results. In fact, they allow the realization of the thesis cluster allowing the important transmission of knowledge, year after year, among students.

Finally yet importantly, when the thesis has a good level of scientific interest a paper will be written and the student becomes one of the co-author [3÷19].

Until now 4 students made bachelor thesis and master thesis inside the Team and after start doing and finish a phD. More than 40 students have been obtained a research grant inside the Politecnico after the degree or during the master.

7. Conclusions

The Team has always believed that hard work is the basis for future success. Students crave for continuously improving and strive for exceeding expectations by nurturing the team spirit in order to create those synergies able to add value to individual performances and capabilities. Therefore, passion and team spirit are really the foundation of H_2politO values.

The work at the Team and the prototype can be perceived as a business laboratory where is required a synergy between technical knowledge and managerial skills. Therefore, H_2politO allowed developing both technical competencies strictly linked to the Prototype/Product and managerial competences characteristics of a business team.

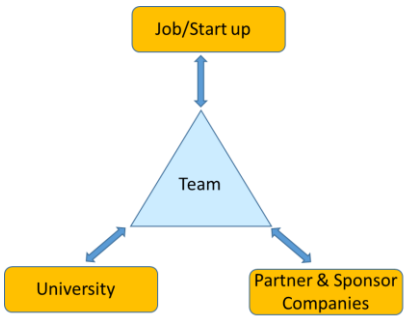

Figure 6: Innovative rule of Team H_2politO

The University believes that the competition is a way to achieve excellence and grow up a new generation of engineers, able to solve quickly probolems anchìd challenge. The market, thus the competition, gives them the possibility to work hard in order to challenge the competitors and produce a more advanced technology vehicle that could become benchmark for its category.

The Team wants, through the University to drive innovation into everything it does (Figure 6). It works to become a mean by which partners and sponsors could create and develop innovative path to prepare the future engineers at the job, in a company or to create new innovative start up but with a “open mind” with a transversal knowledge and approach.

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