Printable Creativity in Plastic Valley UC3M

Alberto Valero-Gomez, Juan Gonzalez-Gomez, Victor Gonzalez-Pacheco and Miguel A. Salichs

***Abstract*—In this paper we present an Open Source Community Oriented Project Based Learning (CO-PBL) educational model for engineering studies. We explain the pedagogical basis of our proposal and present a training course in which the model has been implemented. The chosen project has consisted of the design, building, and programming of a printable mobile robot (PrintBot). To print the robot's parts we used open source 3D printers, creating a community of students (Plastic Valley) interacting with other designers spread all over the world. As it is shown in this paper, this initiative has proven to be highly motivating to the students and it enabled an explosion of creativity.**

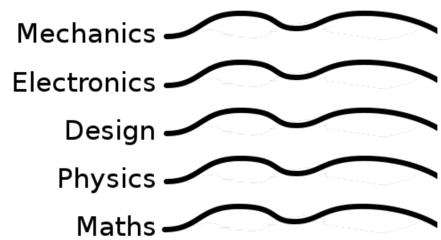

Figure 1. Multi Stack Educational Model

I. Introduction, Motive, and Problem Statement

Boosting students' creativity and motivation is one of the main challenges at which professors and educators have to face. Motivation is required for any person enrolling in academic studies [4]. Creativity is even more crucial in engineering, as engineers should be capable of solving real life problems in a creative manner [2].

Undergraduate studies in current engineering curricula are, currently, mostly focused on giving the students a strong scientific ground. This ground, will enable them to face the technical problems that they will face in their future professional careers. Students must acquire the fundamentals of mathematics, physics, chemistry, technical design, and so forth. In the latter years of their degrees they are taught specialised courses such as electronics, mechanics or management. All these subjects are not applied to any particular problem, but are aimed to provide the tools for any general problem that may be solved with these tools. For example, differential calculus is not specific for heat transfer, and physics is not directly aimed to solve robotic kinematics problems. They cover the whole spectrum of knowledge that a good engineer should know. This could be seen as an horizontal education model, understood as a stack of layers, where each one requieres to get basic mastery of the previous matters, and loosely connected among them. This model conforms the typical engineering program (Fig. 1).

Students learn in universities how to solve triple integrals, complex dynamic systems, PID controllers, Nyquist plots, etc. But when they will face their first professional job, they will probably realize that they do not know where to start. It is not anymore an exam about integrals, which they know (or do not know) how to solve. They may be aware that they have all the knowledge required to solve the task, it is just that they not know how to move from the exams made in paper during their college years, to the real life professional work. In most cases their companies have to train them in order to enable them to solve a particular task which is part of a bigger production process.

Albero Valero-Gomez, Juan Gonzalez-Gomez, Victor Gonzalez-Pacheco and Miguel Angel Salichs are with the Robotics Laboratory of Universidad Carlos III de Madrid, Spain. alberto.valero@uc3m.es, juan@iearobotics.com, victor.gonzalez@uc3m.es, salichs@ing.uc3m.es

This possible risk derived from the high specialization of engineering is disclosed with an inspiring clarity by E.F. Schumacher on his essay: "Technology with Human Face" [18]. A technology that inserts the worker in the production chain without providing him or her a vision of the whole drives to dehumanization. The person loses the perspective between his or her work and the final product. According to Schumacher, technology should provide the worker with the necessary tools to boost his or her creativity, capacities and potentialities, so that his or her personal signature can be appreciated in the final product.

This implies that she must understand how the part he is developing relates to the whole. For example the factory worker should see in the screw he tights, the whole ship the screws will be tightening, and why not, he or she could have also an intuition on what a ship is, how does it manages to move in water, which are the skills required for sailing, and how a screw prevents accidents in case of storms. Whenever he sees the ship, he or she should feel a relation of mutual belonging with it. Understanding the whole and encouraging interdisciplinary research has demonstrated to help innovation precisely from the particular position in the global chain [9], [12].

Similar ideas about science are present in the *Thoughts* of Pascal [14] under the concept of *Honnête Homme*. In Pascal's words, *"one should not be able to say either 'He [the honnête homme] is a mathematician' or 'a preacher"'* as he is able to depict the whole picture, in which he is specialist only of a singular part. Like Schumacher, Pascal does not ban specialization, but supports that the fair scientist cannot sacrifice universal knowledge for the shake of unilateral specialization.

The University years are a privileged time for training *honnête homme*s: highly specialized but without sacrificing their knowledge of the whole. This task begins by integrating together all the knowledge they acquire in their mathematics, physics, or electronics courses, showing the students the whole picture of their curriculum and how it relates to the reality. Completing the *horizontal education model,* a vertical thread joining together the horizontal stacks (Fig. 2) can give the student the idea of the whole, letting him or her afterward deepen in any of the particular topics he or she is interested in. This vertical model is not a substitute of the traditional horizontal education, but a natural complement that joins together all the parts giving a vision of the whole.

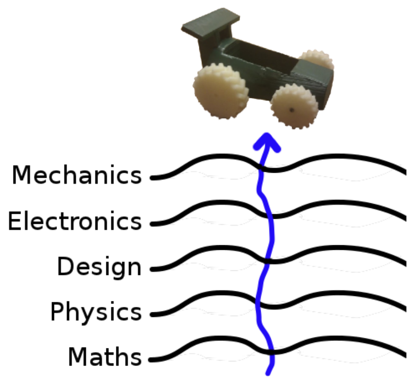

Figure 2. The Vertical Thread

Another important aspect of current engineering is its “non-located” nature. As a result of specialization, engineering is increasingly distributed. It is difficult that a a single work-group concentrates all the knowledge and means to develop hi-tech products. This involves that today’s engineers work in a completely different environment than a decade ago. They should learn how to work in distributed environments where the teams are no longer local but spread around the world [3], [7]. In addition, the increasingly competitive world demands greater creativity in problem solving in order to provide original solutions. The new working scenario can be defined as coopetitive (cooperative + competitive) [21]. There is, therefore, a growing necessity of providing an engineering curriculum that covers aspects such as the use of on-line tools and how to be part of these distributed communities.

A way of facing both specialization and distributed working has been present in the Open Source development model for years, which has proven to be successful [22], [10]. Thousands of people around the world create communities and cooperate together, according to their particular expertise, to improve the software at wich they are working on. This model has given us the hint to propose our students an open source Community-Oriented Project Based robotics course. The three basis of this course are:

- *Open Source*: All provided and generated knowledge is open and available,
- *community oriented*: it is oriented to receive feedback and contribute to, and from, a distributed community, and
- *project based*: aims to cover all the knowledge disciplines involved in robotics.

In this paper we describe the course and what i) Open Source, ii) Community Oriented, and iii) Project Based Learning mean and involve in our educational proposal. We close the paper showing the resulting robots of the course and their impact on the community as a proof of the creativity and acquired knowledge of the students who where involved in.

II. Open source Community-Oriented Project Based Learning

This section describes the Open Source Community-Oriented Project Based Learning (CO-PBL) educational model that we propose. The model is based on three main pillars: open source, community oriented, and project based learning. First we will describe these pillars and latter we will show how we have integrated them into a robotics course.

A. Open Source model

The open source model has the unique characteristic that the source code is available to everyone. The open licenses grant the users the freedom of using it, studying, copying, modifying and sharing. This has some important consequences. The first one is that open source enables the creation of communities of people (developers, translators, users...) which evolve and improve the project in a distributed manner. Due to the increasing importance of these communities for the software industry, some authors are proposing metrics for measuring their performance [19].

A second characteristic is the arousal of creativity and new ideas. According to [5] “the role of interaction and collaboration with other individuals is critical to creativity. Creative activity grows out of the relationship between individuals and their work, and from the interactions between an individual and other human beings”. In these communities the members interact via mailing list and forums, interchanging their opinions and knowledge.

The third characteristic is learning. These is one of the most important reasons why developers participate in open source projects [6]. In addition, in contrast with the classical enterprise model, the motivation is not money but entertainment and the passion that arises from the project in which the developer is participating and feels involved in [15].

The ideas of the open source model have also been extended to other scopes such as hardware, photography, art and so forth. In these communities, people are sharing the design files, instead of the source code. One of the biggest successful hardware community is the Arduino project[1], were electronic boards are being shared under an open source hardware license [13]. In this community, people are sharing electrical schematics and firmware. The users are not only allowed to use, modify, copy and study the designs but also to build them or even sell them. This is a big step forward, as these communities are not only sharing digital objects, but they have jumped to share physical objects.

The communities around physical objects are very young (around six years old). The members share the design files, which have open source like licenses (typically creative commons or open source hardware). Nevertheless, there could

[1] http://www.arduino.cc/

appear some restrictions when sharing the designs if the format is not standard or open. For example, if an open source mechanical design has been created using a proprietary software which has its own proprietary format, only the users that have paid the license can exercise the freedom of modifying the design. Thus, this community is not open to everybody but only to the users of such program. This problem is compounded because of the lack of a standard open format in both mechanical and electrical CAD software tools. Our solution is to create a community in which all the software tools used for designing are open source. This community will create open source designs only with open source tools, or at least, allowing to save the source code in an open source format than can be opened and modified by everyone without any restriction. We call this *squared open source*.

B. Community Oriented Model

The community model is inherent to the open source. In fact, much of the open source philosophy is based on the principle of allowing participation to as many people as possible [16]. Initially the developers are attracted by the technical details, but according to [17], “participating in an open-source community is a continuous learning process, where not only technology is to be considered but other factors, such as group work and communication”. Very likely, the future engineers will have to integrate themselves in one or several of these communities. Therefore, it is important for them to know how to develop their work being part of these communities. Moreover, students should learn how to create, lead and inspire these communities.

Nowadays, communities are getting more and more important. Some companies have created the figure of the *community manager*: a very qualified professional with high social skills who is capable of forming and leading their own communities. This is the case of Cannonical, which has a big community of people in charge of maintaining packages, back-ports, support, documentation, artwork, bug squad and so forth. The Ubuntu Community Manager has written a book on “the Art of Community-building the New Age of Participation” [1].

In the community oriented model, the students publish their work from the very beginning and receive the feedback from others. They should learn how to use tools such repositories (svn, git...), wikis, blogs and forums. In addition, they can learn from other’s work. The great advantage of the community oriented learning lays in the fact that knowledge is not anymore centralized on the professor. Technical feedback can arrive from any person with expertise. This, that could be received as a threat by some professors, is on the contrary a relief, as the professor can concentrate his or her efforts on guiding the students without worrying about their lack of expertise in any of fields. The figure of the professor derives into a tutor, which is in charge of leading his or her students through the entire learning process, showing them the methodology of studying, researching and developing. The new role also requires from the tutor to have a general knowledge of the topic and a predisposition to learn new things together with the students he or she is tutoring.

The purpose of our course is to teach our students, through the building process of a robot, to create and participate in an open source community, teaching them how to be part of it and how to behave. This community should not only be local, but accessible to anyone connected to Internet. We have chosen Thingiverse, an on-line community, as a starting point to share designs of physical objects. Through this platform the students interact with the community publishing all their works. Nonetheless, the interaction with the community is not limited to this web platform, as their work naturally expands to other sharing networks as YouTube, blogs, social networks, etc. Far from discouraging this, our aim is to teach them to use these tools to get advantage of the community knowledge and to contribute with their own expertise.

C. Project Based Learning

Project Based Learning (PBL), is a widely used educational model where the students learn by doing “real-life like” problems.

According to [11], PBL is “a systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic questions and carefully designed products and tasks.”.

In PBL, the students are required to answer a *Driving Question* or to solve a complex problem which are tied to the content standards in the curriculum of the course. The question or problem are packed in the form of a project. Hence, to answer that question or solve that problem, the student is required to construct its own solution from the learned contents of the course. But it also needs to use other side skills such as communication, planning, teamwork, etc.

In essence, a PBL project is defined by five criteria [20]:

1) PBL projects are central, not peripheral, to the curriculum. I.e., the project is the main teaching strategy.
2) PBL projects are focused on questions or problems which "engage" students to encounter, work with, and learn the central concepts and principles of a discipline.
3) PBL projects involve students in a constructive investigation.
4) Projects are student-driven to some significant degree. I. e., PBL projects are not, teacher-led, scripted, or packaged. For example, homework exercises or Laboratory practices are not PBL projects.
5) PBL projects are realistic projects instead of school like projects. In other words, PBL projects are real-life challenges instead of simulated or controlled problems or questions.

Adopting a PBL education model provides several benefits to the students. From the research view point, there are some benefits when compared to other traditional teaching strategies. [20] highlights some of them: PBL is more accepted by students and teachers than traditional methods. Moreover, both groups believe that PBL is beneficial and effective as an instructional method. Additionally, [20] states that some studies report unintended beneficial consequences of PBL such as an increase of professionalism and collaboration between teachers and an increase of the attendance and the positive

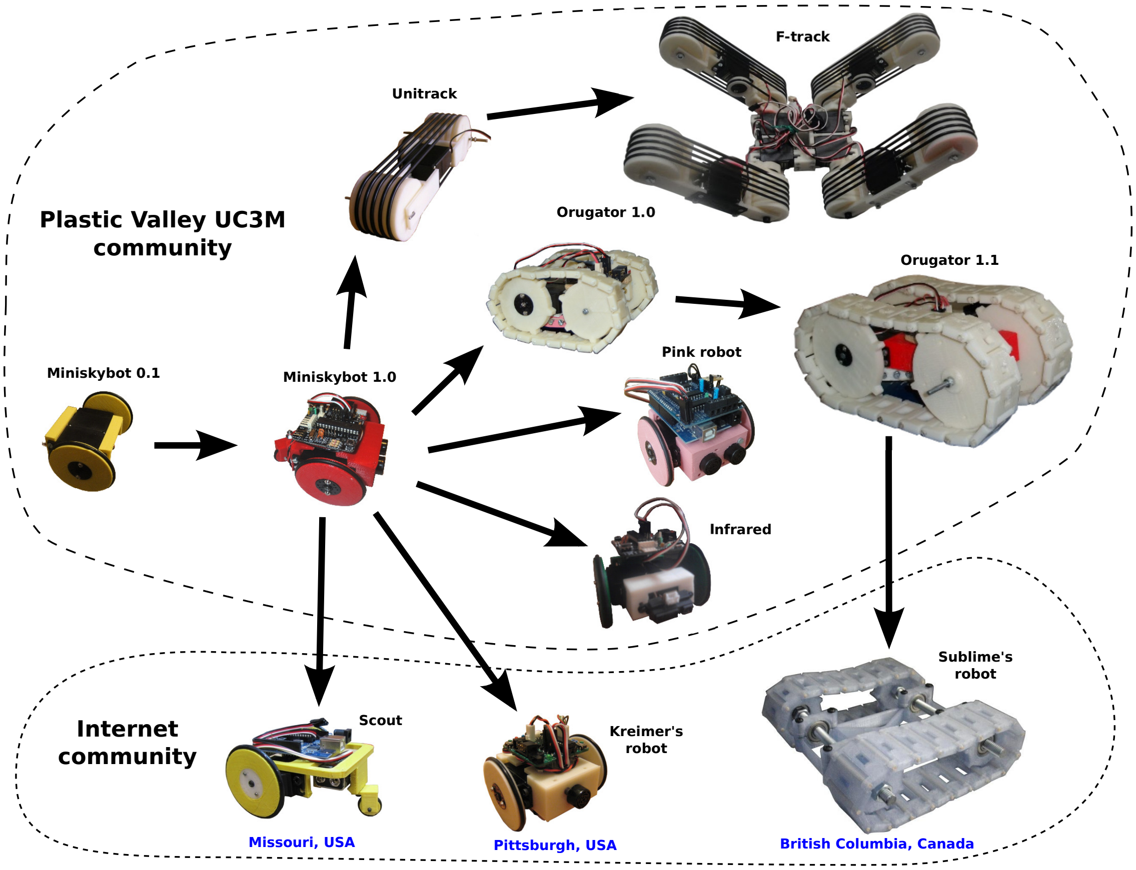

Figure 3. The robots developed by the students. Starting from an initial design (Miniskybot 0.1), the robot design evolved propelled by the students creativity. As the students shared their designs, other people from the international community developed new robots based on them.

attitudes towards learning form the students. Apart from that, PBL enhances the quality of learning and leads to higher-level cognitive development through students' engagement with complex, novel problems. Finally, there is ample evidence that PBL is an effective method for teaching students complex processes and procedures such as planning, communicating, problem solving, and decision making, although the studies that demonstrate these findings do not include comparison groups taught by competing methods.

There are also some reports from teachers stating the benefits from PBL that they have experienced. In the following list are gathered some of these teachers' reports [11] :

- Helps the students to both ''knowing'' and ''doing.''
- Supports students in learning and practicing other "side" skills such as problem solving, communication, and self-management.
- Encourages the development of habits like lifelong learning, civic responsibility, and personal or career success.
- Forces the teachers to evaluate the students with criteria similar to those they will found in the real world, thus encouraging accountability, goal setting, and improved performance.
- Creates positive communication and collaborative relationships among the students.
- Engages and motivates uninterested or indifferent students.

But, despite all its benefits, PBL has some drawbacks that must be considered. From all of them, PBL's main setback is that it is not an appropriate method for teaching certain basic skills such as reading or computation. However, it does provide an environment for the application of those basic skills [11].

III. Course Description

Insofar we have explained the pedagogical basis of our educational proposal. In this section we are focusing on the particular implementation of this proposal. The first workshops following the CO-PBL have been offered to students belonging to mid-school, high school, and undergraduate technical studies through the last ten years. The two most popular workshops were:

- The SkyBot workshop[2]
- The modular snake workshop [3].

In these courses, the students built the Skybot or the modular snake from their parts, mounted the electronics, and then programmed them. Sometimes they proposed wonderful modifications to the robot design or suggested modifications in the electronics, but it was not possible to implement them during

[2] http://www.iearobotics.com/wiki/index.php?title=Taller_Skybot (in Spanish)

[3] http://www.iearobotics.com/wiki/index.php?title=Training_on_modular_snake_robots

the course due to the time it takes to a manufacturer to build a new part (apart from the cost).

This has been the classical shape of robotics workshops in recent years. They must focus, by necessity, on the programming of the robotic agent given a particular platform. Even if only this can be quite challenging and inspiring, with the incorporation of low cost 3D printers, the teaching programme must not be focused any more only on the robot building and programming, but it may also include its mechanical design and mechanization.

In April 2009, one of the authors of this paper, acquired a MakerBot CupCake 3D printer for personal use and experimentation. He redesigned and printed the SkyBot robot. This evolution lead to the Mini SkyBot, a printable robot for research and education [8]. In March 2010 the University Carlos III of Madrid bought a MakerBot Thing-O-Matic oriented to train students in 3D design and printing. This printer was at the total disposal of the students. Due to the high utilization of this printer and the acceptance among the students, the University acquired a second MakerBot Thing-O-Matic printer, with the improved MK7 extruder. The contribution of the 3D printer to the CO-PBL ideas has become invaluable.

In order to apply CO-PBL methodology we designed a robotics course and offered it to our undergraduate students. In the following paragraphs we will show how the CO-PBL ideas were implemented in this course.

A. *Project Based Learning*

The design of a robot requires a multidisciplinary formation. Therefore, building a robot is a good project to teach the students how different engineering fields relate to others. Moreover, building a robot demands a considerable integration effort. Bearing in mind the idea of the vertical teaching we considered that building a robot from scratch suited perfectly the methodology of project based learning.

In 2009/2010 academic year we offered to our 2nd year students the possibility of assisting to a voluntary course in which they would be taught robotics, from design through programming. The proposed project was to design, build and program a mobile robot from scratch. The course consisted of weekly seminars of two hours (during 28 weeks). These seminars were held out of the regular lesson hours in the University classrooms. No official curriculum refund was offered to them. 14 students enrolled this initiative. 10 of them continued until the end of the course.

The seminars focused on providing the students with all the fundamentals on robotics, including robot mechanical design, electronics, programming, artificial agents design, and so forth. The students were trained to design mechanical parts using only Open Source tools like OpenScad, FreeCad and QCad. They were taught to print 3D objects using a Makerbot's Thing-O-Matic 3D printer. They also had some seminars on how to design an electronic board, how to solder the components, and how to program the microprocessor. Finally, some programming seminars were given about how to program in C/C++. They were introduced into PID controllers, genetic algorithms, fuzzy control, path planning, motion control, mapping, localization, etc. None of these contents were treated deeply. Students were only provided with the fundamental knowledge required to let them deepen their knowledge in these fields autonomously.

An initial simple robot, the MiniSkyBot [8] was provided to the students as a reference design where they could start their own designs. Starting from this robot, the students should design and build their own robot.

In the 2010/2011 academic year the course was offered again to the 2nd and 3rd year students of our University. The proposal was presented as a "robotic challenge" called "UC3M Mars Challenge". The project consisted in a challenge where student-made full-printable robot should be able to rover through a Mars-like arena. The robot should be teleoperated, using wireless communications. The mission consists in picking a Red Bull - Energy Shot mini can that will be placed in the arena, and carry it to another given point[4].

Collecting the experiences of the previous year, the programme was more precise. It consists of 3 major stages.

1) Mechanical Design and Printing.
    a) Designing 3D parts with OpenSCAD.
    b) Designing 3D parts with the C++ OOML (a paper has been submitted to this conference entitled "Boosting Mechanical design with the C++ OOML" in case it is accepted it will be referenced here).
    c) Printing with a MakerBot Thing-O-Matic.
    d) Wacky Cars Race.
2) Electronic Design and Programming.
    a) Mounting (soldering) the SkyMega board[5].
    b) Programming the micro with the Arduino IDE [13].
    c) Incorporating sensors to the board [6].
    d) Wireless communications with the SkyMega board.
    e) Designing a custom board with KiCad.
3) Robotics Agent Programming.
    a) Motion Control of a differential driven mobile robot.
    b) Obstacle Avoidance.
    c) Localization and Mapping with IR and ultra sound range sensors.

46 students enrolled this second year proposal. At the time of writing this paper (November 2011) we have just completed the 1st stage (mechanical design). This stage finishes by a competition of passive robots, which we have called the "Wacky Races[7]". Students organized in couples must design (in OpenScad) and print a "car" without electrical power supply. These cars must go through a 2 meters descending ramp. The challenge consists in completing the ramp before the other competitors. To the date several cars have already been built. The designed cars are shown in Figure IV. The race took place on November 26th (in case this paper is accepted the Figure will be updated with all the participant cars).

[4] http://iearobotics.com/alberto/doku.php?id=teaching:mars
[5] http://www.iearobotics.com/wiki/index.php?title=SkyMega (Spanish)
[6] http://138.100.100.129/mrgroup/doku.php?id=mechs:sensors:ultrasound
[7] http://en.wikipedia.org/wiki/Wacky_Races

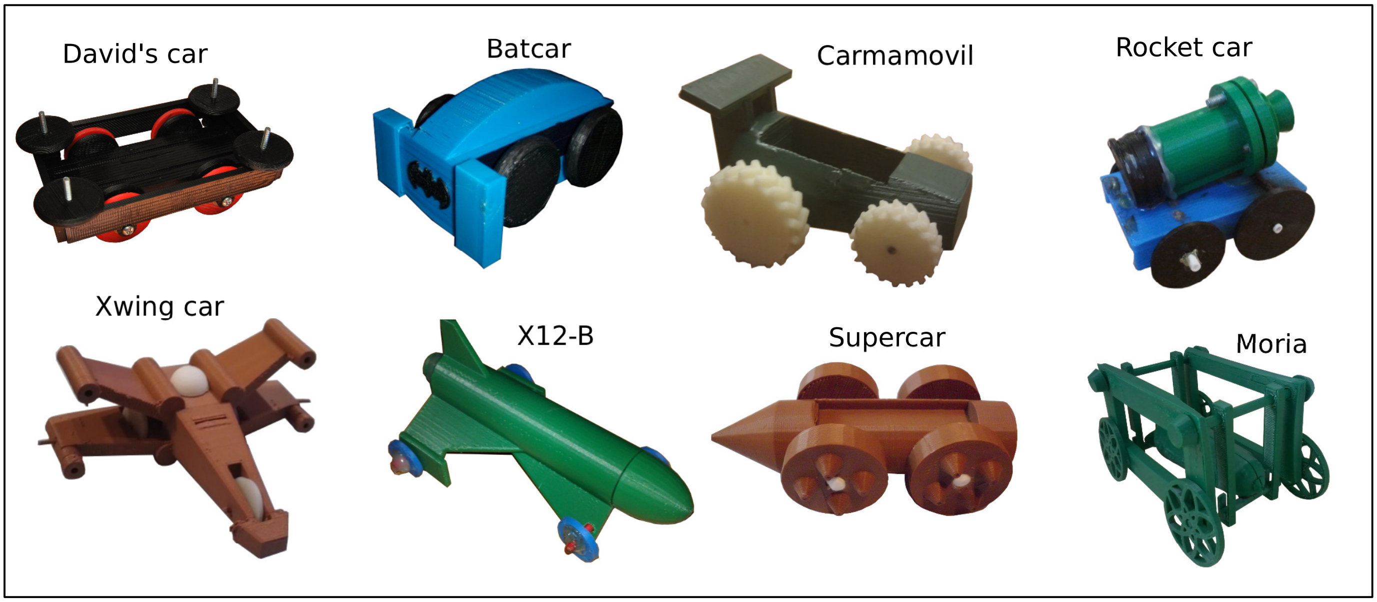

Figure 4. Wacky Races

B. Community Oriented and Open Source.

One of the conditions we put our students is that all the produced material should be published with an open license in an open format, so that others could copy, modify, and improve their work. Their production consists of:

- 3D things (including their OOML or OpenScad code), published on Thingiverse.
- Electronic Designs, published on IEARobotics web page[8].
- Artificial agents, which source code is published on the group webpage[9] with open access.

Also, all the educational material is published on IEARobotics page.

The goal was not only contributing to the community but also receiving feedback from it. Community comments do not only provide technical feedback to the students, but it also encourage and motivate them. This feedback has also created some kind of competitiveness among them, looking for the community recognition, in terms of being featured, visited, voted, etc. Table I presents some data of interaction with the community. This data has been collected on November 21st, 2011. We have chosen only the most impacting designs, but the impact of all the rest can be consulted online by the reader.

IV. Results

Figures 3, 4, and 5 give at a glance a summarized report of the course outcome. We wanted students to learn how to design robots, but they started designing all kind of things as it is shown in Figure 5. These things were not part of the training, but as soon as they learnt to design and print they started to build them up. An example of this is the case of the chalk holder. A student created a chalk holder, then, another student improved its usability, and finally, a third one changed its design to make it look like a light-saber. Currently, every professor of our Department has his own printable chalk holder. All the things designed and printed by Universidad Carlos III de Madrid are tagged with the name UC3M on Thingiverse[10].

The resulting robots of the 2009/2010 academic course can be seen in Figure 3. The students added a castor wheel and front ultrasound range sensors to the Miniskybot 0.1 resulting in the Miniskybot 1.0. From this version there were two modifications, one applied to the electronics and other placing IR range sensors on the front, substituting the ultrasound sensor. Two new designs arose, the Orugator, a tank like robot, and the Unitrack, that eventually resulted in the 4Track.

Apart from the contributions of our students, the robots were modified by people from America (Missouri, Pittsburgh, British Columbia). We proposed the name PrintBots for the printable robots and tagged our robots with that name on Thingiverse. Since then other designers in the Thingiverse community have also tagged their robots with that name[11].

In 2010/2011 course robots have not been yet designed, but the wacky cars of the first stage challenge can be seen in Figure 4.

It is particularly encouraging that while last year 14 students enrolled, this year 46 students are participating in the initiative, and 8 students have decided to undertake their grade final project on topics related with the PrintBots.

Regarding the *community oriented* dimension we can highlight here the impact over the internet of some of the designed things (this completes the numbers presented in Table I).

- The MiniSkyBot rapidly evolved and resulted in a publication [8] and several posts on international blogs[12]

[8] http://www.iearobotics.com
[9] http://www.mrgroup.es
[10] http://www.thingiverse.com/tag:uc3m
[11] http://www.thingiverse.com/tag:printbot
[12] http://blog.ponoko.com/2011/05/04/a-look-at-the-miniskybot/, http://www.colourworks.co.za/2011/08/use-3d-printing-to-create-robots-at-home/

	Thingiverse			YouTube			Tweets	Facebook
	Votes	Comments	Variations	Visitors	Comments	Likes		
4-Track	108	18	0	10262	11	42	14	26
Mini SkyBot 0.1	28	4	1	862	5	5	0	0
Mini SkyBot 1.0	94	14	3	1237	11	11	5	2
Uni-Track	98	22	0	3342	2	14	3	9
Orugator 1.0	11	20	1	548	2	2	2	4
Orugator 1.1	12	20	1	642	2	6	1	5
Animatronic Tail	54	9	0	10574	1	14	5	5

Table I
COMMUNITY INTERACTION WITH THE STUDENTS

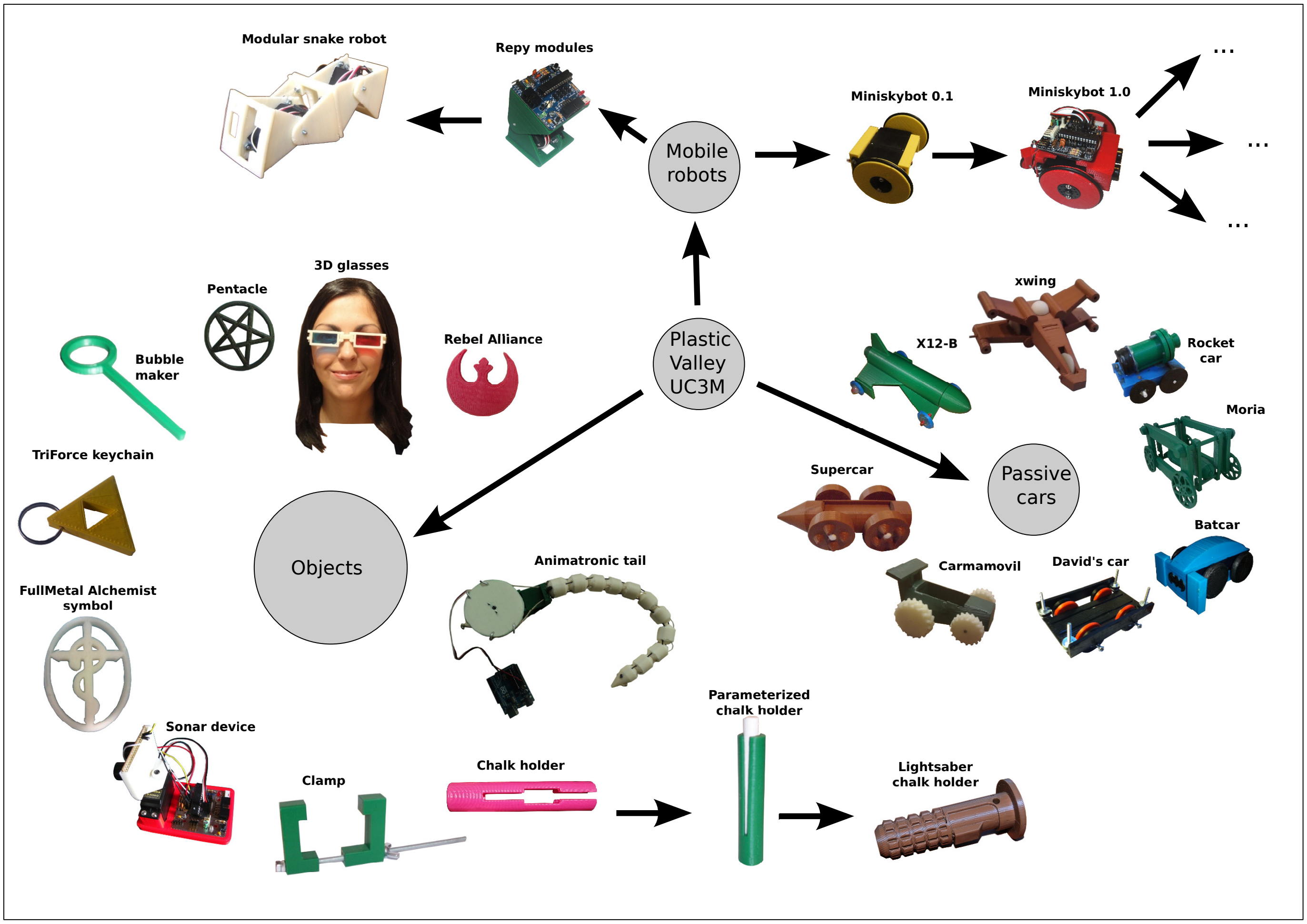

Figure 5. The explosion of creativity in Plastic Valley UC3M. Aside from the proposed project of developing mobile robots, the community has created completely different printable objects, from a chalk holder to an xwing passive car.

- The MiniSkyBot was fully replicated in the United States for teaching robotics in a Boy Scout Camp[13].
- Apart from the robots, the students designed and printed their own objects on self initiative[14].
- The Orugator was the first caterpillar robot design uploaded to Thingiverse[15], an on-line community for sharing printable designs. After sharing this robot, several designers from different countries started using caterpillars for other designs, improving our student's initial design[16].
- The UniTrack was the *Most Popular Thing* on Thingiverse for one month.
- The 4Track is currently the *Most Popular Thing* on Thingiverse.
- MakerBot Industries posted on their blog about one of the "other" designs of our students[17].
- First Parametrized battery compartment designed and printed on Thingiverse. It was also posted by MakerBot Industries[18]
- Due to the number of things shared on Thingiverse by

[13]http://www.youtube.com/watch?v=2EqvuPXYKf0
[14]http://www.thingiverse.com/tag:UC3M
[15]http://www.thingiverse.com/thing:8559
[16]http://www.thingiverse.com/thing:10923
[17]http://www.makerbot.com/blog/2011/06/17/printed-signs-logos-by-kepler/
[18]http://www.makerbot.com/blog/2010/12/08/battery-compartment-with-contacts-by-obijuan/

our students, MakerBot Industries posted on their blog our experience[19].

Due to the success of the experience we have been asked to give a 12 hours seminar to the students of the Master in Automation and Robotics at University Carlos III of Madrid about designing and printing 3D objects. This master seminar counts with 13 students who are currently developing their things (the outcome of this seminar can be included in the final version of the paper).

Another Engineering University in our city, Universidad Politécnica de Madrid, with whom we have research relations have recently bought two MakerBot Thing-O-Matic printers. Together we have created what we have called the *Plastic Valley,* and all our designs are tagged with that name on Thingiverse[20].

Furthermore, a consortium of Spanish High Schools have just started a project for including MakerBots in the classrooms and have asked us to lead the formation of the teachers that will be in charge of them.

A. *Students' feedback*

We have also asked the students that followed the course last year to write their opinion about the course. The students' personal experience can be summarized, using their own words, in the following points:

- "... the chance to learn and put into practice a whole new set of skills that is not taught anywhere else (robot design, actuators, sensors, electronics, programming, using a 3D printer, etc.)"
- "The knowledge and hands-on experience gained by participating in the Plastic Valley UC3M is much more rewarding and practical than the material taught in the university lectures!"
- "Learning to be a self-taught student group. Students are expected to be perseverant and try to solve on their own the difficulties they encounter. At the same time, all information is shared so that we may learn from each other, making the process faster and more efficient. At the end of the day, students become more independent and resourceful people."
- "The satisfaction of looking at your robot at the end of the year and saying: 'I designed, printed, assembled, and programmed that!'"
- "Having fun! Building robots is fun, enjoyable, and very rewarding. That's why we do it".

V. Conclusion

In this paper we have presented the pedagogical foundation for an Open Source Community Oriented Project Based Learning model for engineering. This model tries to adapt engineering education to the current reality of a distributed world in which the internet plays a central role. In such a system engineers must be able to take advantage of the community knowledge and be able to contribute to it. The open source model is probably the most adapted model for the University, as by definition the University *(universitas magistrorum et scholarium*), is the community of teachers and scholars in which knowledge is freely delivered to anyone attaining to it.

Through a robotic project and with the aid of 3D printers, we have been able to give our students an overall view of mechanical design (including mathematics, geometry, physics, ...), electronics, and programming. This experience has driven to an unexpected arousal of creativity and motivation, as it shows the amount of things designed by the students and the increasing number of students interested in the initiative. The course have created a community within the University, known as Plastic Valley, where students share their designs on the internet and interact with other students, researchers, artists, engineers, etc. The PrintBot term has also born from within the course. This term has been adopted by the Thingiverse community as the denomination for the printable robots.

Up to now this course has been offered out of the official curriculum. This year we have offered, for the first time, an official master seminar on 3D design and printing with open source tools. Up to our knowledge this is the first time such a course is offered in Spain and probably in Europe. We are currently writing a formal proposal to include this course also in the undergraduate official programme.

Acknowledgments

The authors are grateful to Prof. Dolores Blanco, head of the Systems Engineering and Automation Department for her support.

The authors also gratefully acknowledge the funds provided by the Spanish MICINN (Ministry of Science and Innovation) through the project *A new Approach to Social Robotics (AROS)*.

Finally we would like to thank all our students for their enthusiasm and generosity. In particular we thank the work of these last days for printing the Wacky Cars shown in Figure 4 so that we could include them in this paper.

References

[1] J. Bacon. *The Art of Community: Building the New Age of Participation*. Theory in Practice. O'Reilly, 2009.

[2] A.J. Cropley. *Creativity in education & learning: a guide for teachers and educators*. Kogan Page, 2001.

[3] Ben Daniel, R A Schwier, and G McCalla. Social capital in virtual learning communities and distributed communities of practice. *Canadian Journal of Learning and Technology*, 29(3):113–139, 2003.

[4] E L Deci, R J Vallerand, Luc G Pelletier, and R M Ryan. Motivation and education: The self-determination perspective. *Educational Psychologist*, 26(3):325–346, 1991.

[5] Gerhard Fischer. Distances and diversity: Sources for social creativity. In *Proceedings of Creativity and Cognition*, pages 128–136. ACM Press, 2005.

[6] Rishab Aiyer Ghosh. Understanding Free Software Developers: Findings from the FLOSS Study. In Joseph Feller, Brian Fitzgerald, Scott A Hissam, and Karim R Lakhani, editors, *Perspectives on Free and Open Source Software*, pages 23–46. MIT Press, Boston/Mass., 2005.

[7] Paul Hildreth, Chris Kimble, and Peter Wright. Communities of practice in the distributed international environment. *Journal of Knowledge Management*, 4(1):27–38, 2001.

[19] http://www.makerbot.com/blog/2011/09/14/makerbot-in-the-wild-universidad-carlos-iii-de-madrid/

[20] http://www.thingiverse.com/tag:Plastic_Valley

[8] Gonzalez-Gomez J., Valero-Gomez A., Prieto-Moreno A., and Abderrahim M. A new open source 3d-printable mobile robotic platform for education. In *Proc. of the 6th International Symposium on Autonomous Minirobots for Research and Edutainment*, may 2011.

[9] L.R. Lattuca. *Creating interdisciplinarity: interdisciplinary research and teaching among college and university faculty*. Vanderbilt issues in higher education. Vanderbilt University Press, 2001.

[10] J. Ljungberg. Open source movements as a model for organising. *European Journal of Information Systems*, 9:208–216, 2000.

[11] T. Markham, J Larmer, Buck Institute for Education, and J Ravitz. *Project based learning handbook: a guide to standards-focused project based learning for middle and high school teachers*. Buck Institute for Education, 2003.

[12] Norman Metzger and Richard N. Zare. SCIENCE POLICY:Interdisciplinary Research: From Belief to Reality. *Science*, 283(5402):642–643, January 1999.

[13] Joshua Noble. *Programming Interactivity: A Designer's Guide to Processing, Arduino, and Openframeworks*. O'Reilly Media, 1 edition, July 2009.

[14] Blaise Pascal. *Thoughts, year = 1909,*. The Harvard classics. P.F. Collier and Son, New York, new york: p.f. collier and son edition.

[15] D.H. Pink. *Drive: The Surprising Truth about What Motivates Us*. Penguin Group USA, 2011.

[16] Eric S. Raymond. *The Cathedral and the Bazaar*. O'Reilly & Associates, Inc., Sebastopol, CA, USA, 1st edition, 1999.

[17] Gregorio Robles, Jesus M. Gonzalez-Barahona, and Jorge Fernandez. New trends from libre software that may change education. In *IEEE Engineering Education 2011 (EDUCON)*, Amman, Jordan, 04/2011 2011. IEEE Education Society, IEEE Education Society.

[18] Ernst Friedrich Schumacher. *Small is beautiful*. Number 87 in Alternative Konzepte. MÃijller, Heidelberg, lizenzausg., 2. aufl edition, 1995.

[19] Martin Soto, Daniel Izquierdo-Cortazar, and Marcus Ciolkowski. Measuring the performance of open source development communities: The qualoss approach. In *Software Metrik Kongress (MetriKon)*, page 219–233, Kaiserslautern, Germany, 10/2011 2009.

[20] John W. Thomas. A review of research on project-based learning. Technical report, The Autodesk Foundation, San Rafael, California 94903, 2000.

[21] Wenpin Tsai. Social structure of coopetition within a multiunit organization: Coordination, competition, and intraorganizational knowledge sharing. *Organization Science*, 13(2):179–190, 2002.

[22] Steven Weber. *The Success of Open Source*. Harvard University Press, 2004.