Journal of Pre-College Engineering Education Research (J-PEER)

Manuscript 1324

PRINT3D, a Service-Learning Project for Improving Visually Impaired Accessibility Through Educational 3D Printing

Oscar R. Lozano

Follow this and additional works at: https://docs.lib.purdue.edu/jpeer

Part of the Accessibility Commons, Engineering Education Commons, and the Service Learning Commons

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.

This is an Open Access journal. This means that it uses a funding model that does not charge readers or their institutions for access. Readers may freely read, download, copy, distribute, print, search, or link to the full texts of articles. This journal is covered under the CC BY-NC-ND license.

PRINT3D, a Service-Learning Project for Improving Visually Impaired Accessibility Through Educational 3D Printing

Abstract

Well-executed service-learning projects are a high-value educational element. However, these projects commonly focus on overused topics and unbalanced executions which can produce the opposite effect to that desired when working with groups of people with functional diversity. PRINT3D is a service-learning project aimed at improving accessibility for people with visual disabilities while helping primary and secondary school students learn basic engineering skills through 3D design and printing. Under the support of the European Erasmus+ Programme, this project brought together nongovernmental organizations, teacher professional development centers, business enterprises, and educational centers to collaborate for two school years. The project activities aimed to promote empathy with visually impaired individuals, understand their accessibility needs, generate and prototype solutions, work collaboratively, and 3D design and print objects such as subway line plans, facility plans, signage, and artistic objects that are accessible to the visually impaired. The results of the project were increased motivation, social awareness, and technical skills, especially among students with a higher risk of dropping out of school.

Keywords

3D-printing, service learning, visually impaired

Document Type

Research Article

Available online at http://docs.lib.purdue.edu/jpeer

Journal of Pre-College Engineering Education Research 12:1 (2022) 60–80

PRINT3D, a Service-Learning Project for Improving Visually Impaired Accessibility Through Educational 3D Printing

Oscar R. Lozano

University of Valencia

Abstract

Well-executed service-learning projects are a high-value educational element. However, these projects commonly focus on overused topics and unbalanced executions which can produce the opposite effect to that desired when working with groups of people with functional diversity. PRINT3D is a service-learning project aimed at improving accessibility for people with visual disabilities while helping primary and secondary school students learn basic engineering skills through 3D design and printing. Under the support of the European Erasmus+ Programme, this project brought together nongovernmental organizations, teacher professional development centers, business enterprises, and educational centers to collaborate for two school years. The project activities aimed to promote empathy with visually impaired individuals, understand their accessibility needs, generate and prototype solutions, work collaboratively, and 3D design and print objects such as subway line plans, facility plans, signage, and artistic objects that are accessible to the visually impaired. The results of the project were increased motivation, social awareness, and technical skills, especially among students with a higher risk of dropping out of school.

Keywords: 3D-printing, service learning, visually impaired

Introduction

Prior research in science, technology, engineering, and mathematics (STEM) education highlights the importance of contextualized learning and the benefits of addressing socially relevant problems related to the real world (Selcen Guzey et al., 2017). Contextualized and authentic learning can be one of the keys to a successful teaching–learning process by bringing learners closer to the real work of scientists and engineers, enriching the learning situation, and increasing the chances of success in understanding concepts and acquiring skills (Chinn & Malhotra, 2002; Strobel et al., 2013). In prior studies in engineering education, the service-learning approach is found to be effective in support of authentic learning while promoting engineering values such as empathy and care (Fila & Hess, 2015; Walther et al., 2017).

PRINT3D is a service-learning project designed to improve designed artifacts to better serve visually impaired users through educational 3D printing as seen in Figure 1. One of the project foundations is the use of the maker movement principles, materialized in the use of 3D technology in the classroom to perform a service to society. Despite the limitations imposed by the cost of the equipment and the time required by the activities associated with 3D printing, there are opportunities for creating exceptional value such as the ease of transitioning from an abstract idea to a concrete object, and the resulting motivation to create creative and useful products. There are also opportunities for developing computer-aided design (CAD) skills, gaining technological knowledge through evaluation of existing designs found in the repositories of ready-to-print designs, and learning science concepts related to 3D printing machines (e.g., mechanics, thermodynamics, properties of materials, programming, etc.). While the use of 3D printing is often understood as a subsidiary educational

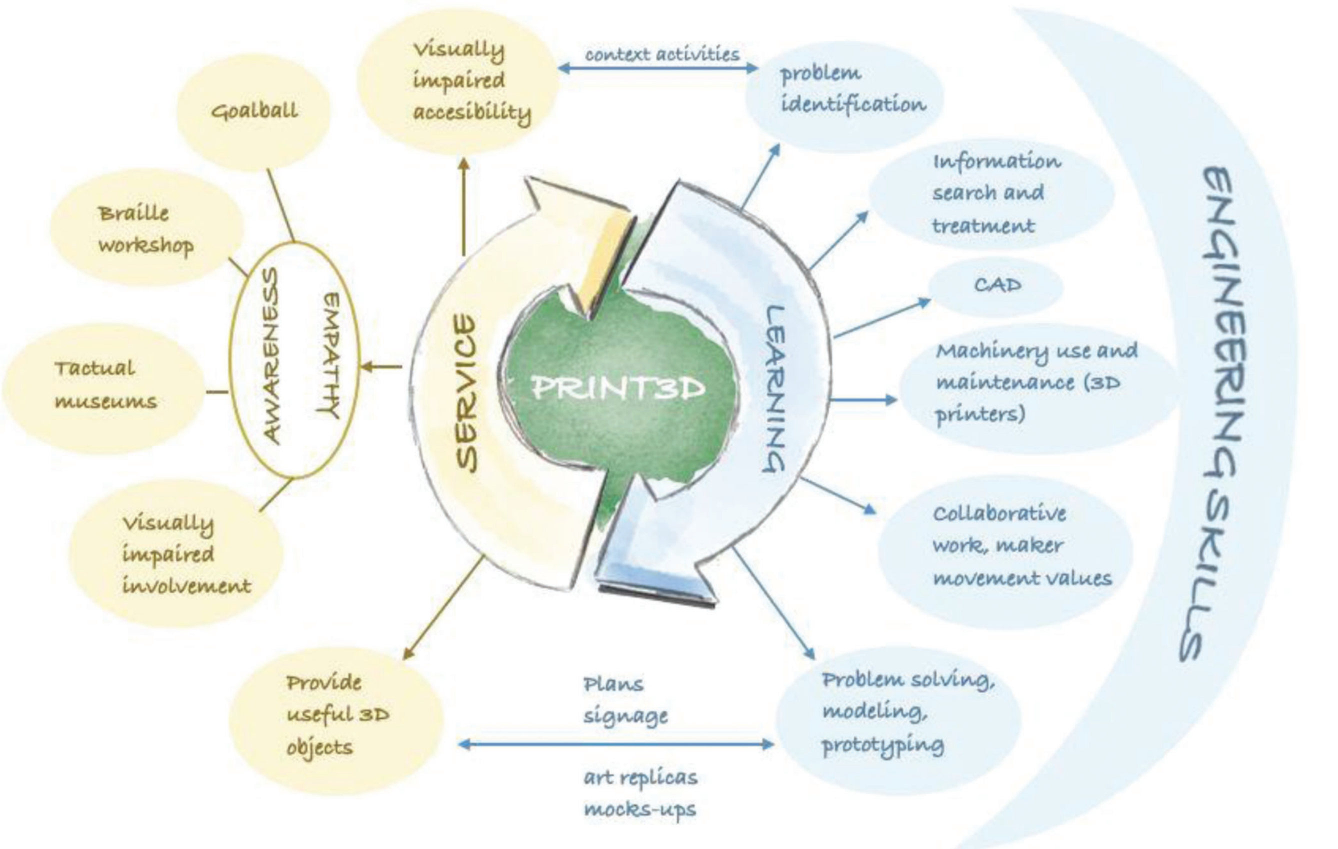

Figure 1. The components of the PRINT3D project.

resource and nonessential compared to other school subjects, there are emergent studies on the educational use of 3D printing to provide solutions for real technological problems in society, and more specifically, for people with disabilities (Knochel et al., 2018).

The PRINT3D project is funded by the European Erasmus+ Programme in its key mission of building "strategic partnerships for school innovation." The project was born from the need detected in students with visual disabilities enrolled in the participating centers. These students received the translations of the usual newcomer documents into Braille, but the plans of the facilities were not included in the *Welcome Information* packs due to the difficulty of making these objects with traditional tiphlotechnical technologies. This starting point gave rise to the design of a program of activities in which students make the plans of their educational centers to facilitate accessibility to their classmates with visual disabilities. Later, the idea expanded beyond the limits of this purpose, serving the needs of the visually impaired community by generating designs and useful objects such as subway plans, works of art, signage, etc. (see Appendix, Figure 2). In this project, design and 3D printing were implemented as an element of engineering curricular development at primary and secondary education levels, through the use of the service-learning methodology. Service-learning projects are usually related to actions on the environment, intervention in the socioeconomically disadvantaged population, support in geriatric care, etc., but there are few initiatives related to people with disabilities and, within them, very few integrate 3D printing to address the needs of the visually impaired community. Paradoxically, 3D printing offers objects with tactile characteristics and, therefore, opens a huge range of possibilities within the visually impaired community. The connection with the real world and the usefulness of the activities carried out in the classroom resulted in an excellent boost to the motivation and effectiveness of the teaching–learning process of engineering in young students.

Theoretical Framework

The Maker Movement and Its Impact on Education

Studies focused on the transposition of the maker movement into the classroom are increasing (Kye, 2020; Martin, 2015). The potential benefits associated with "doing" traditionally addressed to math and science are even more essential in engineering and technology classes. Design and 3D printing seem to be a great technology to carry out this purpose without underestimating more traditional aspects of manufacturing already commonly incorporated in classrooms.

The human being is naturally a *maker* individual. No matter if we are more or less a tinkerer, we all *do* things, be it in the kitchen, with sewing, in the garden, or with electronics. "There once was a time when most Americans commonly thought of themselves as tinkerers" (Dougherty, 2012, p. 11). Nevertheless, the *maker movement* is today understood differently: more related to hobbyists, entrepreneurs, or small manufacturers than to each person *making things* as a tinkerer. The coining of this term with its current connotations could be attributed to the appearance of the first issue of *Make* magazine and, by extension, to the first Bay Area Maker Fair in 2006 (Make, n.d.; Martin, 2015). This "movement" has manifested itself largely thanks to the development of new technologies and new consumer habits. The potential for local development and the opportunity to develop entrepreneurship have driven this movement. Micro-entrepreneurs who bring cultural and artistic vitality to their cities, people with high innovative capacity willing to provide solutions, and small manufacturers who promote the development of their local communities have contributed to the popularity and expansion of this movement (Wolf-Powers et al., 2017). Young people see in the maker movement an open space that requires active participation (Martin & Dixon, 2013) and, thus, we can accept the definition of Halverson and Sheridan (2014, p. 496): "The maker movement refers broadly to the growing number of people who are engaged in the creative production of artifacts in their daily lives and who find physical and digital forums to share their processes and products with others." One of the clearest exponents of the cooperative, collaborative, and entrepreneurial spirit of the maker community was the high number of actions and supportive projects developed in the early phases of the COVID-19 pandemic (Corsini et al., 2020).

Bevan (2017) reviews and analyzes the potential of "doing" by distinguishing three types of approaches to the concept: the entrepreneurial, educational, and development of laboring competencies in the STEM field. In the research, it is shown that through "doing," creative aspects are developed which can facilitate the achievement of general objectives related to students' interests, abilities, and productivity. In the study, it is also pointed out that many studies in the fields of mathematics and science highlight the goodness of "doing." Despite complying with many of the standards provided for engineering learning, studies related to the inclusion of "doing" are more scarce.

The concept of learning by building is not an innovation. Montessori (1912) already exposed the benefits derived from playing and building in the teaching–learning process. The manipulation of objects, materials, and tools and the possibility of testing ideas constructively are the basis of her approach. This fact is contemplated in practically all the study plans of STEM subjects and is the foundation of those subjects where the construction of an object or a final product articulates the learning of the contents. The construction of final products as a response and solution to a technological problem is usually the main objective of the engineer's own working method. Therefore, the method could be emulated in the classroom to achieve "knowledge of basic engineering." This constructive spirit has been greatly reinforced by the boost of the maker movement. However, while the characteristics of the current *educational maker environment* are tremendously favorable in terms of the availability of resources such as laser cutters, 3D printers, Arduino or Raspberry Pi microcontrollers, and affordable electronic components, the conversation should not focus on these aspects. It would be a mistake to link the educational success of maker activities to the availability and accessibility of the tools described. Other elements from the *maker world* with high educational value must be taken into account. The huge community that has developed around the maker movement, mainly in nonformal settings such as museums or libraries (Hirsh, 2020), or the ability to share and collaborate are aspects that must be considered in an educational environment (Martin, 2015).

3D Printing and Its Educational Application

Since its origins in the 1980s, additive manufacturing has promised very diverse applications. Over time, 3D printing has been considered to be one of the key parts of the Fourth Industrial Revolution (Maynard, 2015). The European Commission (2014) itself already picked up the enthusiasm for the advances in this discipline. This drive for innovation in additive manufacturing offers endless possibilities in fields such as medicine, aeronautics, automotive, architecture, and topography (Snyder et al., 2014). The mentioned facts, undoubtedly, are producing a significant social impact (Huang et al., 2013).

In all these cases, in addition to its direct application in the different fields of knowledge, its use in teaching has been outlined. One of the most spectacular cases is in medicine, where 3D printing has revolutionized its teaching–learning tools. There are countless studies on the efficacy of using 3D printed models in this specialty (Bartellas, 2016; García et al., 2018). Likewise, the teaching of other scientific disciplines such as physics or chemistry has benefited from the emergence of a technology that allows the production of objects simply and economically. Tangible three-dimensional models, traditionally manufactured with different technologies, often help to understand physical–chemical concepts. Students of these scientific subjects currently take advantage of learning by using objects made with 3D printers which are now tremendously "affordable" (Jones & Spencer, 2018). Studies such as engineering or architecture have also been "revolutionized" with the inclusion of pieces made with 3D printing. This includes not only the pieces themselves but also the rapid prototyping techniques. The potential is remarkable, but it is not recommended to develop it as something exceptional or unusual. Rather it is suggested to include 3D printing in the curriculum, highlighting its interest (Bøhn, 1997; Celani, 2012; Chien, 2017; Grujović et al., 2011; Stamper & Dekker, 2000).

Deepening its educational aspect, 3D printing has broken into all school levels and has enhanced and empowered the maker movement (Martin, 2015). Regardless of the discipline, the design and printing of 3D pieces have entered early childhood (Avanzini et al., 2019), primary, and secondary classrooms. It is necessary to create awareness and knowledge about the importance of teaching 3D printing throughout the educational world, with specific support for teachers, trainers, and lecturers (Simpson et al., 2017).

Numerous actions have been carried out focusing the power of 3D printing solely on its vision as a manufacturing tool for improving the understanding of concepts of other disciplines. Without underestimating this approach, it does not encompass the educational potential of 3D printing. It is necessary to highlight the pedagogical aspects of the maker movement linked to 3D printing. Its virtues fit in engineering curriculum development, according to the *Technological Pedagogical Content Knowledge*, and facilitate the exchange of knowledge between groups of teachers (Song, 2018). Therefore, the use of 3D printing can facilitate design activities in accomplishing service-learning goals and principles.

Ford and Minshall (2019) provided an intensive review of the published literature on 3D printing. Their review resulted in five goals of 3D printing: (1) to teach students about 3D printing, (2) to teach educators about 3D printing, (3) to teach design and creativity skills and methodologies, (4) to produce artifacts that aid learning, and (5) to create assistive technologies. Our approach is in alignment with these five goals and is further elaborated in the following sections.

Service-Learning Methodology

By promoting service-learning, we are considering that the ultimate goal of education is not only to be trained as an individual but also to learn to be useful to others. Service-learning links learning with social engagement. To do this, students identify a problematic, delicate, or controversial situation in their close environment to try to find a solution through a "solidarity" project, developing skills, abilities, attitudes, and values in the process. According to Martin and Wendell (2021), engineering education can promote these values and reveal to students that engineering should not be limited to simply doing math, but that engineering is looking for solutions to community problems from a more human and inclusive perspective.

Service-learning is rooted differently in various parts of the world. In Europe, it is somewhat less widespread and developed than in the United States where service-learning projects are present in many educational centers (National Center for Education Statistics, 1999; Sotelino-Losada et al., 2021). The service-learning projects are usually related to environmental aspects, tutoring, and individual accompaniment or support (generally geriatric).

Numerous publications show the benefits of the application of service-learning as a methodological tool (Billig, 2002; Celio et al., 2011; Matthews et al., 2015; Warren, 2012). Even so, sometimes it is not clear about the pedagogical bases and principles that should guide service-learning activities to turn them into effective educational tools. Despite the expected flexibility when designing a service-learning activity, sometimes these activities are understood in an unbalanced way. In some cases, the activities are mainly academic with limited community service. In other cases, the activities are hardly related to the curriculum and emphasize service rather than learning (Billig, 2002). Most teachers propose service-learning activities in an attempt to improve their students' commitment as citizens, make them aware of the needs of their community, or achieve greater maturity and social involvement. But some of these goals could be accomplished in community service activities. Therefore, service-learning activities should be viewed from their own particular perspective. Billig (2011) states that a good service-learning activity must contain six essential elements: *investigation*, *planning*, *action*, *reflection*, *demonstration*, and *celebration*. *Investigation* refers to the collection of data and the definition of the problem. *Planning* includes a greater search for information and exchange and sharing of the actions to be taken. *Action* refers to the provision of the service itself and is the only part in common with community service. *Reflection* requires more complex intellectual processes in evaluating what has been done, the impact, and possible changes or improvements. *Demonstration*, which generally includes interaction with stakeholders and policymakers, is the opportunity to publicly display the knowledge and skills acquired in the process. *Celebration* implies recognition and reward for the work done and must be carefully watched so that it does not turn into a counterproductive element. In addition to these six elements, the National Youth Leadership Council (2008) provided eight K-12 Service-Learning Standards for Quality Practice that included: *meaningful service*, *reflection*, *youth voice*, *monitoring of progress*, *link to curriculum*, *diversity*, *partnerships*, *duration*, and *intensity*. These generate their own accomplishment indicators which must be taken into account for carrying out successful service-learning actions (Billig, 2011).

Although it has been pointed out that service-learning projects tend to have diverse approaches, lately the service to communities of people with functional diversity has proliferated. However, it is critical to consider the sensitivity of the people who receive the service. Badly planned or executed service-learning actions can generate a positive feeling in the students involved in the activity but the opposite in the people "receiving the service." According to Gent and Gurecka (2001), "many service-learning projects are rife with disablism" when approached stereotypically. Usually, the problems of people with disabilities are more related to the social attitude towards them than to the disability itself. To avoid this mistake, the authors of the study propose to keep in mind four key elements in the planning and development of service-learning projects: *teacher training in service-learning*, *teacher training in disabilities issues*, *increased emphasis on reflection*, and *cultivating people with disabilities as joint partners in providing service*. These elements have been endorsed in other studies that highlight a clear improvement in the results of students with and without disabilities when students with functional diversity participate (Abernathy & Obenchain, 2001; Case et al., 2020; Dymond et al., 2011).

3D Printing in Service-Learning Projects

Ford and Minshall (2019) completed a systematic review of studies published on 3D printing that articulates a goal of 3D printing as creative assistive technology. Analyzing this aspect in detail, Ford and Minshall argue that most studies are limited to offering indications about 3D printing possibilities for manufacturing products aimed at improving accessibility for people with some disabilities (Buehler et al., 2014a; Gual et al., 2012; Horowitz & Schultz, 2014; Kane & Bigham, 2014; Moura, 2021; Stangl et al., 2014, 2015; Wonjin et al., 2016). Others focus on the use of 3D printing as a vehicle for motivation in special education (Buehler et al., 2014b, 2015, 2016; McLoughlin & Lee, 2010) and even as a technique for social inclusion in nonformal learning environments (Bosse & Pelka, 2020).

Extremely rare are the experiences that include 3D printing as the backbone technique of a service-learning project focused on people with some type of disability and even more those which include the visually impaired as the target group of the service part (Cook et al., 2015). As indicated previously (Gent & Gurecka, 2001), several aspects must be taken into account when developing service-learning projects to avoid misunderstandings or deepening erroneous stereotypes. Well-designed service-learning projects can have the power and all the positive aspects of the different approaches seen: improving the accessibility of people with some disability, proffering participating students, with and without disabilities, the acquisition of competencies related to "making," educating in citizenship, etc.

These examples show how the integration of 3D printing in service-learning projects aimed at improving specific aspects of the lives of people with disabilities can produce very beneficial results (Stone et al., 2020; Suchow, 2016). The key to the educational success of these experiences lies in all the previously verified aspects: the correct curricular coupling, the involvement and adequate training of teaching staff, the incorporation of students (or external collaborators) with the functional diversity object of service, and enough time available to carry out "intense" projects. Finally, increased engineering skills, motivation, and social awareness are expected results when working with 3D printing. The project detailed below contains all these elements and provides a novel approach to pre-college engineering classrooms that can inspire further service-learning efforts related to engineering curriculum development.

The Erasmus+ Programme and the PRINT3D Project

PRINT3D is a project subsidized by the Erasmus+ Programme. The Erasmus Programme began in 1987 with the support of European public administrations to promote the mobility of university students across the European Union (European Commission, 2017). Progressively, the program evolved to subsidize broader actions related to the academic and cultural world. Currently, the program supports actions in education, training, youth, and sports through projects related to values included in the priorities and activities established in the European Education Area. The Erasmus+ Programme focuses on social inclusion, ecological and digital transitions, and promoting the participation of young people in democratic life.

The Erasmus+ Programme is divided into different key actions (KA) depending on the recipients and the type of actions proposed in the projects. The program ranges from job shadowing mobilities to strategic alliances for innovation or exchange of good practices. Many projects can include countries from around the world that are not EU Member States (Erasmus+, n.d.). KA201 supports "Strategic partnerships supporting innovation in the field of education" projects. KA201 highlights proposals where different types of organizations promote activities and pursue objectives related to educational innovation and require *transnational meetings*, *intellectual outputs* (IO, deliverables), *training activities*, and *multiplier events* (ME).

PRINT3D is a two-year KA201 project, with partnerships made up of:

- three organizations dedicated to the inclusion (education and rehabilitation) of the visually impaired (two of them governmental, *National Institute for the Blind, Visually Impaired and Deafblind* from Iceland and *Center for Education & Rehabilitation for the Blind—KEAT* from Greece; and one nongovernmental, *Society of Riga partially sighted and blind "Look at me"* from Latvia),

- a business company that produces 3D printing equipment (*BQ* from Spain),
- five educational centers (four public and one private) where there are some visually impaired students enrolled (*3d Gymnasium Kifissias*, *Ellinoagliki Agogi*, and *4o Primary School of Pefki* from Greece, and *IES Conselleria* and *IES Benlliure* from Spain), and
- a regional Ministry of Education through its STEM Teacher Training Center (*CEFIRE CTEM-Conselleria d'Educació*, from Spain) which acts as coordinator.

Erasmus+ calls for some specific activities to carry out in this type of project: *transnational meetings* (significant moments of control and assessment), IO (deliverables), *training activities*, and ME.

First Phase. First Year

During the first year the project efforts focused on professional development activities in support of the teachers involved in the subsequent implementation. Teachers learned aspects of awareness and knowledge of the particularities of the visually impaired community, details of the service-learning methodological tool, and technical aspects related to 3D printing. To provide the training, three IO were developed:

IO-1

Teacher professional development on the *contributions of new technologies to the methodological development of service-learning oriented to visual impairment. Implications in inclusive education*. IO-1 included the design and the material's performance of a 30-hour training course focused on the service-learning methodology and specifically oriented to actions related to the visually impaired community.

IO-2

Teacher professional development on *3D printing teaching applied to production of useful objects for the visually impaired.* IO-2 included the design and the material's performance of a 30-hour training course focused on the 3D printing skills needed to correctly teach the related contents adapted for making objects ready to use by visually impaired people. The materials involved in these courses were designed considering two different uses: online (MOOC) and face-to-face.

IO-3

Mini-textbook for students and teachers on *3D printing as a curricular element in the inclusion of the visually impaired through a service-learning methodology.* Starting from IO-1 and IO-2, a proposal to design, develop, and produce IO-3 was introduced. In addition, along with the teaching guide, a textbook was developed for use by students in which the main aspects of 3D printing and the service-learning methodology were presented. The contents and course materials of these IO are shown in Table 1.

There was an exhaustive assessment plan, including surveys and direct feedback in face-to-face piloting to assure the quality of the products before launching them to the general public. The dissemination included free dissemination through websites, repositories, social media, conferences, and the *ad hoc* ME held in Latvia and Spain.

All the participating teachers followed the training process both in the technologies associated with the design and 3D printing and in the service-learning methodology focused on the visually impaired community. The training was addressed from all possible approaches with the advice of the organizations focused on people with visual disabilities, the 3D printing manufacturing enterprise, and the teacher training center.

Implementation in Educational Centers

The project was implemented in five participating educational centers with 74 students and 10 teachers fully involved. However, thousands of students and hundreds of teachers were aware of the project through brochures, roll-ups, and 3D objects. Two centers in Spain, one in Latvia, and one in Iceland followed the project closely. In addition, the teacher training center (CEFIRE) offered several courses focused on 3D printing and service-learning which had hundreds of participants.

In the piloting groups, the second phase started raising the problem that would constitute the main nucleus of the project through activities such as follows:

- *Think of 3–5 important places in your area/country that should be accessible/more accessible to the blind or visually impaired (could be an airport, a historical site, a museum, an official building). How are they already accessible (if they are), and what could be improved?*

Table 1
Intellectual outputs.

IO	Contents	Course materials
1	• Students with visual impairment. Inclusive strategies • Service-learning oriented to visual disability • New technologies as driving tools for inclusion • The role of new technologies in the inclusion of visually impaired people	• Course guide program. Timing and content structure • Selection of conceptual contents • Activity program. Pre-filled activities, questionnaires, exercises • Practical activities to reinforce acquired skills • Evaluation tools • Bibliography
2	• General information about 3D printing • Technical features, advantages, and disadvantages of different 3D printers for educational purposes • Didactic use of 3D printing • Assembly and configuration of a 3D printer • Three-dimensional modeling programs: OpenSCAD, Tinkercad, FreeCAD • Pieces designed based on the mapping of different buildings and cultural facilities • Quality control and enhanced performance of the 3D printer in order to obtain the best possible three-dimensional pieces for tactile use	• Course guide program. Timing and content structure • Selection of conceptual contents • Activity program. Pre-filled activities, questionnaires, exercises • Online 3D models libraries • Practical 3D printing activities • Evaluation tools • Bibliography
3	*Students*: • Visual impairments and blindness • Service-learning • 3D printing *Teachers*: • Visual impairments and blindness • Service-learning • 3D printing • Implementation of the PRINT3D project in schools	• Justification • Methodology activities • Didactic materials • Timing • Evaluation • Activities aimed at deepening and reinforcing theory and practice • Study orientations

- *Is the place easy and safe to navigate for people with little or no vision? Does it have information written in Braille or large letters, or audio guides? Should it have?*

After activities like this, the central problem that guides the students toward the service-learning project was posed: Is your school accessible to visually impaired or blind students? What do you think would make the building more accessible?

All the centers worked on a similar sequence of activities in order to arrive at the main problem of how to make the educational center more accessible. The students agreed on the actions necessary to achieve a more accessible center: the creation of tactile objects such as signage or tactile plans, the incorporation of marks on the ground distinguishable with sticks, or elements with highly contrasting colors that are easy to see by people with reduced vision. The project was already more refined and concrete.

Despite using the same approach, there were differences between the participating centers. Although the "service part" is common (civic education), the "learning part" varies since primary, secondary, and vocational education training (VET) centers participated (see Appendix, Figure 3).

Table 2
Participating centers, curricular contents, and teachers' profiles.

School and country	Grade level/subject	Teachers' background	Curricular objectives
4th Primary School of Pefkis (Greece)	Primary/science and technology	*Primary teachers*. Both science and technology specialists	"I create and express myself with presentations and multimedia," "I know the Internet—I communicate and I collaborate," "I program the computer," "I implement work projects/research with ICT," "I build digital education and literacy"
Ellinoagliki Agogi (Greece)	Primary/science and technology	*Primary teachers*. Two ICT and one English teacher	"I create and express myself with presentations and multimedia," "I know the Internet—I communicate and I collaborate," "I program the computer," "I implement work projects/research with ICT," "I build digital education and literacy"
3d Gymnasium Kifissias (Greece)	Secondary/computer sciences	Two computer engineers and one English teacher	Computational thinking Understand the main principles of solving problems by using computers Skills necessary to apply understanding to solve computer-based problems using several basic programs
IES Benlliure (Spain)	Secondary/technology	One industrial engineer and one agricultural engineer	Identify and solve technological problems, applying the engineering design process Obtain, analyze, and select information in a reliable and secure way Develop basic skills in the configuration, use and maintenance of machines, tools, applications, and digital systems Express and communicate ideas, opinions, and proposals correctly, using the language of the subject correctly
IES Conselleria (Spain)	Initial vocational training/computer engineering	*VET teachers* All of them are computer engineers	Configure and use computer applications and understand their final purpose. Use utilities provided by the Internet, configure them, and identify their functionality and benefits Identify material, tools, and elements necessary for setting up and assembling electrical and electronic equipment with a specific and functional purpose

Table 2 groups together the curricular descriptions of the five participating centers and also shows the profile of the teaching staff responsible for the project. In all centers, there are common Cross Curricular Key Competencies including social and political (civic) education, solidarity and interest in solving social problems, improving the integration of vulnerable groups, and participating in community activities showing behavior contrary to any type of discrimination.

The previous training allowed teachers to adequately adapt the activities to the different educational levels. The centers chose different models of 3D printers: *Hephestos*, *Witbox2*, and *Witbox go!* from the manufacturer BQ in both Spanish centers and *Craftbot Plus* from the manufacturer Crafbot in the three Greek centers. All models of 3D printers are based on fused filament fabrication with PLA as the most common material. For design learning (CAD), the two main programs used were Tinkercad and Freecad which are both freely accessible and adapted to different levels of aided design knowledge. However, other complementary programs were used such as Inkscape and PrintLab. Likewise, the students were instructed on the different options to transform STL design files into GCode 3D printing files with Ultimaker-Cura. In addition, searches in repositories such as Thingiverse (n.d.) or MyMinifactory (n.d.) were frequent in order to have references as starting points.

The 3D printing of objects for the visually impaired must take into account certain conditions. The best option to make successful pieces is to try to enroll visually impaired students in the project. Unfortunately, only one center (IES Benlliure) had a student fully involved in the project. Another student from the same center was helping out by giving feedback from time to time. In the other Spanish center, some visually impaired students from other classes occasionally participated when necessary. In any case, people with visual disabilities recruited by CERB and ONCE (Spanish National Blind Organization) frequently participated by giving advice and feedback in the five centers.

Since the printed objects are likely to be handled a lot, it should be kept in mind that the parts of the objects must not be very fragile or too thin. The texture of a finished printed object is much rougher than paper, so it is necessary to be careful that the text or drawing information consists of not too fine lines that stand high enough to be readable. People who rely on their fingers to read text and information usually develop a keen sense of touching in one or more fingers. To generate Braille, the TouchSee (n.d.) website was very useful. The website allows people to write text, convert it into Braille, and save it as an STL file. When adding written information in Braille, it must be kept in mind that the text may take up more space than expected especially compared to written text intended for the sighted.

While Braille needs to be raised, it is necessary to be careful not to raise it too much as that can be confusing. Creating a computer-based 3D model of something overly detailed and complicated can be quite challenging, and it should be recommended that students' tasks/expectations be kept realistic. It is highly recommended to show students what can be achieved with practice and training.

To understand the importance of the sense of touch in the visually impaired and improve the approach to solutions, various activities were carried out systematically in all centers. Some examples are:

- *Select different objects with different textures like soft, rough, hard, small, big, cold, warm, using a blindfold and taking turns in handling the objects.*
- *How is it to touch the material? Is it hard, soft, smooth, cold, warm, etc.? Does it have any form like round, square, triangular? Does the material have a smell? What does it smell like? Does the material make any sound when you touch it?*
- *Create a map of an area, e.g., the school hallway, the school grounds, the route to a selected location. Use something that can be felt by hand, like by gluing yarn to the paper, using paper with different textures, and making raised lines by drawing on the opposite side of the paper (with a soft underlay). Let your classmate figure out how to use the map.*

Moreover, in order to raise awareness among other students, teachers, and families, numerous activities were carried out such as talks, workshops teaching Braille, practicing the adapted sport goalball, and visits to tactile museums (see Appendix, Figure 4). These activities make the service part meaningful and avoid the aforementioned risk of limiting the project to a mere charity action which undermines the true aim of service-learning (Gent & Gurecka, 2001). The following sections present student learning outcomes as well as lessons learned from three educational centers. These descriptions are based on teachers' statements and observation reports.

Student Outcomes, Challenges, and Lessons Learned

4th Primary School of Pefkis

Pefkis is a public primary school located in the Athens, Greece, metropolitan area. Eighteen Pefkis students of ages 10 through 12 participated in the project. The first proposed activities quickly led to the main need of creating more accessible spaces for the visually impaired. From this moment on, awareness-raising activities led to the learning of values and the development of positive attitudes such as empathy with the visually impaired.

This awareness remains constant throughout the process. In the case of this center, the visit to the tactile museum in Athens was quite relevant, because the students attended numerous workshops with the help of the museum (Tactual Museum, n.d.). The collaboration with CERB made it possible to answer all the questions from people with visual disabilities. Children often commented on how dangerous places in the school such as the schoolyard and the stairs leading to the basement could be for the visually impaired, how unfriendly the streets around the school were, and endless details about the lives of the visually impaired and the accessibility problems they face in everyday life. These awareness-raising activities led directly to one of the basic learning objectives: to identify real technology problems and develop critical and problem-solving skills as well as take responsibility for suggesting applicable and realistic real-world solutions.

Working in small groups, many proposals were made. In this sense, a second curricular objective was reinforced: the students learned to interact and value the opinions of others, improving their communication and collaboration skills. 3D printing emerged as an interesting solution to solve many of the accessibility problems detected. The students began to look for information in this regard. Always guided by the teacher, they learned details about the 3D printing manufacturing process. In this search for information, repositories such as Thingiverse emerged as very interesting reference sources. Another curricular goal of retrieving and processing information was developed.

The basic principles of CAD were learned with the Tinkercad program. The students saw how many of their proposals could be materialized in specific designs. It took a long time to master the program itself, but printing objects from the repositories was done in parallel which was very motivating for students and encouraged them to learn CAD. Maturity at that age entails recovering from certain design failures. The students had some difficulty understanding why some of their designs could not be printed. They also had difficulties with scaling the size of their designs on screen and the 3D printer. Their creativity was beyond the laws of physics and the 3D printer capability.

Some technical contents related to 3D printing were discussed in the classroom such as basic details about maintenance and environmental aspects related to the nature of PLA and other materials. With the help of other teachers, the students used applications such as Touch-mapper (n.d.) to print plans of the Athens Olympic Stadium area and the TouchSee (n.d.) application to create signage for the Acropolis. They also created objects for use in mathematics and printed objects recovered from repositories related to ancient Greek culture.

The students' motivation and interest in 3D techniques were remarkable. In fact, some of them asked their parents to buy a 3D printer, others bought a 3D pen, and one of the students went every Friday to her mother's office to 3D design and print. They also started using Blender on their own to create 3D pictures for their games (such as Minecraft). The students were too young to decide on how to use 3D technology for their academic future. However, many of them told their relatives how important 3D design and printing would be for studies in architecture, game design, and robotics. They think that learning 3D printing and design would be useful for their future careers, but it was in their own unique, child-like way: the girls talked about designing and printing jewelry and the boys talked about designing 3D objects from their games and 3D digital game worlds.

It is a fact that new technologies generate excitement and engagement in the classroom. With 3D designing and printing, the students were actively involved in experimental science, technology, engineering, art, and mathematics (STEAM) activities and had the opportunity to actually test and understand the differences between the digital and real world. They learned to manage their disappointment when their designs failed in printing, increase perseverance through patience while waiting for printing to complete, learn from failures, and collaborate and help each other. By creating maps for the visually impaired, the students also learned to solve real-world problems, apply critical thinking, negotiate their ideas, take initiative, and learn from each other. The interdisciplinary activities involved in this project (e.g., information and communications technology, computer science, mathematics, geometry, art, architecture, social studies) gave each student the possibility to develop and discover some new skills they were not aware they had and made them more confident in themselves.

The students learned how technology and engineering can be used to raise awareness for people with disabilities and gained an understanding of the need to include everyone in our everyday life. The empathy they developed for visually impaired children was reflected also in their behavior in the classroom as they showed more understanding for each other. Regarding the teachers, they were asked what they had learned from the project. The following is one of the most significant reflections:

> This project was very demanding regarding personal knowledge (understanding visually impaired needs, 3D design software, managing 3D printers, designing maps, research…), as well as regarding the design of the lessons and scenarios. It was also quite challenging to manage different groups of students who were working on different aspects of the project at the same time. The project helped me to develop new skills (professionally), discover the world of visually impaired people, realize how our educational system and schools are not equipped to include them efficiently, how technology and 3D printing could be an answer to many real-world challenges, how our young students were able to understand and use new technologies and be prepared to create a better world.

IES Benlliure (Spain)

Benlliure is a secondary public school located in the Valencia, Spain, metropolitan area. Fifteen Benlliure students of ages 15 through 16 participated in the project. As in the previous case, specific competencies of the subject were worked on in parallel with awareness-raising activities. The great advantage of this group is that there was a student with a visual impairment fully integrated into the project. The project was carried out in the "technology" subject which has a curriculum that integrates content from basic engineering and computer science.

The ONCE has a specialist teacher who periodically supports the two students with disabilities at the center and who was in charge of stimulating the different awareness-raising activities performed. Some of them were highly valued by students such as learning the basic concepts of Braille, knowing its characteristics as a language, visiting emblematic city buildings which have tactile metal models, and playing goalball with blindfolds. In addition, some visually impaired neighbors went to the center to talk about the accessibility problems they face in their daily lives. The mentioned activities allowed the students to achieve the objectives related to citizenship education and gave them a concrete start to the project including better knowledge of the facts and more judgment to make meaningful proposals.

Students quickly discovered the need to make spaces more accessible, thus complying with the first curricular premise "identifying real-life technological problems." Possible solutions, taking into account the possibilities offered by design and 3D printing, were proposed: make models of the center to know the building, make plans of the classroom and the main facilities of the center, develop 3D posters to improve the signage of the center, and, finally, in coordination with the other secondary schools participating, a proposal was suggested to make tactile plans of the subway lines.

The students, working in small groups, began to design a variety of simple objects to become familiar with the design program Freecad. They learned to use the slicing program, feed filament, calibrate the machine, and, in short, operate and troubleshoot a 3D printer. Once the students had mastered the basic techniques, they began to design useful objects to improve accessibility. According to the design level of each student, they were distributed into balanced working groups with different responsibilities and tasks: model the school building in three dimensions, create the ground floor and cross-section of the building, design logos and signs to label the entire center, and build plans of the city metro lines (see Appendix, Figure 5).

Numerous curricular aims were achieved including information searching and processing, collaborative work, graphic expression techniques, and properties of the materials. With ongoing feedback from disabled peers, they realized that 3D models need to be simple. The visually impaired do not have the same overview as sighted people, so they have to read one part at a time and then put them together in their minds to realize what they are touching. Too many small details do not really help them understand. They also learned that partially blind people need high-contrast color combinations for more accessible information. They also managed to improve their skills in (a) problem-solving, by analyzing all the factors involved, using critical thinking, and proposing solutions; (b) communication, by interacting with others; (c) collaboration, by working successfully towards a common goal with others; and (d) creativity, by managing to think "out of the box." Through the design process, they faced several challenges and came up with real solutions. They learned how to transfer a 2D image into a 3D design (Millan, 2018) by working with different software. They also realized that it was necessary to split a big design into smaller pieces in order to get it properly printed. It was necessary to know and apply the Spanish Braille Commission recommendations for the preparation of plans and labels on pieces for people with visual disabilities (ONCE, 2012, 2014) for the Braille language to be readable. They also found out that "vertical Braille" is the best method of printing Braille with a 3D printer.

Ultimately, 3D printing offers students the ability to experience their projects from the initial stage to the actual creation of the model according to a typical Model Eliciting Activities (MEA). This created excitement, engagement, and a better understanding of the design process as they gained hands-on experience from conception to creation, experimenting with ideas, as well as expanding and growing their creativity. The project promoted self-learning as the problem-solving process helps students to take initiative and responsibility for their own learning. The process required students to make reasoned decisions and defend them, motivating them to understand concepts on a deeper level. Students earned self-respect and satisfaction by creating innovative solutions and improving teamwork abilities at the same time. The knowledge and the skills that students developed can be applied to other school subjects as well as in everyday life to solve real-world problems.

3D printing gives students perspective to learn that it is perfectly acceptable to fail on the first try and then try again in order to improve, while understanding that failure is part of the process. The students became less afraid to attempt and execute new and different ideas in life which built their confidence. Teachers enjoyed having self-motivated, self-confident students. As students explore and grow their imagination, it cultivates innovation where the students create their own unique 3D projects that can solve problems. By learning how to troubleshoot and solve 3D printer problems, students learn to practice persistence and endurance in overcoming difficulties. Feeding students' creativity skills can help develop a passion for original thinking and creativity that can later be applied in business as well. The enormous quantity of useful pieces printed is the best proof of the achievement of all this learning. The teachers were also asked about their personal experiences. The most relevant answer was:

> The project has given me the opportunity to improve professionally in several aspects: on the one hand, I have learned that a well-applied service-learning methodology is highly motivating for both students and teachers and allows the development of many curricular aspects. I have also discovered the accessibility problems of a society that does not always take into account the needs of people with functional diversity. In addition, I have improved my skills in CAD design and have learned the operation and possibilities of 3D printing.

IES Conselleria (Spain)

Conselleria is a secondary and VET public school located in the Valencia, Spain, metropolitan area. Twelve students of ages 15 through 17 participated in the project. The program was developed into an initial (basic) VET course in computer engineering. In Spain, the students who usually choose initial VET studies have a profile very prone to early school leaving. This type of student often shows low self-esteem caused by poor grades obtained in their academic life. Consequently, these groups are characterized by a strong lack of motivation for learning. The initial VET curriculum is structured in different modules. The project was developed through two modules, one more focused on the design part and the other on the printing part whose curricular competencies are shown in Table 2. The procedure was similar to previous cases beginning with awareness-raising activities and activities to acquire knowledge about using Freecad design and 3D printing. In this center, the focus was on the development of the metro lines of the city of Valencia. A *Witbox2* printer and a *Hephestos* (BQ) were used in this center. The *Hephestos* (BQ) was supplied disassembled, and the assembly became its own learning activity. This group devoted the most classroom time to the project. The previous educational centers oscillated between two and four hours per week dedicated to the project while this group averaged 10–15 hours per week. The awareness-raising activities were very similar to previous ones. They had some students with disabilities in the center (not in the class group) and, therefore, also the support of specialists from ONCE.

The main outcome was self-esteem improvement. Students who are often unmotivated and at high risk of dropping out of school found the project a stimulus for learning. Feeling useful to the disabled community, understanding their point of view, and empathizing with them provided students with a considerable improvement in their self-esteem. The positive results in the manufacturing of the pieces made them gain self-confidence, finding meaning and usefulness in school learning. The students improved considerably by solving the challenges they faced. Perseverance throughout the development process was highlighted while working in small, coordinated groups. The students went from listening in disbelief to the project description and aims because of its significance and the unknown technology to autonomously generating the design of subway lines according to specific requirements for the Braille labels and printed objects (Millan, 2019).

They were in contact with visually impaired people throughout the project in addition to the students with disabilities from the school. Several blind people collaborated in the implementation of the project and provided direct feedback to the students in the classroom (see Appendix, Figure 6). It was an important learning experience in which students received feedback from the real recipients of their achievements—quite different from the traditional practice based on an assumption. Perhaps the key element was gaining first-hand knowledge of the challenges the recipients of the service faced. The students then worked to solve a real problem that affects colleagues from their school, not simply to pass a test or an evaluation. 3D technology, which due to its novelty may seem to be the main motivating element, especially among students in the technological branch of vocational training, acted just as a necessary tool.

The participating students had never had a close relationship with visually impaired people. During the visits, they were very interested and asked many questions about the way they read (necessary for the purposes of the project) but also about aspects of daily life and the different technological tools that they use (e.g., how they use a mobile phone, how they orient themselves on the street, in the institute, in the classroom). Thus, a bond of empathy was established. In fact, when asked at the end of the project what interested them most about it many of the students mentioned the experience of meeting a visually impaired person and discovering how they do everyday things and the devices they use.

As for 3D printing, the students showed their interest by designing and printing objects outside of the project. They made small designs for themselves such as key rings, symbols, and coins, and they even asked permission to print outside of school hours. From time to time, they brought pictures of some 3D printers that they had seen in a store, and their characteristics were discussed in class.

When asked at the end of the project, everyone agreed that knowing how to design and print objects in 3D would be useful for their academic and professional future, and the formal evaluations were very positive. Additionally, several participating students carried out their training period in work centers in companies or institutions where they usually work with 3D printers, showing a perfect and quick adaptation immediately after finishing the project. All the students received a positive rating from their instructors at the companies. This is also a clear indicator of the professional skills acquired during the project which were later reinforced during the internship period.

The greatest benefit of the project was to provide a motivating action context (the service) in which the pedagogical intervention achieved the planned objectives and professional skills (i.e., 3D printing, learning to learn, teamwork), social skills (i.e., problem-solving), and integration of vulnerable groups. They maintained that interest and predisposition throughout the project even when things did not progress because of typical failures in printers.

As already mentioned, the initial VET students come from a situation of school failure and, in general, they are highly unmotivated, easily distracted, and have few learning habits. However, during the project, the students showed great motivation which was rewarded when they received approval from the visually impaired once all the metro lines were completed. This positive reinforcement obtained after completing a project which they had worked on for several months has great value in the academic and social development of the students. They assembled 3D printers, designed and printed simple 3D objects, and various combinations of them carried out configuration and maintenance actions with 3D printers. When asked about the lessons learned from the project, the teachers responsible for the activity replied similarly. One of them said:

> As a teacher, I practically share the experience of the students. In my case, I was the first to participate in 3D design and printing courses, learning to use this technology. Later I participated in raising awareness activities and from there, exchanging experiences with other teachers participating in the project, with people with visual disabilities or who work with people with visual disabilities and with the advice of the teacher training center. I designed the project execution activity in the classroom for the group, following the service learning approach, according to the previous training I had received. It was a very motivating experience.

At the end of the project, the objects were donated to specific educational organizations for people with visual disabilities as well as to transport companies in Athens and Valencia. As a result of the learning experience for both students and teachers, numerous designs were uploaded to public repositories. Additionally, different blog posts with tips and

Table 3
Students' perception questionnaire results.

	All students, $n = 74$ (Likert 0–5: 0 = totally disagree; 5 = totally agree)					
	Question	**1**	**2**	**3**	**4**	**5**
1	After participating in the project, I feel more sensitized towards the visually impaired community	2 (2.7%)	0 (0.0%)	10 (13.5%)	22 (29.7%)	40 (54.1%)
2	I am more interested in 3D printing technology after my participation in the project	4 (5.4%)	2 (2.7%)	5 (6.8%)	26 (35.1%)	37 (50.0%)
3	Learning 3D design and printing can be useful for my academic future	4 (5.4%)	2 (2.7%)	7 (9.5%)	28 (37.8%)	33 (44.6%)
	Only secondary students, $n = 43$ (Likert 0–5: 0 = totally disagree; 5 = totally agree)					
4	Learning 3D design and printing can be useful for my future career/ job	3 (7.0%)	3 (7.0%)	5 (11.6%)	12 (27.9%)	20 (46.5%)

Table 4
Student answers in semi-structured interviews.

Initial question	Student answer
How do you feel about participating in the project?	Student A: Well, I have felt useful, teacher. I am very happy to think that what we have done in class will be used by blind people. Student B: It's been really cool doing nice things for people who need it. This is the first time I have done at school something that seems useful. Student C: Very happy because the pieces have turned out very well. The blind people will surely take advantage of them. Student D: It has been a lot of fun. We have had a great time and on top of that we have done something productive while learning. Awesome teacher!
Do you think the things you have learned in the project will be useful for your future?	Student 1: Sure! Next year we will continue doing things like that, right? I want to learn more to do things for my home. Student 2: Of course. This is really cool to learn. I already have plans to design some figures to print in class or in the fab-lab and show them to my friends. Student 3: Yes, of course. You can do a thousand things and I am sure that in any job the boss will appreciate that I know how to make 3D pieces. I want to learn how to make more complicated pieces.

suggestions were published. All project results can be consulted on a website (Erasmusprint3d, n.d.) and the Erasmus+ Project Results Platform (Erasmus+, n.d.). Likewise, the two training courses were accepted in the repository of the Scientix platform (Scientix, n.d.).

When finishing the project, a simple questionnaire based on a Likert scale was used to evaluate the students' perception of the project. The students from the five participating centers responded to this questionnaire ($n = 74$). An additional question was proposed to students from the three participating secondary schools ($n = 43$). Results are shown in Table 3. As can be seen, the student perception was very positive in terms of raising awareness and increasing interest in 3D technology (direct and for their future).

Although the motivation of the students, in general, was presupposed because it was a European project with a service-learning methodology and a novel technology, this fact was especially important and revealing in the initial VET group. The motivation of these students was exceptional. Semi-structured interviews were carried out with this group. Many of them confessed that for the first time in their academic lives they felt that they were doing something useful in school. Some even noted that this project was the first time they were doing something useful in their lives. Table 4 contains some of the most representative answers. This fact was used by the teachers of this group to involve the students not only in the project but also in general in the continuation of their academic training. So much so that even the proposal from this group received a national service-learning award (Aprendizajeservicio, 2019).

Conclusions and Recommendations

The project described is an example of an educational innovation designed on the argument that the use of emerging technologies such as 3D printing has many characteristics that are ideal for learning. The students who participated in this study improved their knowledge in aspects such as detection of real-world technological problems, information search and processing skills, communication and teamwork, problem-solving skills, creative thinking, advantages of learning "by doing," seeing how their ideas can be materialized in tangible models, as well as intrinsic concepts related to this technology such as CAD, handling and maintenance of machinery, and properties of materials. 3D printing is a technology that, due to its characteristics, is opening a universe of possibilities to improve accessibility for people with visual disabilities. This fact allows the principles of the service-learning methodology to be ideally coupled.

In this example, we can observe how contents related to civic education were worked on, raising awareness and empathy towards people with disabilities. Besides, the students' motivation was remarkable, especially in cases of students at risk of leaving school early. The correct application of the service-learning methodology was essential to achieve educational success: adequate training of teachers, involving people with disabilities in the project, dedicating enough time to reflection and proper execution, and avoiding stereotypical visions or purely charitable performances.

All these conclusions are based on the survey of students' perceptions, on interviews with some of the participating students, and, mainly, on teachers' statements based on classroom observation and evaluation. Deliverables shared through different platforms, websites, and numerous tangible objects placed in participating educational centers or donated to visually impaired organizations are also indicators of success.

The presented project can serve as an inspiring example for starting similar projects in formal or nonformal educational environments. In fact, some of the partners of this project have continued their work on this subject with a new project approved in a new Erasmus+ call: *Adapting Museums to Educational Inclusive Goals, 2019-1-ES01-KA201-063923*. In this new project, students from educational centers learn more concepts associated with 3D printing technology such as scanning and photogrammetry to make tactile pieces for museums. Thus, museums can incorporate such replicas into their collection resulting in more accessible spaces for the visually impaired community. Despite the scarce published studies on this topic, the benefits of conducting a service-learning project focused on the visually impaired and 3D printing are enormous.

Acknowledgments

This work was supported by European Commission agreement 2017-1-ES01-KA201-038019 (Erasmus+ program). Disclaimer: "The European Commission support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein."

Author Bio

Oscar R. Lozano holds a PhD in science teaching. He was a high school technology teacher for twenty years and currently works as a professor in the Department of Science Teaching at the University of Valencia, and as a STEM teacher training consultant in Valencian Regional Ministry of Education. His research focuses on STEM teacher training. Email:oscar.lozano@uv.es

References

Abernathy, T. V., & Obenchain, K. M. (2001). Student ownership of service-learning projects: Including ourselves in our community. *Intervention in School and Clinic*, *37*(2), 86–95. https://doi.org/10.1177%2F105345120103700203

Aprendizajeservicio. (2019). *Acta del veredicto del jurado de los premios Aprendizaje-Servicio 2019*. https://aprendizajeservicio.com/wp-content/uploads/2019/11/ACTA-VEREDICTO-JURADO-PREMIOS-APS-201905112019.pdf

Avanzini, F., Baratè, A., & Ludovico, L. A. (2019). 3D printing in preschool music education: Opportunities and challenges. *Qwerty-Open and Interdisciplinary Journal of Technology, Culture and Education*, *14*(1), 71–92. http://dx.doi.org/10.30557/QW000012

Bartellas, M. P. (2016). Three-dimensional printing and medical education: A narrative review of the literature. *University of Ottawa Journal of Medicine*, *6*(1), 38–43. https://doi.org/10.18192/uojm.v6i1.1515

Bevan, B. (2017). The promise and the promises of Making in science education. *Studies in Science Education*, *53*(1), 75–103. https://doi.org/10.1080/03057267.2016.1275380

Billig, S. H. (2002). Support for K-12 service-learning practice: A brief review of the research. *Educational Horizons*, *80*(4), 184–189. http://www.jstor.org/stable/42927126

Billig, S. H. (2011). Making the most of your time: Implementing the K-12 service-learning standards for quality practice. *The Prevention Researcher*, *18*(1), 8–14.

Bøhn, J. H. (1997). Integrating rapid prototyping into the engineering curriculum: A case study. *Rapid Prototyping Journal 3*, 32–37. https://doi.org/10.1108/13552549710169264.

Bosse, I. K., & Pelka, B. (2020). Peer production by persons with disabilities: Opening 3D-printing aids to everybody in an inclusive MakerSpace. *Journal of Enabling Technologies*, *14*(1), 41–53. https://doi.org/10.1108/JET-07-2019-0037

Buehler, E., Comrie, N., Hofmann, M., McDonald, S., & Hurst, A. (2016). Investigating the implications of 3D printing in special education. *ACM Transactions on Accessible Computing (TACCESS)*, *8*(3), 1–28. http://dx.doi.org/10.1145/2870640

Buehler, E., Easley, W., McDonald, S., Comrie, N., & Hurst, A. (2015). Inclusion and education: 3D printing for integrated classrooms. In S. Kurniawan (Ed.), *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility* (pp. 281–290). Association for Computing Machinery. https://doi.org/10.1145/2700648.2809844

Buehler, E., Hurst, A., & Hofmann, M. (2014a). Coming to grips: 3D printing for accessibility. In *Proceedings of the 16th international ACM SIGACCESS Conference on Computers & Accessibility* (pp. 291–292). Association for Computing Machinery. https://doi.org/10.1145/2661334.2661345

Buehler, E., Kane, S. K., & Hurst, A. (2014b). ABC and 3D: Opportunities and obstacles to 3D printing in special education environments. In *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility* (pp. 107–114). Association for Computing Machinery. https://doi.org/10.1145/2661334.2661365

Case, L., Schram, B., Jung, J., Leung, W., & Yun, J. (2020). A meta-analysis of the effect of adapted physical activity service-learning programs on college student attitudes toward people with disabilities. *Disability and Rehabilitation*, 1–13. https://doi.org/10.1080/09638288.2020.1727575

Celani, G. (2012). Digital fabrication laboratories: Pedagogy and impacts on architectural education, *Nexus Network Journal*, *14*, 469–482. https://doi.org/10.1007/s00004-012-0120-x

Celio, C. I., Durlak, J., & Dymnicki, A. (2011). A meta-analysis of the impact of service-learning on students. *Journal of Experiential Education*, *34*(2), 164–181. https://doi.org/10.1177/105382591103400205

Chien, Y. H. (2017). Developing a pre-engineering curriculum for 3D printing skills for high school technology education. *Eurasia Journal of Mathematics, Science and Technology Education*, *13*(7), 2941–2958. https://doi.org/10.12973/eurasia.2017.00729a

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*(2), 175–218. https://doi.org/10.1002/sce.10001

Cook, K. L., Bush, S. B., & Cox, R. (2015). Creating a prosthetic hand: 3D printers innovate and inspire a maker movement. *Science and Children*, *53*(4), 80.

Corsini, L., Dammicco, V., Bowker-Lonnecker, L., & Blythe, R. (2020). *The maker movement and its impact in the fight against COVID-19*. University of Cambridge CTM Working Paper Series. https://doi.org/10.17863/CAM.60248

Dougherty, D. (2012). The maker movement. *Innovations: Technology, Governance, Globalization*, *7*(3), 11–14. https://doi.org/10.1162/INOV_a_00135

Dymond, S. K., Renzaglia, A., & Slagor, M. T. (2011). Trends in the use of service learning with students with disabilities. *Remedial and Special Education*, *32*(3), 219–229.

Erasmus+. (n.d.). *Erasmus+ project results*. https://ec.europa.eu/programmes/erasmus-plus/projects/eplus-project-details/#project/2017-1-ES01-KA201-038019

Erasmusprint3d. (n.d.). *PRINT3D*. http://www.erasmusprint3d.eu/

European Commission. (2014). *Additive manufacturing in FP7 and Horizon 2020*. European Commission, Brussels.

European Commission. (2017, January 26). From Erasmus to Erasmus+: *A story of 30 years*. https://ec.europa.eu/commission/presscorner/detail/en/MEMO_17_83

Fila, N. D., & Hess, J. L. (2015). Exploring the role of empathy in a service-learning design project. *Analyzing Design Review Conversations*, 135–154.

Ford, S., & Minshall, T. (2019). Invited review article: Where and how 3D printing is used in teaching and education. *Additive Manufacturing*, *25*, 131–150. http://dx.doi.org/10.1016/j.addma.2018.10.028

García, J., Yang, Z., Mongrain, R., Leask, R. L., & Lachapelle, K. (2018). 3D printing materials and their use in medical education: A review of current technology and trends for the future. *BMJ Simulation and Technology Enhanced Learning*, *4*(1), 27–40. https://doi.org/10.1136/bmjstel-2017-000234

Gent, P. J., & Gurecka, L. E. (2001). Service-learning: A disservice to people with disabilities? *Michigan Journal of Community Service Learning*, *8*(1). http://hdl.handle.net/2027/spo.3239521.0008.104

Grujović, N., Radović, M., Kanjevac, V., Borota, J., Grujović, G., & Divac, D. (2011). 3D printing technology in education environment. In *34th International Conference on Production Engineering* (pp. 29–30). Serbia University of Niš.

Gual, J., Puyuelo, M., Lloverás, J., & Merino, L. (2012). Visual impairment and urban orientation. Pilot study with tactile maps produced through 3D printing. *Psychology*, *3*(2), 239–250. https://doi.org/10.1174/217119712800337747

Halverson, E. R., & Sheridan, K. M. (2014). The maker movement in education. *Harvard Educational Review*, *84*(4), 495–504. https://doi.org/10.17763/haer.84.4.34j1g68140382063

Hirsh, K. (2020). *The maker movement and learning in school libraries*. LIS Scholarship Archive. https://doi.org/10.31229/osf.io/ungxk

Horowitz, S. S., & Schultz, P. H. (2014). Printing space: Using 3D printing of digital terrain models in geosciences education and research. *Journal of Geoscience Education*, *62*(1), 138–145. https://doi.org/10.5408/13-031.1.

Huang, S. H., Liu, P., Mokasdar, A., & Hou, L. (2013). Additive manufacturing and its societal impact: A literature review. *The International Journal of Advanced Manufacturing Technology*, *67*(5), 1191–1203. https://doi.org/10.1007/s00170-012-4558-5.

Jones, O. A., & Spencer, M. J. (2018). A simplified method for the 3D printing of molecular models for chemical education. *Journal of Chemical Education*, *95*(1), 88–96. https://doi.org/10.1021/acs.jchemed.7b00533.

Kane, S. K., & Bigham, J. P. (2014). Tracking @stemxcomet: Teaching programming to blind students via 3D printing, crisis management, and Twitter. In *Proceedings of the 45th ACM Technical Symposium on Computer Science Education (SIGCSE '14)*, Atlanta, GA, USA. https://doi.org/10.1145/2538862.2538975

Knochel, A. D., Hsiao, W. H., & Pittenger, A. (2018). Touching to see: Tactile learning, assistive technologies, and 3-D printing. *Art Education*, *71*(3), 7–13. https://doi.org/10.1080/00043125.2018.1436320

Kye, H. (2020). Who is welcome here? A culturally responsive content analysis of makerspace websites. *Journal of Pre-College Engineering Education Research (J-PEER)*, *10*(2), Article 1. https://doi.org/10.7771/2157-9288.1190

Make. (n.d.). *Community—Home*. Make. Retrieved October 5, 2022, from https://make.co

Martin, L. (2015). The promise of the maker movement for education. *Journal of Pre-College Engineering Education Research (J-PEER)*, *5*(1), Article 4. https://doi.org/10.7771/2157-9288.1099

Martin, L., & Dixon, C. (2013). Youth conceptions of making and the maker movement. In *Proceedings from Interaction Design and Children Conference*. New York, NY: ACM.

Martin, L., & Wendell, K. B. (2021). Reflections on asset-based pre-college engineering education to promote equity: An introduction to the special issue. *Journal of Pre-College Engineering Education Research (J-PEER)*, *11*(1), Article 3. https://doi.org/10.7771/2157-9288.1325

Matthews, P. H., Dorfman, J. H., & Wu, X. (2015). The impacts of undergraduate service-learning on post-graduation employment outcomes. *The International Journal of Research on Service-Learning and Community Engagement*, *3*(1).

Maynard, A. D. (2015). Navigating the fourth industrial revolution. *Nature Nanotechnology*, *10*(12), 1005–1006. https://doi.org/10.1038/nnano.2015.286

McLoughlin, C., & Lee, M. J. (2010). Personalised and self regulated learning in the Web 2.0 era: International exemplars of innovative pedagogy using social software. *Australasian Journal of Educational Technology*, *26*(1), 28–43. https://doi.org/10.14742/ajet.1100

Millan, C. (2018, September 21). *Como convertir un plano a 3D en 3 pasos*. CEMEBlog. https://blog.cemebe.info/como-convertir-un-plano-a-3d-en-3-pasos/

Millan, C. (2019, June 9). ApS: *Diseñando planos de metro táctiles en la FP Básica*. CEMEBlog. https://blog.cemebe.info/aps-disenando-planos-de-metro-tactiles-en-la-fp-basica/

Montessori, M. (1912). *The Montessori method*. Frederick Stokes Co.

Moura, B. N. D. (2021). *MAUC Tátil: Um ponto de vista do design dentro da cartografia na produção de um mapa tátil para o Museu de Arte da Universidade Federal do Ceará por meio da prototipagem rápida em impressão 3D*. http://repositorio.ufc.br/handle/riufc/59085

MyMinifactory. (n.d). *MyMinifactori*. Retrieved October 5, 2022, from https://www.myminifactory.com/es/

National Center for Education Statistics. (1999). *Service-learning and community service in K-12 public schools*. https://nces.ed.gov/surveys/frss/publications/1999043/index.asp

National Youth Leadership Council. (2008). *K-12 service-learning standards for quality practice*. https://www.nylc.org/page/standards

ONCE. (2012). *Requisitos técnicos para la confección de planos accesibles a personas con discapacidad visual*. https://www.once.es/servicios-sociales/braille/documentos-tecnicos/documentos-tecnicos-relacionados-con-materiales-en-relieve/documentos/r1-planos-accesibles-1.pdf/download

ONCE. (2014). *Recomendaciones sobre la elaboración de planos de evacuación para personas con discapacidad visual*. https://www.once.es/servicios-sociales/braille/documentos-tecnicos/documentos-tecnicos-relacionados-con-materiales-en-relieve/documentos/r4-planos-de-emergencia-v1-2.pdf/download

Scientix.eu. (n.d.) *Home*. Scientix. http://www.scientix.eu/

Selcen Guzey, S., Harwell, M., Moreno, M., Peralta, Y., & Moore, T. J. (2017). The impact of design-based STEM integration curricula on student achievement in engineering, science, and mathematics. *Journal of Science Education and Technology*, *26*(2), 207–222. https://doi.org/10.1007/s10956-016-9673-x

Simpson, T. W., Williams, C. B., & Hripko, M. (2017). Preparing industry for additive manufacturing and its applications: Summary & recommendations from a National Science Foundation workshop. *Additive Manufacturing*, *13*, 166–178. https://doi.org/10.1016/j.addma.2016.08.002

Snyder, T. J., Andrews, M., Weislogel, M., Moeck, P., Stone-Sundberg, J., Birkes, D., Hoffert, M. P., Lindeman, A., Morrill, J., Fercak, O., Friedman, S., Gunderson, J., Ha, A., McCollister, J., Chen, Y., Geile, J., Wollman, A., Attari, B., Botnen, N., & Graft, J. (2014). 3D systems' technology overview and new applications in manufacturing, engineering, science, and education. *3D Printing and Additive Manufacturing*, *1*(3), 169–176. http://dx.doi.org/10.1089/3dp.2014.1502

Song, M. J. (2018). Learning to teach 3D printing in schools: How do teachers in Korea prepare to integrate 3D printing technology into classrooms? *Educational Media International*, *55*(3), 183–198. https://doi.org/10.1080/09523987.2018.1512448

Sotelino-Losada, A., Arbués-Radigales, E., García-Docampo, L., & González-Geraldo, J. L. (2021). Service-learning in Europe. Dimensions and understanding from academic publication. *Frontiers in Education*, *6*, Article 604825. https://doi.org/10.3389/feduc.2021.604825

Stamper, R. E., & Dekker, D. L. (2000). Utilizing rapid prototyping to enhance undergraduate engineering education. In *30th Annual Frontiers in Education Conference. Building on A Century of Progress in Engineering Education. Conference Proceedings (IEEE Cat. No. 00CH37135)* (pp. F3C/1–F3C/4). Kansas City, MO, USA.

Stangl, A., Hsu, C. L., & Yeh, T. (2015). Transcribing across the senses: Community efforts to create 3D printable accessible tactile pictures for young children with visual impairments. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility* (pp. 127–137). Association for Computing Machinery. https://doi.org/10.1145/2700648.2809854

Stangl, A., Kim, J., & Yeh, T. (2014). 3D printed tactile picture books for children with visual impairments: A design probe. In *Proceedings of the 2014 Conference on Interaction Design and Children* (pp. 321–324). Association for Computing Machinery. https://doi.org/10.1145/2593968.2610482

Stone, B., Kay, D., Reynolds, A., & Brown, D. (2020). 3D printing and service learning: Accessible open educational resources for students with visual impairment. *International Journal of Teaching and Learning in Higher Education*, *32*(2), 336–346.

Strobel, J., Wang, J., Weber, N. R., & Dyehouse, M. (2013). The role of authenticity in design-based learning environments: The case of engineering education. *Computers & Education*, *64*, 143–152. https://doi.org/10.1016/j.compedu.2012.11.026

Suchow, R. (2016). 3D printing & service learning: Social manufacturing as a vehicle for developing social awareness. *Journal of Catholic Education*, *20*(1), n1.

Tactual Museum. (n.d.). Μουσεο Αφς. Retrieved October 5, 2022, from http://www.tactualmuseum.gr/

Thingiverse. (n.d). *MakerBot Thingiverse*. Retrieved October 5, 2022, from https://www.thingiverse.com/

Touch-mapper. (n.d.). *Touch-mapper*. Retrieved October 5, 2022, from https://touch-mapper.org/en/

TouchSee. (n.d). *TouchSee*. Retrieved October 5, 2022, from https://touchsee.me/

Walther, J., Miller, S. E., & Sochacka, N. W. (2017). A model of empathy in engineering as a core skill, practice orientation, and professional way of being. *Journal of Engineering Education*, *106*(1), 123–148. https://doi.org/10.1002/jee.20159

Warren, J. L. (2012). Does service-learning increase student learning? A meta-analysis. *Michigan Journal of Community Service Learning*, *18*(2), 56–61.

Wolf-Powers, L., Doussard, M., Schrock, G., Heying, C., Eisenburger, M., & Marotta, S. (2017). The maker movement and urban economic development. *Journal of the American Planning Association*, *83*(4), 365–376. https://doi.org/10.1080/01944363.2017.1360787

Wonjin, J., Jang, H. I., Harianto, R. A., So, J. H., Lee, H., Lee, H. J., & Moon, M. W. (2016). Introduction of 3D printing technology in the classroom for visually impaired students. *Journal of Visual Impairment & Blindness*, *110*(2), 115–121.

Appendix

Figure 2. Art pieces, signals, mocks up, etc., made at classroom.

Figure 3. Students working at classroom (designing and printing).

Figure 4. Raising awareness activities.

Figure 5. Students designing and printed plans of metro lines from Valencia and Athens.

Figure 6. Blind collaborators assessing the pieces quality.