The "E3D+VET" Erasmus+ project: Interdisciplinary teaching and learning in VET centres through 3D printing

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Abstract. The "E3D+VET" (Erasmus+ for the immersion in 3D printing of VET centres) is an Erasmus+ KA2 project aimed at developing educational resources for the VET system, providing new competences to both teachers and students and serving as important means of innovation and acquisition of effective knowledge on interdisciplinary STEAM topics. The project started on October 2017 and it will last up to the end of March 2020. In this work, we present the main outcomes from the project activities carried out so far. In particular, after a description of the general objectives of the project, we introduce the methodology developed for making 3D-printing a valuable resource for supporting physics teaching in a highly motivating learning environment and three didactical exercises as examples of 3D-printing based tools that can support teachers in their physics class. As a part of the project plan, here we finally present the preliminary training program specifically designed for the teacher professional development about the knowledge of 3D-printing potential for an effective teaching of physics contents and, at the same time, for improving student transversal abilities.

1. Introduction

The practice of today scientists is often exerted at the intersections of different fields within interdisciplinary contexts where creativity, particularly in design processes and data analysis, flexibility and innovation are the mainly required professional skills. Students should demonstrate to hold both specialist-discipline knowledge, abilities to solve practical problems, competences on using mathematical, scientific and technological tools and the mindset for undertaking lifelong learning [1, 2]. All these competences can be developed through an effective physics instruction, which would be able to guide the students towards a deeper understanding of disciplinary fundamental concepts and, at the same time, to strengthen their reasoning abilities and transversal skills (see [3] and references therein). Importantly, recent updates of the American standards of science education strongly encourage the development of instructional environments focused on the engagement in the practices of design, being convinced that this latter is equally important in the process of learning science, as the engagement in the practice of science [4]. At this regard, the use of 3D printing technology to motivate learning and foster a deeper understanding of physics concepts in a design-based approach has been already introduced in recent years, from the “Sculptures of Complexity using 3D printing” by a group of researchers from Imperial College London [5], who has successfully demonstrated how complex theoretical physics can be transformed into a physical object using a 3D printer, up to 3D-printing applications in Medical Physics Practice [6] and the very recent 3D-printing laboratory in the field of solid state physics nanostructures [7].

The lowering of 3D printers’ cost has promoted their massive spread in different educational centres and secondary schools across the world. However, many schools purchase 3D printers to keep up with trends, not realizing that they’re also valuable tools for student learning. Incorporating 3D design in physics classes might support the engagement of students in hands-on, problem-based learning with real-life applications, by addressing the core principles of the Next Generation Science Standards [8]. Nevertheless, despite the growing interest in 3D printing of didactical tools for supporting physics teaching (visit www.thingiverse.com, for example), the epistemological value of this technology applied to the development of an effective physics knowledge is still far from being established.

The “E3D+VET” (Erasmus+ for the immersion in 3D printing of VET centres) is a project supported by the European Commission through the Erasmus+ programme, Key Action 2 - Strategic Partnership for vocational education and training on Development of Innovation. The aim of the project is to develop educational tools for the VET system, which will provide new competences to both teachers and students and will serve as important means of innovation and acquisition of effective knowledge on interdisciplinary STEAM topics. The project started on the first day of October 2017 and it will last 30 months, up to the end of March 2020. The main objectives of the project can be summarised as: (1) train teachers non-CAD (computer-aided design) skilled in VET centres with the aim of using 3D printing across almost of all subjects, (2) improve student transversal abilities through the use of 3D printing, (3) heighten concentration of students with Attention Deficit Disorder, (4) improve 3D printing skills of VET teachers without technologic background as the best way to transfer this innovative knowledge to 21st century students. The activities that the project team has planned to carry out are mostly related to the development of a common methodology to improve the key competences in VET learners, create innovative education practices by means of the model-based 3D printing industrial technology, introduce systematic approaches to, and opportunities for, the initial and continuous professional development of VET teachers, trainers and mentors in both school and work-based settings.

In the context of physics education, the E3D+VET project teams are engaged in developing a methodology for an effective use of the 3D-printing technology in teaching and learning physics. At this regard, the project researchers are focusing their work on the manifold educational potential of the 3D-printing: the physics involved into multi-scale additive manufacture, such as melting polymers in injection molds, or the realization of 3D-printing didactical exercises to be experienced by teachers and students in physics classrooms. In the next few months, the project team will organize a professional development course for a sample of selected teachers in secondary schools and VET centres in Italy and Germany, with the aim of providing the teachers with the necessary background to define their own 3D printing educational resources. As a result of this course, the trained teachers will carry out an experimentation of the 3D-printing based physics didactical exercises in their classrooms. This experimentation will address the potential of a hands-on and multidisciplinary approach to the study of physics through the 3D printing technology and the support offered by a design-based learning method to the achievement of higher levels of reasoning skills in solving physics problems.

In this work, all the main pedagogical aspects of the project will be presented (Section 2), together with three 3D-printing didactical exercises involving physics topics and their application as interdisciplinary educational resources for teaching and learning science in a wider perspective (Section 3). A plan for a classroom pilot test of the teaching design-based materials will be also presented within the contest of teacher professional development and student experimentation (Section 4). In Section 5, the expected efficacy of the global formative process will be discussed.

2. The E3D+VET project

The 3D printing is an innovative rapid prototyping technology where different materials are laid down, layer by layer, to produce a 3 dimensional object. This process is known as additive manufacturing. The use of 3D printing is playing an important role in school system. It has been observed that this type of technology heightened the interest of students with poor concentration in different subjects and improved their desire to learn with tangible and very quick results. On the other hand, it is important also for teachers because it was demonstrated that some of them, mostly amongst non-design and technology teachers, have lack of CAD expertise and it is perceived as a barrier to using the 3D printer to its full potential.

The 3D printing is important for teaching and learning STEAM (Science, Technology, Engineering, Arts and Mathematics) subjects. Its use is transforming how users learn because it offers a hands-on experience that inspires them to pay attention to details, get more creative and see the physical realization of their work. “E3D+VET” (Erasmus+ for the immersion in 3D printing of VET centres), is a project funded by the European Commission through the Erasmus+ programme, Key Action 2 - Strategic Partnership for vocational education and training on Development of Innovation. The aim of the project is to develop educational tools for the VET system, which will provide new competences to both teachers and students from secondary school and will serve as important means of innovation and acquisition of effective knowledge on interdisciplinary STEAM topics. The project started on October 2017 and it will last 30 months, up to the end of March 2020. E3D+VET project is carried out by six partner organisations from Italy, Germany, Spain and Slovenia. They are involved in creating and establishing a collaboration that will end up in the production of several outcomes all aimed at increasing the skills and competences of teachers and students on the use of 3D printing technology. Specifically, the objective of the project is to create innovative education by a new and innovative industrial technology, which creates physical objects using digital models. The project will improve the knowledge of teachers about the 3D printing technology by developing specific Intellectual Outputs. In this way innovative teaching methods will be created and tested in several school and in different subjects by using the 3D printing technology.

One of the main goal of the project is to train teachers who are not computer-design-skilled, in order to make them able to introduce the use of the 3D printing in their subjects. Physics, in particular, is one of the STEAM subjects where 3D-printing technology might support both the development of an effective knowledge of the contents and the achievement of reasoning skills and problem solving abilities. As a matter of fact, the use of this technology in the VET system will improve the educational transversal skills of the students. Furthermore, it aims to enhance the concentration of students and will allow them to progress in the school subjects. At mid-term, also, it will feed an industry that is in high growth with future professionals and students interested in the topic. The project also wants to find innovative approaches to curriculum implementation of VET through methodologies, software creation and learning tools.

The project partners will strictly collaborate with VET schools where the 3D exercises developed will be tested during school lessons. This phase will be very important as it will validate and evaluate the outputs and the methodologies previously created. It therefore constitutes the key factor for project evaluation and sustainability.

The partners will implement a series of activities that will guarantee a good impact over the target groups and a sustainable effect over time. The Intellectual Outputs that will be developed are:

- Methodology for defining 3D printing exercises suitable for transversal education.
- 3D printing exercises and the correspondent STL files.
- A Networking software tool for connecting schools and 3D printing industry.
- The 3D printing exercises created will be tested in schools among students. The pilot phase will be organized by the schools involved in the project and the students and teachers involved will acquire competences on the use of 3D printers.
- Set of webinars on 3D printing to open a dialogue and forecast the use of 3D printing in VET education.

These results will have a great impact on 4 different groups:

1. Teachers:
   - Enrich their teaching methods and encourage creativity.
   - Improve the way of teaching and working in groups in VET schools and with other schools in other countries in EU.
   - Develop new ICTs skills.
2. VET schools:
   - Inclusion of new teaching methods in the VET's curricula thanks to the 3D printing.
   - Enhancing the internationalization process of the VET centres.
   - Growth of VET centres prestige locally, nationally and at European level by examples of good practice generated by project.
3. Students:
   - Increase of learning motivation through project interdisciplinary activities.
   - Improve the use of 3D printing and ICTs as a tool for learning, work and communication.
   - Development of transversal competences.
   - Enhance employability by means of being part of a heterogeneous partnership with industrial partners that will reflect the reality of job market.
4. Industry sector:
   - The number of job ads requiring workers with skills related to additive manufacturing and 3D printing will increase.

At the end of the project, to enhance its impact, four Multiplier Events will be organised in Spain, Italy, Slovenia and Germany to show the project results to stakeholders from education community and industry sector.

3. 3D printing didactic resources for physics education

In the context of physics education, the E3D+VET project promotes the use of 3D printing technology within the pedagogical framework of an inquiry based method of instruction [9, 10]. In inquiry-based learning, the students are engaged in identifying scientifically oriented questions, planning investigations, collecting data in laboratory and/or in real life situations, building explanation models, sharing their findings and eventually addressing new questions that arise. Depending on the amount of information and support provided by the teachers, the learners may be involved in a structured, guided or open inquiry [11-14]. A model of sequencing learning experiences is represented by the 5E model [15, 16] that leads students through five phases of learning: Engage, Explore, Explain, Elaborate, and Evaluate. In the context of 3D printing, the different phases can be described as follows: (1) Engagement involves the setting of the learning environment in a way that stimulates interest and curiosity towards the 3D printing technology; (2) Exploration is the beginning of student engagement in inquiry, by raising questions on specific real-life problems involving physics concepts, approaching 3D modelling and design, and experiencing 3D printed tools; (3) Explanation involves the process of data acquisition and evidence-processing techniques for individual groups or entire class (depending on the nature of investigation); (4) Elaboration is the state in which acquired information are shared and discussed with peers with the aim of generalizing the acquired knowledge to new situations; (5) Evaluation involves students' capacity to make an overall evaluation of their work, in comparison with the work performed by their classmates.

Within this instruction model, a set of didactical exercises has been designed in order to become future educational resources for effective teaching and learning physics in secondary schools and VET centres. In the following we describe three examples of 3D printing models that will be used for the subsequent experimentation in physics classrooms.

3.1. Wind turbine

Most wind turbines fall into one of two general categories: horizontal axis (HAWT) and vertical axis (VAWT). There's a limit to how big HAWTs can get, and once we reach that limit we cannot further increase their efficiency. Without the stress of holding up 80-meter metal blades by one end, VAWTs can potentially become much larger and, placed closer to each other in a wind farm, they can generate more electricity in a given area. The design and construction of a wind turbine is an extraordinary learning ground to study physics in a practical and effective way.

In this project, we adopted a VAWT model consisting of 10 pieces printed in 3D (Figure 1). The largest parts to be print are the blades. Each of them is made with three solids joined together that form a single piece. The blades are linked to each other with two connectors. The triangular shaped connectors are designed in such a way that inside them there is the space to link the blades. This structure, in turn, thanks to opposing holes in the connectors, is connected to the central axis formed by three pieces linked together. Everything is blocked with a circular gasket placed under the last connector. The entire structure is connected to a base to allow its balance.

The model will be used by the teacher to introduce the students to the physics behind the design and construction of a vertical axis wind turbine. It can be used to explore solid body rotation (symmetry axes) and make practice about the physics concept of torque and angular momentum. This model can be used outdoor on a windy day or inside the classroom with the support of a fan. Students will use the model as help to figure out how the presence of the wind can be considered a useful source of renewable energy.

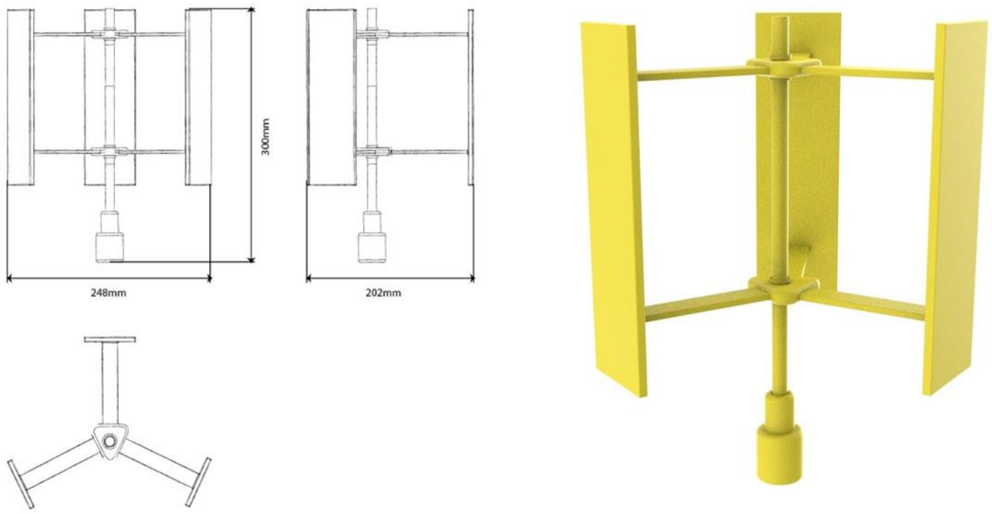

Figure 1. Wind turbine design from different axial views (left) and the 3D-printed model (right).

The benefits of this didactical exercise are mostly related to the opportunity of a hands-on exploration of the model. The tactical sense, in addition to the optical one, and the design and 3D printing practice of a wind turbine in the vertical configuration of the model will increase the student comprehension of the physics concept of moment of inertia and axial symmetry, as well as the wider science concept of energy and energy transformation. The model will stimulate the students to design and build their own models of wind turbine. Wind powered systems can be used to introduce the students to renewable sources of energy and their social impact on the planet. Interdisciplinary issues related to Engineering, Art-Design, and Social Science can be easily integrated in a student-centred multidisciplinary learning path.

3.2. Lever balance

The balance is one of the older instruments to perform mass measurements and surely represents one of the first the students use in their approach to physics laboratory experiences. In this work, the model will be used to stimulate the students to inquiry about the physics concepts of mass, weight, force, balance of rigid bodies and rotation, and the concept of lever. The model consists of 14 independent pieces (Figure 2). In the round base is fixed a vertical and central rod on which are connected, by 2 joints, that allow the rotation, two horizontal elements. On the horizontal elements, two vertical rods are fixed, by means of connectors, which have two circular plates at their upper ends.

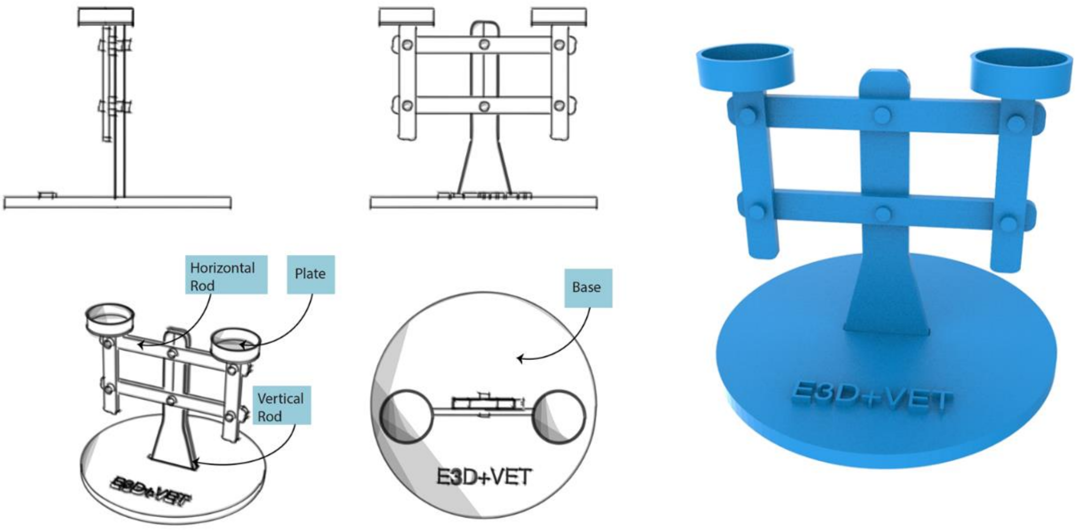

Figure 2. Balance design in different perspectives (left) and the 3D printed model (right).

The model will be used by the teacher to involve students in the guided exploration of the physics mass, weight, gravity, equilibrium of rigid bodies and rotation, and the concept of leverage. The model will be used to introduce the students to the different types of equilibrium (stable, unstable) and to the symmetry axes of solid bodies. In fact, it can also be used to explore the rotation of the solid body, torques and angular momentum. The difference between inertial mass and gravitational mass can be easily introduced to the students by means of this 3D printing exercise. Finally, the model can be also used to understand the history of mass and weight measurement systems in the International System of Units, in comparison with today's digital systems.

The benefits of using this didactical exercise are related to both the understanding of the design process and to the subsequent practice of the 3D printing model. The experience of the different equilibrium configuration of the model will increase the student comprehension of the involved physics concepts since the initial design phase, through the assembling stage and, finally, to the balance use for specific physics explorations. This model is finally suitable for a multidisciplinary approach to the study of physics, by including, for example, mathematical calculations of the centre of gravity of a rigid body and its axial symmetries, engineering design concepts and history of science.

3.3. Car for mobile

The model will be used to support students' exploration of the physics laws of kinematics and dynamics. The model represents a toy car able to host a smartphone (Figure 3), which will be used as a device for collecting movement data (velocity, acceleration etc.). It is composed of 9 independent pieces: the larger one represents a model car frame, 2 axes, 1 aileron composed by 2 pieces and 4 wheels. The model car frame should be designed in order to host a horizontal-positioned smartphone with 5.5 inches display.

The model will be used by the students to explore the physics laws of kinematics and dynamics. The smartphone inside the model will be used to collect the data about velocity and acceleration of the toy car, by mean of suitably applications installed on the phone (as "Physics Toolbox Sensor Suite", for example). The model car can be pushed by the students or let it go down an inclined plane at different angles. The model can be used to estimate the all the forces (propulsion, friction, gravity) acting on it.

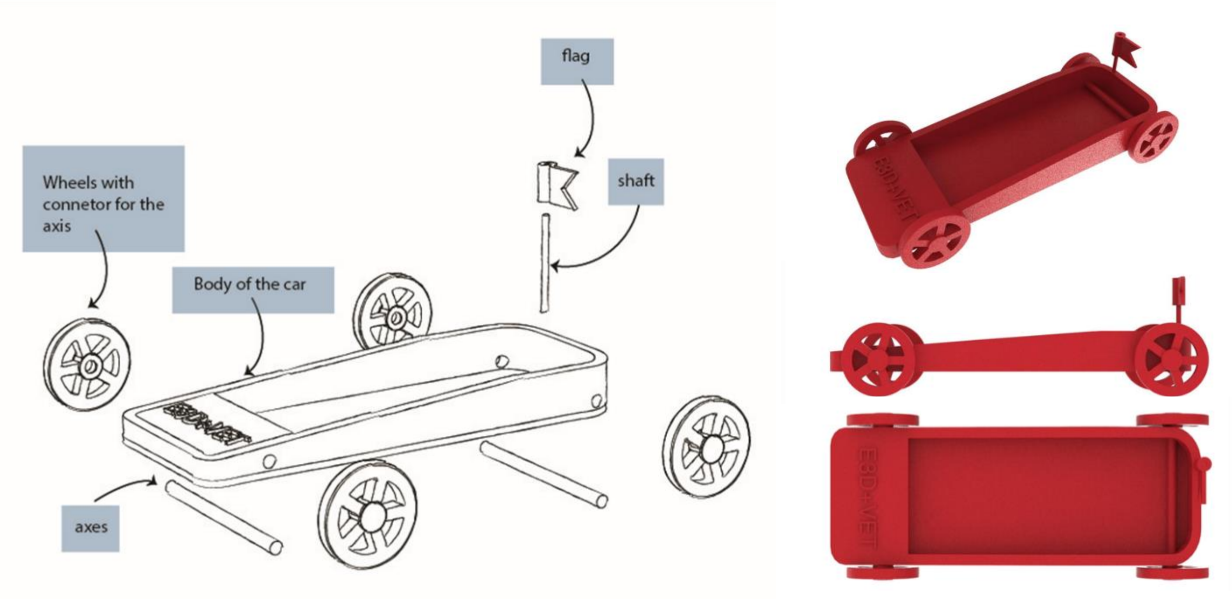

Figure 3. Design of the toy car for mobile (left) and 3D printed model in different views (right).

The benefits of using this model are related to the opportunity of a practical exploration of the physics laws governing the moving objects. The analysis of the data collected by the smartphone will foster student comprehension of the kinematics and dynamics concepts. In particular, the practice of the different kinds of movement of the toy car will help the students to understand the difference between velocity and acceleration. In addition, the learners will have the opportunity to better understand the concept of inertia (by observing and quantifying the differences on velocity and acceleration due to the use of smartphones having different weight). The students will also use the model to estimate the gravity acceleration by analysing the data collected during the motion in an inclined plane. Rotational friction can be also explored. The data collected through the smartphone will be used to quantify the energy transformation and the amount of energy lost with friction.

This model can be used within a multidisciplinary learning context. In fact, the process of data collection, making plots, analysis and drawing conclusions will support the improvement of student reasoning, mathematical and ICT skills. This model will finally represent a motivation for students to go deeper into the 3D-printing designing of evolved models of moving objects carrying a mobile data collector, bringing to an effective understanding of more complex physics concepts.

4. Physics teaching and learning through 3D printing

4.1. The E3D+VET program for teacher professional development

In the next few months the project's partners from Italy and Germany will select a group of teachers to be involved in a specific training for the immersion of 3D printing in VET centres, with the aim of promoting a highly motivating environment for learning physics. The teacher selection will be carried out in Italian and German secondary schools and VET centres on a voluntary base first and, secondly, by choosing mainly those teachers interested to perform both the professional development course and the subsequent experimentation in their classes.

The course will be organized in some face-to-face meetings where the teachers will have the opportunity to spend their time to interact with the educators, discuss with each other, and share their knowledge about 3D printing in a blended learning environment. Some of these meetings will be devoted to practice in 3D-printing laboratory sessions. A final meeting will host the teachers who will share the outcomes from their learning experience to an audience of both the educators and other teachers interested but not included in this first course. All the 3D printing physics exercises realized by the teachers during this course will upload in a dedicated online sharing platform of the project E3D+VET.

4.2. A multidisciplinary student learning path based on 3D printed physics tools

One of the main objective of the E3D+VET project is focused on student learning. The study of physics in secondary school and VET centres is too often characterized by a lack of interest and method, providing the learners with a knowledge based on the memorization of facts and laws which cannot be considered an effective understanding of the physics concepts. In this view, the use of 3D printing and ICTs as a tool for increasing students' motivation to learn physics more meaningfully might be an effective strategy. Student understanding of physics concepts can be driven within a multidisciplinary learning context which will also show the potential for improving work and communication skills, develop transversal competences and enhance employability, by means of being part of a heterogeneous partnership with industrial partners that will reflect the reality of job market.

The 3D printing didactical exercises described in Section 3 will be used to support the teachers to involve their student in a discovery learning of physics concepts through the 3D printing technology. An inquiry based method of instruction will be adopted by the teachers in their physics classrooms, as mentioned at the beginning of Section 3. In particular, the teachers will take the role of facilitators to drive students learning, by choosing the most suitable level of inquiry-based approach, depending on the previous knowledge and experience of the learners about the 3D printing technology. Teachers will be encouraged to follow their own method of instruction, within the framework of the 5E model, by taking care of the time needed by the students to face each phase of the learning cycle. A final peer-to-peer reporting of the results and an overall discussion about the explored physics concepts will be useful for the global assessment of the efficacy of the 3D-printing design-based learning process.

5. Conclusions

In this study, we present the state of the art of the E3D+VET European project for the inclusion of 3D-printing technology into the practice of physics teaching in secondary schools and VET centres. The project has just concluded its first year of activity, during which the methodology and several 3D-printing didactical exercises have been developed. In the context of physics education, the project has adopted an inquiry-based teaching approach as the natural framework where to develop design-based skills and opportunities for learning physics in highly motivating technological environments. The educational value offered by the 3D-printing technology is presented in this work by reporting three examples of didactical exercise which teachers can use to engage their students in designing, printing, assembling and experimentation of physics tools to be used for an active construction of meaningful knowledge. The plan for teacher professional development and the subsequent experimentation of the 3D-printing design-based teaching approach is also presented. The project highlights the relevance of a transversal education by promoting didactical exercises in which the physics contents can be easily embedded into a multidisciplinary learning path including mathematics, engineering, art, history. The project also promotes social and economic issues that can be addressed through the exploration of the physics behind the design and construction of devices for renewable sources of energy.

In the next few months, the results gathered by collecting teachers' feedback from their 3D printing designing course and the subsequent classroom experimentation will support an improvement of the methodology for defining 3D printing exercises suitable for transversal education. Finally, a networking community tool for teachers using 3D printing for immersion of 3D printing in education and training will be released.

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