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Open Education through Interactive Training Material

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Received: 5 August 2020; Accepted: 11 September 2020; Published: 16 September 2020

Abstract: This work has come about as a result of an attempt to improve educational practices by taking advantage of research experience in the field of additive manufacturing technologies. As a result of the work carried out, an open educational resources project was developed by the group of educational innovation Ingeniería de Fabricación of the University of Las Palmas de Gran Canaria. It consists of interactive teaching material adapted to the new international standards that regulate these technologies and includes a methodology for selecting the most appropriate technology for the specific application. In this paper, we describe the co-creation process that was carried out with students in order to develop the resources, as well as a description of the didactic material itself together with its interactive elements. An analysis of its use in various academic courses is included and also an evaluation of its impact, both in teaching a specific subject and in other training activities. Our findings indicate that the process has led to the production of didactic materials that present content in an attractive way and which, in combination with active methodologies, noticeably improves students' learning experiences, and is also considered a successful experience in open educational practices.

Keywords: open educational practices; open educational resources; additive manufacturing; interactive training material; flipped classroom

1. Introduction

Open education aims to allow access to educational, scientific, and cultural information without economic, technical, or legal restrictions [1]. It aims to substantially modify the way in which authors, teachers, and students interact with knowledge; sharing, revising, improving, adapting, and using it. Its foundation and inspiration are rooted in the free software movement, which is based on the principles of freedom of use, distribution, study, and modification. Open education contributes to UNESCO's Sustainable Development Goals (SDGs), especially in SDG 4 Quality Education, which has, as one of its goals, obtaining satisfactory learning results in an equitable and effective way at all levels and in all environments, including life-long education and training [2,3].

The open education movement suggests that higher education institutions should rethink their concept of how to redefine the construction, re-working, and dissemination of knowledge and consequently also that they rethink their pedagogical approach and learning activities. Therefore, movements that favour educational innovation are based on a deep reformulation of the principles upon which education is based. The transformational opportunities they offer are already part of the discourse on educational change and innovation in many highly-regarded international higher education institutions. These institutions are beginning to consider how these principles can revitalise their academic offerings by developing new models of student participation and using both interdisciplinary and globalising approaches to knowledge [4]. In open education, the concept of openness to freedom of use, dissemination, learning and collaboration in the generation of any type of didactic material is extended, and, in this context, referred to as open educational resources (OER). These are very varied digitised materials that are freely and openly offered to teachers, students, self-educated people and researchers to use and reuse in teaching, learning, and research. Open educational practices (OEP) is a broad term that describes practices including the creation, use, and reuse of OER as well as open pedagogies and open sharing of teaching practices [5]. The generation of this knowledge through methodologies that promote participation, collaboration, and openness to different agents such as students, teachers, researchers, companies and institutions, constitute very valuable experiences for the open education movement [6].

The purpose of this work is to showcase an experience of open education carried out by the Group of Educational Innovation Ingeniería de Fabricación (Manufacturing Engineering, GIEIF) at the University of Las Palmas de Gran Canaria (ULPGC). This work has emerged as a result of experience gained in new Additive Manufacturing (AM) technologies through participation in several studies and knowledge transfer projects undertaken by the Research group into Fabricación Integrada y Avanzada (Integrated and Advanced Manufacturing) at ULPGC, to which many members of the GIEIF belong. The research questions we wanted to answer were:

1. How can lecturers take advantage of research experience in this field to improve the teaching of this content?
2. Can students achieve deeper learning of engaging content by using didactic material that they can use more autonomously?
3. Can lecturers rely on educational material to deliver engaging content whilst using fewer teaching sessions and more participatory sessions?

This experience led to an OER Project, the main objective of which was to achieve the maximum possible dissemination of the teaching material based on AM technologies. This research work, therefore, presents a successful OEP that includes a description of both the collaborative process of interactive teaching material (ITM) development and the teaching phase during which this material was used in different teaching activities aimed at a range of educational levels and also to support continuous training.

1.1. Open Educational Resources and Practices

Open educational practices is a relatively recent concept that has varied from an approach focused on the creation and use of OER to a broader vision that considers the teaching and learning process as a whole without a requirement to use OER [7]. The primary goal of OEP is to make this process simpler, more flexible and collaborative, and to even up the active roles of teachers and students. In the final report of the EU OCLOS project, OEP were defined as " ... practices that involve students in active, constructive engagement with content, tools and services in the learning process, and that promote learners' self-management, creativity and working in teams" [8]. It is also indicated in this project that OERs can play a very important role in teaching and learning processes, but that it is vital that they be accompanied by changes and innovation in educational practices. The Open Education Quality (OPAL) initiative conceptualised OEP as a transition using OER to transform learning: "OEP, essentially, represent collaborative practice in which resources are shared by making them openly available, and pedagogical practices are employed which rely on social interaction, knowledge creation, peer-learning, and shared learning practices" [9]. The UKOER programme from the Higher Education Funding Council for England showed that OER and OEP are not necessarily coincident. OEP often emerges through OER activities, but the creation/use of OER may not always be the first sign of openness in educational practice. It also indicates that OEP seeks to balance the hierarchical relationships between teachers and students, as well as suggesting that different academic disciplines tend to adopt the aspects of OEP that best suit their existing academic practices. [10].

The centre for innovation in learning and teaching at the University of Cape Town highlights the importance of OER studies including OEP with the widest possible vision. The inclusion of the term "practices" is a recognition of the close relationship between the content of an OER and the context of its development and initiatives such as Research in Open Educational Resources for Development project (ROER4D) are based on this [10].

According to the Basic guide to open educational resources developed by UNESCO in 2015, the term OER refers to any educational resource that is fully available for educators and students, or any other person interested in its contents, without having to pay for them and also any resource that is governed by David Wiley's 5 Rs of Openness: Retain, Reuse, Revise, Remix, and Redistribute [11,12]. These educational resources incorporate a license that facilitates their reuse, and potential adaptation, without the need to request prior authorisation from the copyright owner. Although OERs refer specifically to teaching and learning materials there is an obvious overlap in higher education as students also need access to scientific research publications in order to complete their studies to the highest possible quality level [13].

Many highly-renowned international educational institutions are making strategic decisions to increase their levels of investment in the design and development of educational programmes with improvements in the quality of teaching and learning. One of the strategies they have adopted is the promotion of collaborative OER projects, in order to avoid duplication of effort, eliminate costs derived from copyright, and improve the quality of educational materials. This avoids the effect of "reinventing the wheel" since it focuses on the construction, dissemination and review of knowledge as a collaborative process in a particular discipline [14]. In addition, there is already evidence to indicate that these initiatives are giving more visibility to institutions and thereby attracting more students, so they are becoming an increasingly important promotional tool. OER projects can extend access to learning to non-traditional groups of students that can be attracted to higher education. They can more effectively promote lifelong learning, encourage the realisation of educational cultural activities and bridge the gap between non-formal, informal, and formal learning [13].

OERs are not only potentially educational materials of great value, but they can also facilitate and encourage collaboration between educators and students from different institutions applying OEP. This new approach related to the distribution of knowledge, and the effective use of it, is seen as key to institutional success in the current context. For this reason, hundreds of educational institutions have formed international consortia and alliances in open educational technologies, with the aim of developing and sharing new models of free repositories, teaching materials, and collaboration for the production and distribution of educational resources [15]. These initiatives are clearly aligned with the alliances established to achieve the ODS 17 [3,16], as can be seen in the results of initiatives presented in the ROER4D research project in the last two years [17].

For all the aforementioned reasons, the Conference of Spanish University Principals (CRUE) prepared a report on OER in 2018 [18]. Following an analysis of the current situation in Spain in this report there are some guidelines or recommendations for the promotion of OER in Spanish Universities, among which are:

1. to establish an institutional mandate or guideline to publish open educational resources in repositories, banks, or other institutional platforms that ensure their accessibility with open licenses and to avoid the dispersal and duplication of teaching materials on external platforms where there is no control over communication and visibility aspects.
2. to take advantage of the international trend in open educational resources and institutional support so that teachers can create and explore the potential of OER.

Open educational resources are classified into three categories. The first is that of educational content ranging from publications, complete courses, educational software, compilations, and modules or learning objects. The second is that of computer tools for content management and training, as well as for content development and the creation of educational communities. The third is implementation resources for open content licenses, design recommendations based on good practices, and content translation [13].

Within the training contents are the teaching or didactic materials, these are defined as a set of materials that involve and facilitate the teaching-learning process [19]. These materials can be both physical and virtual, and, assume as a condition, an ability to awaken the interest of the students, adapt to their physical and psychological characteristics, facilitate teaching by serving as a guide, and adapt to any type of content. In turn, other authors define them as means and resources that facilitate the teaching–learning process within a global and systematic educational context and appeal to the senses to encourage easier access to information and easier acquisition of capabilities and skills and to facilitate the formation of attitudes and values [20].

The main characteristics that a teaching material should have are, amongst others; an ability to motivate students, to provide specially-adapted information, to stimulate and facilitate learning, to exercise skills, and to guide the teaching-learning process. These characteristics are achieved by carrying out different operations; some related to the contents and others to the forms or appearance of the presentation, and of course, some to the interactivity of the chosen presentation medium [20]. Interactive teaching material is that which allows the student to participate actively in the possibilities offered by the material to improve the learning experience [21].

The GIEIF of ULPGC knows that research on the use and production of educational resources is of increasing interest and importance, and for this reason, they have spent several years applying OEP and working on the development of interactive teaching materials both as support for classroom instruction and also as a motivational element to enhance the student's autonomous work [22]. Among them is the teaching material subject of this article, which has characteristics and objectives common to OER.

1.2. Additive Manufacturing

The term additive manufacturing has been used to refer to a group of technologies that have evolved over several years. When they first emerged, their objective was the development and production of prototypes and, due to that reason, they were referred to as 'rapid prototyping processes'. They were called 'rapid manufacturing processes' because when these technologies were developed, they offered greater performance, and were thus used to manufacture fully-functional parts, products and tools. Other names have also emerged due to their use of digital files, such as e-manufacturing or 3D printing colloquially. The American Society for Testing and Materials (ASTM) Committee F42 was formed to standardise AM designation in 2009. According to the ASTM definition, which is endorsed by International Organization for Standardisation (ISO) at that time [23], AM is "the process of joining materials to make objects from 3D model data, usually layer upon layer".

AM development began in the 1980s and it continues to evolve. The first stage was aimed at the development of different AM technologies and this is when many technologies were patented. During this stage, AM was characterised by being very expensive and limited in its scope. At the beginning of this century, many of these patents expired, so the growth and development of AM is rapidly expanding [24]. The second stage, where we currently are, is characterised by increasing accessibility to AM. In addition, industrial capacity is increasing, opening up new fields of application for AM within biomedicine or micro-manufacturing. Due to this AM evolution, standardisation and the creation of norms to regulate its use and guarantee the quality of the products manufactured by them is particularly important. In order to facilitate the development of these standardisation activities, the European Union has promoted projects such as SASAM (Support Action for Standardisation in Additive Manufacturing) to develop a roadmap of the activities to be carried out in order to standardise AM [25].

These technologies will continue to coexist with conventional manufacturing processes and understanding the advantages and disadvantages which they present in contrast to traditional processes is crucial. According to the specialist website additively.com [26], the general advantages which stand out are freedom of design and the possibility of producing complex parts without cost overrun and customised parts; material optimisation; capacity for innovation; reduction in time to market; profitability of manufacturing in short series and its function as an accelerator of the democratisation of manufacturing [27]. Moreover, AM supports the trends of the Fourth Industrial Revolution (Industry 4.0) as it implements flexibility in production and allows for the decentralisation of production using cloud computing tools [28]. On the other hand, AM presents several generic disadvantages such as low production capacity and production ratios, a need for post-processing, constraints depending on the size of manufacturing, materials and formats, immaturity and a lack of development of some technologies, and a lack of a broad standardisation that would provide guarantees related to the use of the products produced.

With regard to sustainability considerations, AM-produced objects must comply with current regulations to maintain control over their environmental impact. Initially, there is a reduction in the resources necessary along the whole productive chain and this can make AM a more efficient and sustainable alternative, although, in concrete cases, AM can result in a negative result overall due to the fact that these technologies often require more energy than conventional processes. However, AM also allows maintenance and aftersales services to be carried out and that can extend the useful life of certain products, thus lessening environmental impact. AM greatly accelerates the development of products that increasingly have shorter life cycles, better adjusting to demand and therefore significantly improving social and economic sustainability. Some challenges for sustainability in both environmental and socio-economic aspects are related to the production and use of raw materials [29], waste generation and recycling [30], the release of volatile organic compounds and harmful particles [31], the efficiency in energy consumption [32], their overexploitation for superfluous applications and paradigm shifts in production and consumption models [33], amongst others. On balance, however, it is widely accepted that AM technologies appear to be more promising for sustainability than traditional manufacturing systems.

In addition, the fourth industrial revolution, and especially digital manufacturing technologies, will facilitate a qualitative leap in higher education and the development of open innovation and open education practices [34,35]. The breakthrough in the market of low-cost equipment is causing changes in that consumers are increasingly looking for customised products, so engineers and other independent professionals are all potential consumers of AM. An example of this is digital fabrication laboratories (Fablab). In these labs, entrepreneurship is stimulated through global networking between different users to pursue innovation and online communities share designs and develop collaborative projects [36]. These Fablab platforms have become part of the technological world heritage and are protected by Creative Commons licenses [37]. This bank of shared knowledge, archives, and projects favour informal lifelong learning. As a result of this, the "maker" and "DIY" movements are growing strongly and a global community which shares knowledge and projects is gradually being created [38], giving a new impetus to "maker education" [39,40] and experiential education through technology [41]. The enormous potential of AM to provide a range of new technologies in the context of Industry 4.0 [42] has been starkly demonstrated during the current health crisis caused by COVID-19. The fairly widespread use of these technologies has allowed many users, either alone or in a range of different groupings, to help with the local manufacture and immediate delivery of protective equipment for health service workers [43,44].

All the above aspects will demand the development of specialist jobs targeted at these technologies, and this will offer opportunities in the coming years to future engineers and other professionals with knowledge and experience of working with these technologies. It is precisely this training that is called for in order to create such jobs that can be met through quality educational resources as tools that can be used flexibly and are adaptable to the learning rhythms of people interested in this content.

2. Materials and Methods

According to the definition provided by Cronin in Openness and praxis: exploring the use of open educational practices in higher education and collaborative practices for the development and use of teaching materials can be considered OEP if pedagogical models that promote participation, interaction, peer-learning, knowledge creation, and empowerment of learners [5] are used. The way the groups that develop free software projects work can be employed to generate digital content using innovative application methodologies in the teaching-learning processes for higher education [45]. SDG 4 encourages the use of information and communications technology and the generation of learning resources that offer both variety and flexibility in their use, allowing a high level of adaptation to both the user and their context. It encourages the production of these learning resources through both formal and non-formal means [46].

After the GIEIF's first experience in the development of educational material, a new model based on the External Practices (EP) module and the Final Degree Project (FDP) was identified as the subject for the next set of materials. This teaching model was based on the voluntary participation and commitment of motivated Students as Partners (SaP) in a process of collaborative creation of interactive teaching materials. SaP represents an array of practices and possibilities through which students collaborate with academic staff and also other students in teaching and learning activities [47]. This is a very unusual organisational model for developing collaborative work in the field of educational innovation in Spanish universities offering industrial engineering studies.

The process normally starts with an FDP-themed proposal that is initially developed by one student and is later complemented by another while completing the EP within the GIEIF and in close cooperation with teachers and researchers. This helps to cultivate student–staff partnerships through educational practices [48]. The project will also have benefitted from the knowledge and experience of a range of collaborating companies, in a number of which some of the students will have completed their internships. The students' point of view is of vital importance in making the assimilation of content easier and also evaluating the effectiveness of the proposed solutions. This is because all the students will already have passed the subject where this content is taught. The invaluable collaboration of the technical staff of the Library Service and the Scientific Publications and Dissemination Service of ULPGC is also fundamental. All these agents contribute to an ecosystem where good practices are shared, and an Open Education experience is generated. This experience has facilitated the development of rich learning resources through collaborative production.

The need to develop a concrete project based on a key topic within an emerging research field, such as additive manufacturing technologies, commonly called 3D Print, became clear as a result of a methodological renewal process aimed at the development of interactive teaching materials. The identification of this need was reinforced by the fact that AM content is widely dispersed in a range of different types of publication and, in many cases, not adapted to the new norms that are emerging. This content is also mainly available in English, so an opportunity was identified to develop teaching material in Spanish that could be used both inside and outside academic settings, and thus meet the need for more widespread dissemination of this knowledge in Spanish-speaking countries. The ability to use this teaching material both in the classroom, and autonomously outside it, was established as a design requirement, and therefore it was also a requirement that it should be usable alongside active learning methodologies. From its conception, the idea was to create materials that allowed flexible use adaptable to the different styles and learning rhythms of the people interested in this content, that is, a certain level of adaptive learning relevant to different user profiles [49].

This educational innovation project analyses different ways of using several ITMs. One of the main objectives of this teaching material was to provide a support tool for face-to-face teaching in subjects, mainly in the field of manufacturing process engineering, allowing a certain degree of autonomous learning for the student. It has been used in topics at different training levels, and in combination with active methodologies like "flipped classroom", to seek greater application from the student in their work outside the classroom. As this methodology can be used alongside other types of resources it makes a change from the usual videos used [50]. This particular ITM has been used in lifelong learning activities, both for companies and for disadvantaged groups.

A small-scale study of action research in education [51] has been employed in this work to assess the teaching material itself as well as the impact of its introduction on the academic results within the study subject. The selected topic was Product Development Technologies in the fourth year of the degree in Engineering in Industrial Design and Product Development at ULPGC, with between 40 and 50 students in each academic year. It is a subject where a project-based learning methodology is applied in groups of three or four students and where the competence of teamwork is examined and has significant weight in its marking and evaluation. The results were analysed using mixed-method research. First, a quantitative analysis of three academic years' cohorts was carried out. This was followed by the second phase of interviews with relevant participants in each of these cohorts.

A pilot test of the didactic material was carried out to evaluate it as a support tool for face-to-face teaching. The material was judged according to its suitability and usability by ITM students and the degree to which it complied with the stated objectives. A previous version of this ITM was initially and experimentally used during the academic year 2016/2017, and the lecturer used it only as support material for seminars. Subsequently, at the request of students, part of the material was made available to them in order to partially deliver course content related to a project on product development using advanced manufacturing technologies. This activity constituted the practical application of the methodology taught during the course explaining how to select technologies for products that had been developed during the course itself.

The results obtained in this pilot test were substantially better than those that had been achieved in previous years. There was more active participation from a greater number of students who asked more relevant and specific questions. Higher-quality coursework was produced, and this led us to consider this ITM, and its associated methodology, suitable for academic use in the formation of the content.

During the academic year 2017/18, the authors decided to provide an improved and complete version of the ITM so that this teaching material could be used as independent learning material ahead of face-to-face sessions. This was initially used together with flipped teaching methodology. The aim was to make better use of time during the face-to-face sessions and to achieve a more active and participative attitude amongst the students. Although the experience was very positive, the need for an orientation session explaining how to use the teaching material was immediately apparent. Some students indicated that a simple introduction to the use of ITM and how the content and information was structured, including how to access it, would have helped them to make more efficient use of the time they spent preparing the content in advance of their face-to-face sessions. In the following academic years, 2018/19 and 2019/20, an orientation session of approximately thirty minutes was introduced prior to the autonomous use of the material.

3. Results

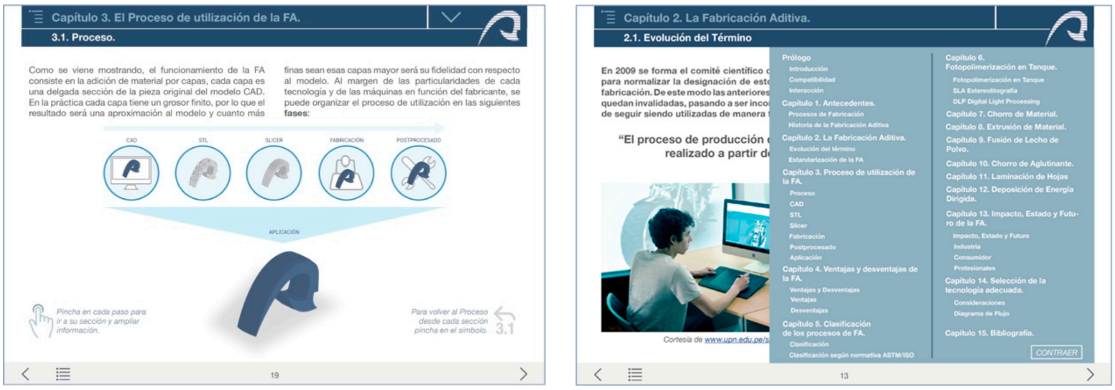
The results obtained in this work are divided into two blocks. The first one describes in some detail the interactive teaching material developed within these open educational practices, as well as the methodology for selecting additive manufacturing technologies that it includes. In the second block, the results obtained from an analysis of the impact of the teaching material in the subject under study are presented.

3.1. Interactive Traning Material

Before describing this interactive training material, it is important to note that these materials have so far only been developed as interactive PDF files. It is also necessary to describe the types of users at whom this ITM is aimed. Initially, these will be students in the field of engineering where the topic of manufacturing processes, or similar, is taught. It may also hold great interest for professionals in the field of product development, or even amateurs interested in understanding technological development and its applications. In response to the different needs of these users, the ITM has been designed in such a way as to facilitate reading by any of these groups whilst also allowing the more expert users the option to delve into more specialised content on AM.

The way in which the content has been designed and organised provides an overview of the AM process and the ULPGC graphic identifier or logo has been used to customise some content and to help the user identify with the institution, Figure 1. This content is structured across 15 chapters and within each of them, the main themes are divided into different sections.

1. The historical background of AM.
2. The evolution of the term Additive Manufacturing and its standardisation.
3. The generic description of AM Process.
4. The advantages and disadvantages of AM.
5. The classification of AM processes.
6. A description of the main characteristics of the seven categories of AM
7. The impact, state of, and future of AM.
8. The proposed selection process of the correct technology in the design process.
9. The bibliography and references (Presenting the sources of information upon which content presented here is based).



(**a**) (**b**)

Figure 1. Example pages with the structure of contents with an institutional logo: (**a**) Additive Manufacturing (AM) process linked to each stage of its process; (**b**) Drop-down index of chapters.

In the ITM contents, the information is summarised and supported with graphic content in order to facilitate compression of the content and to provide interactivity in layers. This allows the information to be structured hierarchically. This idea is examined in the prologue of the ITM along with an examination of aspects of its usability. With interactive elements and links between content in the document, users can easily access the content related to each stage of the selection process. In many pages of the document, there is additional information in the form of pop-up windows. As a result of this, the user can select the information they want to consult in greater depth. It also ensures that at any point, the most relevant information is visible. As an example, in the timeline, complementary information for each of the milestones are referenced and can be consulted, Figure 2.

In addition, from any chapter or section, you can access a comprehensive list of chapters in order to easily find the information that you require, Figure 1. You can also return to the front page of each chapter to access another section within that chapter. This allows the user to access any content, even if it is not directly related to that shown on the page being consulted. Interactivity is achieved through numerous multimedia resources which appear in the ITM and the user can select and expand these to full screen, including operation schemes for each group of technologies or datasheets. Image galleries allow you to include several illustrative examples of the contents of a page without taking up more space than absolutely necessary. Videos of real examples of processes and software simulations of AM have been included, some of them expressly created for this ITM. These elements are identified in the document through the use of specific icons presented at the beginning of ITM in the usability section so that the user can identify that resource, Figure 2.

(**a**) (**b**)

Figure 2. Example pages with interactive elements: (**a**) Example of a pop-up window; (**b**) Key to icons.

This common structure for all AM categories enables them to be easily compared to each other and it follows the recommendations and proposals made by other organisations, thus increasing consistency. This structure consists of an initial page that briefly describes the definition process, the compatible materials, links to variants within that process and the advantages and disadvantages of the technologies discussed. With this first page, the user acquires a basic idea of the process and its capabilities. On the following pages, users are presented with more detail about the technology: a page with a more extended description, the operation scheme and an explanatory video. There is also a page about the post-processing and an explanation of how to obtain the final parts and a page about process limitations and design conditions. The content then continues with images of compatible machines and materials and ends with a page featuring applications and sectors of application including graphic examples. Figure 3 shows the pages of one of the technologies (VAT Photo polymerisation) that serves as an example of the structure under discussion. The format of these pages aids easy identification of content.

Figure 3. Example of the structure of an AM-specific category.

This section, which describes the different AM technologies is complemented in Chapter 14, with the definition of a methodology to enable selection of the most appropriate technology depending on the user's requirements. If the AM is considered suitable, concrete recommendations are given for use of specific technologies taking into account the stage of development at which the project currently is. The first step is to identify what potential AM provides in manufacturing the product when compared with other traditional processes. One way to assess potential is to weigh up the advantages and disadvantages that AM generates. Only if this potential is medium to high should the use of AM be considered. After deciding to use AM, the specific technology to be utilised must be determined by:

1. identifying the key part requirements according to the development phase, Figure 4,
2. comparing the 7 fundamental categories of AM processes.

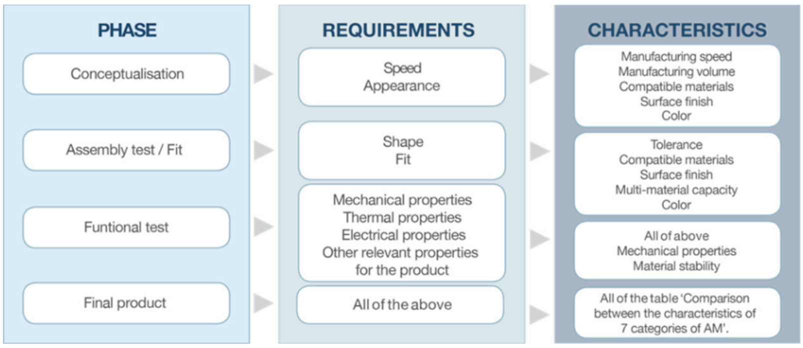


Figure 4. Product development phases, requirements and characteristics.

Once the technology has been chosen, the flowchart is followed using an iterative process of economic evaluation, testing, analysis and redesign until a viable solution is reached, Figure 5. A complete production by AM could be economically unviable, and a more specific application might generate greater interest. AM will not usually entirely replace traditional methods but will, rather, complement and integrate them into the productive processes making them more efficient.

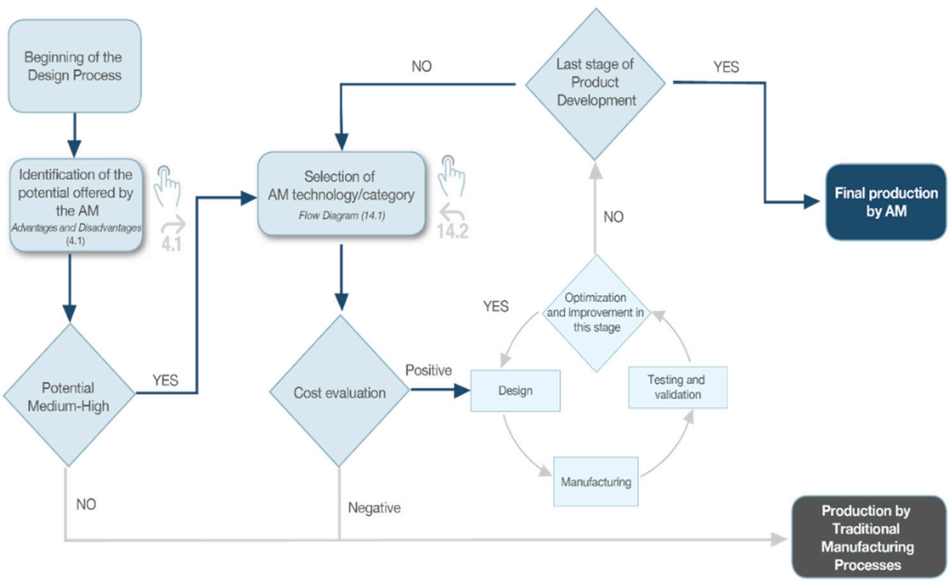


Figure 5. Flowchart to select the appropriate AM technology.

3.2. *Impact Assessment*

As mentioned in the previous section, this evaluation was carried out using a mixed method that included first a quantitative phase, through the use of a survey, then a second qualitative phase of student interviews. During the academic years 2017/18, 2018/19, and 2019/20, the same survey was completed by the students of the aforementioned subject of ULPGC. A Likert scale with 5 levels was used from 1 (not adequate) to 5 (very adequate). The survey was completed voluntarily by 39 participants representing 30% of the total number of students enrolled in that subject in these academic years. The results of this survey can be summarised with the following points (see Appendix A for all results and questions):

1. The first set of questions was related to the design of the teaching material and its multimedia resources; more than 80% of students gave a positive response (4 or 5) and fewer than 10% of students gave a low rating (1 or 2).
2. In the second set of questions, the students responded to questions about the functionality of the teaching material and its capacity to be studied independently. More than 60% gave a positive rating (4 or 5) and only 10% of students graded the level of adequacy as a 2.
3. The third set of questions was related to the usability and interactivity of the material. Over 65 % rated this 4 or 5, and fewer than 10% of students rated it as inappropriate.
4. Finally, in the fourth set of questions, an assessment of the quality of and the level of understanding afforded by the content were made. Over 80% rated this as 4 or 5, and 5% of students gave a low rating (2 of 5).

The main limitations of this small-scale study of action research are twofold: Firstly, it has a limited field of study and the use of questionnaires can result in demand characteristics, where participants may feel directed towards a particular response which may reflect what they think the teachers want to hear. For this reason, in the second stage, three individual interviews per academic year were carried out. Students interviewed were selected according to their level of commitment and involvement in the subject and were amongst the highest-achieving scorers in the course work element. The method used was an open interview with an informal and relaxed nature to obtain complementary information to that already provided in the individual responses to the open questions in the survey (see Appendix A). These questions were then analysed in greater depth, providing qualitative information to supplement, compare and expand upon the quantitative evidence from the first stage. This gave the researchers the opportunity to ask participants to provide additional information about themselves and how they used the teaching material, any problems they identified and any preferences that they had with regard to the presentation of the content. We were interested in contrasting this additional information with the general results from the open questions to determine their level of relevance to the study, concluding that they were reasonably acceptable taking into account its limitations.

The overall results obtained from the open questions were affected by the fact that the material was mainly accessed via computers (47.7%) and mobiles (34.1%) and that some students had problems viewing the teaching material on some platforms (23.1%), e.g., errors in the interaction between text and images, videos or pop-ups windows. In addition, the majority of students questioned (66.6% that rated the material 4 or 5) preferred this way of preparing the subject content compared to the traditional method of presentation, but they considered that an introduction and orientation session on the use of teaching material was necessary (76.9% that rated 4 or 5). Some observations and suggestions for improvement were also provided in some specific sections of the teaching material e.g., the need to include costings for each technology or the difficulty of responding using mobile phones.

Throughout the academic years 2017/18, 2018/19, and 2019/20 an analysis of the overall results in the subject was carried out, and the marks of the students who passed the course are shown in Table 1. The teaching team for the subject remained the same, the size of the class groups remained very stable, and the same evaluation process was used, which was mainly based on project work carried out in teams of 3 or 4 students on related subjects. Both the final result and the process followed to achieve this through teamwork-based competences were assessed. The academic year 2015/16 was taken as a reference point because some of the educational practices mentioned had already been introduced, but the teaching material and the active methodologies which it supports had not yet been used, and the results from this year were compared with the results from our analysis period. For these reasons, the global grades of the subject are considered a good indicator of the validity and impact of the introduction of these educational practices supported by the new teaching material.

Table 1. Final grades of approved students.

Academic Year	Acceptable	Good	Excellent
2015/16 [1]	24 (54.5%)	18 (40.9%)	2 (4.5%)
2017/18	13 (28.9%)	25 (55.6%)	7 (15.5%)
2018/19	6 (13.6%)	30 (68.2%)	8 (18.2%)
2019/20	6 (15%)	28 (70%)	6 (15%)

[1] ITM was not used

4. Discussion

The results presented in the previous section allow us to affirm that valuable teaching material for this specific content has been developed. Students have assessed it very positively, and the impact on the academic results of the subject is also significant. Through the mixed methodology applied in this example of action research in education, it has been possible to collect the experiences, perceptions and interpretations of the students to better understand how to make the changes required to improve the process of teaching-learning in this topic. As a result of the introduction of this material, face-to-face sessions were very dynamic with a high level of interaction with ITM and increased overall student participation. The students in groups working following the introduction of the autonomous teaching material selected the AM process for their projects and justified this decision in a presentation in front of their classmates in the classroom. Most of the groups demonstrated an understanding of the process by selecting appropriate technology. Equally, in the same session, those groups that did not select or justify appropriately, understood their mistakes thanks to the explanation of their own classmates, further illustrating the effect of the prior, autonomous learning. Moreover, in these sessions, lecturers gave more complimentary feedback about actual examples when this type of process is used in industrial applications. This could not be done in the previous course when the flipped teaching methodology had not been applied as the time for such discussion within the sessions would have been more limited and progression slower, so it is safe to conclude that the learning experience has been enriched through the use of the materials developed.

This material has also been used in 2018/19 through the OPEN ULPGC e-training platform to teach the use of these technologies in sessions on a postgraduate degree called "Diseño y desarrollo de componentes de plásticos inyectados" (Design and development of injected plastic components) at the University of Zaragoza. In this case, the teaching material was provided before the session to allow students to consult it in advance and, in the interactive session, the contents were taught with better time-usage. Additionally, the students' questions, which they had either prepared in advance or which arose during the session, were answered and explained. The experience of using the teaching material through this online learning platform was judged to be positive as a result of the comments provided by the participants at the end of the session. It has been suggested that there could be a possibility to repeat this experiment using some of the modules in a course called "Taller de Inyección de la Industria del Plástico, TIIP" (Workshop of Injection in the Plastic Industry) offered by the University of Zaragoza.

Another unique application of this material was as a support element in a technical advice meeting with technical managers from the company called "Dos por Dos Grupo Imagen, S.L.". This company was considering investing in AM large format equipment and they asked for collaboration from the research group to do a viability analysis for the introduction of this technology into their production line. As a result of this meeting, the staff of this company were able to understand the capabilities and limitations of these technologies and the implications of this investment became clear to them. They appreciated the presentation given and supported with this teaching material as educational, simple to understand, useful and relevant, and it facilitated their decision-making process with regard to the purchase of this equipment.

This teaching material has also been used in a course organised by the Gran Canaria Economic Promotion Society (SPEGC) and the Yrichen Foundation, whose mission is to support different groups with addiction problems or maladaptive habits. This course was framed within a youth guarantee program for the promotion of entrepreneurship and youth employment and training in 3D modelling technologies and digital manufacturing. The experience was very positive and enriching for both the students and the many teachers who participated in this activity. This teaching material was used both in the initial sessions of introduction to 3D printing technologies, as well as in several specific sessions on the types and properties of materials that can be used in the manufacture of prototypes or customised final parts. The results achieved in the project carried out by these students were presented at a public exhibition session at the SPEGC, which has proposed a repeat of this successful experience in future programmes, opening them to other disadvantaged groups.

This teaching material was published in digital book format in an interactive series of the publication "Cuadernos de Innovación Educativa del Servicio de Publicaciones y Difusión Científica" (Educational Innovation Textbooks from the Scientific Publications and Dissemination Service, SPDC) at ULPGC. The editorial committee congratulated authors on the quality of the material, and it was considered an outstanding work by the Union of Spanish University Publishers in July 2018. This teaching material has been presented at several scientific events and has received great interest from Spanish-speaking researchers and professors in particular. The great potential of this material in Latin America is clear because there is little Spanish material that includes an educational vision and an overview of the different AM technologies. Therefore, a project to convert this publication into an OER has been proposed to the Scientific publications and dissemination service at ULPGC, and thus follow the recommendations of CRUE with regard to availability in the open access institutional repository called "accedaCRIS" [52]. This way of converting existing publications into OER provides a quality guarantee for this type of open resource, which is still one of the main challenges of the OER movement.

5. Conclusions

Additive manufacturing is considered by the international scientific community as a group of emerging technologies with countless applications in the context of the fourth industrial revolution. Some of these technologies are already very accessible by any user and are part of the basic processes of the Maker movement, demonstrating the enormous potential of these technologies for rapid responsiveness to some of the needs arising from the global health crisis caused by COVID-19. It has been observed that a higher level of training in AM technologies is required to achieve a more effective response. Therefore, the need to share and make available knowledge and understanding in order to find a way out of this situation in the fastest and most appropriate way is crucial.

Open education practices, described in this research, have been very enriching for the group of educational innovation Ingeniería de Fabricación. The continuous collaboration between students, teachers, researchers, companies, and institutional services at ULPGC has allowed the development of high-value educational practices and quality learning resources that have had a very positive impact on teaching and learning processes.

The objective of having updated, versatile and useful interactive teaching material in various training contexts has been achieved in this case, allowing a certain degree of autonomous and adaptive learning for the student, and at the same time creating material of great value in face-to-face training. It also addresses a subject in the field of additive manufacturing that is of great interest and which is in continuous evolution; that of being organised according to the most recent applicable regulations. The content is presented in an attractive format and can be easily consulted using the interactive elements that it incorporates.

It also includes a methodology for selecting appropriate technologies, so it can be used not only as reference material but also as a working tool in decision-making related to the use of these technologies. Its use, in combination with active methodologies in the classroom, has enriched the teaching and learning process, prompting a more participative attitude on the part of the student, promoting cooperative learning and achieving better results.

The assessment carried out by the students has shown very positive results with regard to its suitability, functionality, ease of use and interaction. The teachers who have used this didactic material consider that the time and effort dedicated to its development has been well spent as they have a very helpful tool for teaching.

The development of open educational resources in Spanish is of great interest in the Hispanic community because there are few good quality OERs in this language and yet the potential number of users is significant.

This successful experience has shown us that open education is possible, desirable, transferable, sustainable, and worthy of our efforts, since it allows people interested in learning, from anywhere in the world, to access knowledge in an easier and more effective way. The research questions posed in the introduction section have been answered and the initial expectations of the educational innovation group have been far exceeded with this research work.

Author Contributions: Article conceptualization and project administration, P.M.H.-C.; investigation and methodology, M.D.M.-R., M.D.M.-A. and P.M.H.-C.; data curation, resources, software, visualization and validation, M.D.M.-R., L.S.-G. and A.G.-B.; writing—original draft preparation, M.D.M.-R., L.S.-G., M.D.M.-A. and P.M.H.-C.; review and editing, M.D.M.-R., M.D.M.-A. and P.M.H.-C.; supervision and conclusions, M.D.M.-A. and P.M.H.-C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The Group of Educational Innovation Ingeniería de Fabricación wants to show its appreciation to the University Library of the ULPGC for their collaboration during the development phase of this teaching material. In addition, we want to thank the Scientific Publications and Dissemination Service of the ULPGC for their help both in the publication of this interactive training material, as well as in the reception and support provided which helped to turn it into an Open Educational Resource project. The authors also want to especially thank the reviewers of this work for their constructive criticism and suggestions for improvement that have allowed us to learn much more about Open Education. Finally, we also want to recognise and thank the students and companies that have participated or collaborated in the development of these Open Educational Practices.

Conflicts of Interest: The authors declare no conflict of interest

Appendix A

In this supplementary section, the questions posed to the students in the quantitative analysis are included. Four types of questions were asked: 5-level Likert scale questions, binary questions, multiple-choice questions and open questions (short and long answers). These questions were divided into 6 blocks: (1) design and multimedia resources, (2) functionality, (3) usability and interactivity, (4) quality of contents and effectiveness, (5) portability and reliability and (6) other questions related to the global opinion about didactic material and the methodology in comparison with traditional methods. There were only two open questions: "What problems did teaching material have and on which platform?" and "Suggestions for and observations on the teaching material". Tables A1 and A2 show a summary of the questions and answers to the questionnaire.

Table A1. Questions and results of the quantitative questionnaire to the students.

Block	Question		Options [1]				
			1	2	3	4	5
Design and multimedia resources (didactic material)	(1) How do you rate the structure of the contents?	Frequency	0	1	7	18	13
		Percentage	0	2.6	17.9	46.2	33.3
	(2) How do you rate the quality and adaptation of the graphic design?	Frequency	0	3	5	18	13
		Percentage	0	7.7	12.8	46.2	33.3
	(3) How do you rate the usefulness of graphic and multimedia resources to explain the contents?	Frequency	0	0	6	15	18
		Percentage	0	0	15.4	38.5	46.2

Table A1. *Cont.*

Block	Question		Options [1]				
			1	2	3	4	5
Functionality (didactic material)	(4) How do you rate the ability of the material to be independently studied?	Frequency Percentage	0 0	4 10.3	10 25.6	15 38.5	10 25.6
Usability and interactivity (didactic material)	(5) How intuitive has use of the interactive elements been?	Frequency Percentage	0 0	3 7.7	10 25.6	17 43.6	9 23.1
	(6) Are the size of the icons and buttons suitable for use on different types of devices (computers, tablets and mobiles)?	Frequency Percentage	0 0	2 5.1	8 20.5	20 51.3	9 23.1
	(7) Are the different ways to navigate the content useful?	Frequency Percentage	0 0	1 2.6	5 12.8	18 46.2	15 38.5
Content quality and effectiveness	(8) How do you consider the usefulness of these contents in your future education and career? Is it related to current topics?	Frequency Percentage	0 0	0 0	7 17.9	16 41	16 41
	(9) How do you rate the understanding of the explanations?	Frequency Percentage	0 0	1 2.6	6 15.4	17 43.6	15 38.5
	(10) How do you rate your level of assimilation of the contents?	Frequency Percentage	0 0	2 5.1	5 12.8	24 61.5	8 20.5
Other questions	(13) How do you consider this methodology compared to a traditional exposition of the content by the teacher?	Frequency Percentage	0 0	2 5.1	11 28.2	10 25.6	16 41
	(14) How necessary is the introductory class to the contents before the independent learning?	Frequency Percentage	0 0	1 2.6	8 20.5	13 33.3	17 43.6
	(15) How do you rate the Didactic material in its entirety?	Frequency Percentage	0 0	1 2.6	6 15.4	20 51.3	12 30.8

[1] 1: very unsuitable, 2: inappropriate, 3: average adequacy, 4: suitable, 5: strongly suitable.

Table A2. Questions and results of the quantitative questionnaire to the students (continuation).

Block	Question	Options	Frequency	Percentage
Portability and reliability (didactic material)	(11) Which devices did you use to access the Didactic Material?	Computer Tablet Mobile	21 8 15	47.7 18.2 34.1
	(12) Has the Didactic Material presented problems in any used devices?	Yes No	9 30	23.1 76.9

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