Adaptive learning using interactive training material

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ABSTRACT

The purpose of this chapter is to describe experience in the development, use and evaluation of interactive didactic material oriented towards the ISO GPS system that has been introduced into recent academic courses of subjects of various engineering degrees at the University of Las Palmas de Gran Canaria. The Educational Innovation Group Ingeniería de Fabricación sought to generate a tool that would help students with a learning difficulty that had been identified as generalisable across various degree subjects.

Student feedback was utilized in the development and evaluation of this didactic material. The results obtained allow us to confirm that the introduction of these materials has had a positive impact and that this preliminary experience of adaptive learning should be supplemented further in order to extend the significant improvement observed, both in the students' learning and the lecturers' teaching, in the last academic year.

Keywords: Adaptive computer learning, Flipped classroom, Students assessment, Learning environment, Problem solving, ISO GPS, Manufacturing

INTRODUCTION

This adaptive experience of learning arises as a result of the identification of significant and generalised learning difficulties in a block of content found across introductory courses for manufacturing processes in engineering. After analysing the situation and assessing different alternatives, it was decided to generate interactive didactic material aimed at those students.

The didactic material is oriented towards the introduction of the ISO Geometric Product Specifications (GPS) system of dimensional tolerances. A brief description of the methodology applied has been carried out and also of the different blocks into which it has been organised as well as its relationship with other content in the basic courses where it will be used. It has been developed as an interactive PDF file, with multiple multimedia resources.

In this work, an evaluation of the impact which the introduction of this interactive didactic material has had is carried out, presenting the results obtained across three different courses and during four academic years. These results have been compared with those achieved in the course prior to its implementation. Both quantitative and qualitative aspects are analysed to determine the impact achieved.

The principal objectives of which were the following:

- To introduce an adaptive learning method for this content based on the characteristics of the courses and the students in order to increase their motivation and level of engagement.

- To be suitable for use outside the classroom for levelling-out activities and reinforcement, promoting autonomous learning and to be adapted to the capabilities, style and rhythm of the students.
- To improve the quality and effectiveness of the learning process, prioritising useful content through the introduction of a range of multimedia resources.
- To be suitable for use as support material for the lecturer in face-to-face sessions and for both introductory and advanced theory in the classroom and in laboratory practicals.
- To better take advantage of the valuable time in the classroom in order to work on important aspects at the same time that methodologies of the Flipped Classroom are introduced.
- To adapt content to a new international application regulation which is currently undergoing a process of adaptation and homogenisation.

BACKGROUND

This experience is part of a project of educational innovation and methodological renewal for the design and manufacture of teaching resources that is being developed by the Educational Innovation in Engineering Group of the University of Las Palmas de Gran Canaria. The basic objective of these materials is to be appropriate for many subjects in the field of Knowledge of Manufacturing Processes within Engineering, and in some other complementary areas, in order to improve both horizontal and transversal coordination in new degree titles.

Adaptive Learning

The use of adaptive learning in the university sphere has experienced an important boom in recent years, according to the numerous references published in the NMC Horizon Report Higher Education Edition 2017 (Adams Becker et al., 2017). According to this work, adaptive learning is expected to be implemented in many higher education centres within a period of approximately one year or even less. It must be borne in mind that this type of learning is part of the broader concept of personalisation of teaching, based on an educational model centred on learning (Lerís & Sein-Echaluce, 2011). Although there has been a broad coincidence in the need to implement custom learning methodologies in all educational contexts, it has not been until the last decade that a large number of technological tools or platforms have been promoted (Graduate XXI, 2018), which have facilitated the incorporation of these new learning models.

It is certainly true that an adequate implementation of these techniques requires that, in the university environment, some aspects of group work be modified. This is the case, for example, with the grading scale (indicator of the efficiency of learning in the current university model) which refers to the relationship between the total number of credits passed by the group and the total number of credits submitted for examination. Also from the group. However, in a paper about adaptive learning by Moodle authors demonstrated that the application of adaptive learning techniques allowed the success rate of the degrees to increase by improving the motivation of students who have adapted their teaching plan based on their weaknesses and strengths (López, Muniesa, & Gimeno, 2015).

Although there are several categories of adaptive learning, we can distinguish two general models (EduTrends, 2014): the content-driven and the evaluation-driven. The first case is based on the analysis of the data obtained after the interaction of the students with the contents and it is the teacher who decides what should be modified in the content to favour personalised learning. The second case is the one that is most directly identified with adaptive learning. It is a computer tool that analyses and makes the necessary adjustments based on the results of the student's evaluation.

The specific case work presented here, is considered to be a means of responding to the specific needs of each student within a group, and allows adaptation of content learning in Dimensional Tolerances for each individual. This work has been proposed as an initial phase of the adaptation model driven by content; as a pilot project prior to the implementation of a more automated and flexible learning model. It is, therefore, an approach towards adaptive learning of concrete content and it aims to design formative action, which can be integrated into a more complete model of adaptive learning. In addition, it should be noted that although adaptive learning focuses on the individual student, its application in collaborative learning is being studied through the use of Artificial Intelligence tools that are already incorporating the LCMS (Learning Content Management Systems) (Marcus, Ben-Naim, & Bain, 2011).

Didactic Material

The ISO GPS (Geometrical Product Specifications) system is an international language of symbols that are used to express tolerances in technical documentation. It is the only language available worldwide to communicate the geometric requirements of the products. The need for this project was identified following the experience of a group of teachers in the engineering area of manufacturing processes, across several academic courses, when evaluating the topic of Dimensional Tolerances. This subject is included within the thematic block of Dimensional Metrology, in several introductory course units for manufacturing processes in several different degree courses. A significant and generalised learning difficulty was observed in the practical application of these areas to some simple problems. Only simple operations of addition and subtraction are required to solve these correctly, but it is essential to understand clearly some minimum basic concepts that the students were not recognising or understanding correctly. For this reason a very high percentage of students failed the first assessments of these topics or passed with very low grades that significantly influenced their overall grades in the subject. There was also a need to change traditional materials that had been used; to adapt them to the new or modified standards that have emerged in recent years related to the ISO GPS System.

Most of these subjects in the new undergraduate degrees are found in the 2nd year and are worth 4.5 ECTS, so it is not possible to devote many face-to-face sessions to any of the thematic blocks in which they are structured. In the planning of the course content between 5 and 6 hours of class time can be devoted to these topics, divided between theoretical sessions and classroom based problem-solving sessions. After analysing the situation and evaluating different alternatives, the decision was made to create interactive didactic material aimed at those students who needed extra support. The main objectives of this material were:

- to guide pupils in the learning of these topics.
- to be usable outside the classroom to reinforce autonomous learning.
- to have content adaptable to a new international application regulation, which is currently in a process of adaptation and homogenisation.

The first didactic material was developed based on a methodology that had been in other didactic materials created by the Educational Innovation Group (Hernández-Castellano et al., 2017). This consisted of the description of practical cases of application of different conformation processes, in the design of a product that was easily associated with the ULPGC. An ambitious objective was initially set: to cover, with a degree of detail, all the types of tolerances included in the ISO GPS system. The work was designed with a focus on the use of manufacturing tolerances, encompassing both dimensional, geometric and surface finish tolerances. The work was structured in several blocks, one for each of these large groups of tolerances, and another for its application with CAD software that was used in other subjects using Graphics as part of their degrees. A final block was included for the exhibition of practical cases showing application of these themes. A Final Degree Project (TFG) was proposed to a student who was considered to have a suitable profile, as he had great interest in this subject and had enrolled on the Degree in Engineering in Industrial Design and Product Development after completing a foundation course in technical drawing.

Despite the fact that the student wanted to maintain a global vision in the Project, it became noticeable during the completion of the TFG, that the work was excessively broad. The result obtained was of great interest to the teacher but of little use or importance to students, as it was a very extensive body of work with important theoretical content, based on a group of international standards written using excessively technical language, which would only be interesting for a small group of students with a high level of motivation. This structure of didactic material, which had shown good results with a more descriptive type of content, lacked sufficient appeal to be used autonomously by the students. It was considered that the work developed was, nonetheless, of great value, although to increase its effectiveness, it would have to be redesigned and divided into several more specific materials, and at the same time it was necessary to rethink the strategy to approach this new type of didactic materials. Figures 1 and 2 show some pages of this didactic material written in Spanish.

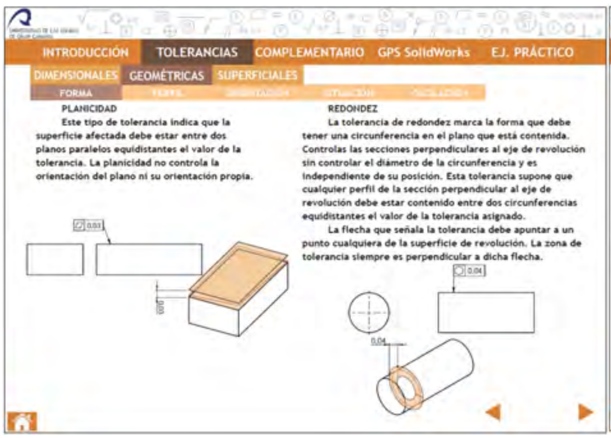

Figure 1. Page from tolerances section *Figure 2. Page from practical example section*

As a result of the above, the decision was made to propose new teaching material aimed at a more specific part of the ISO GPS system, such as dimensional tolerances and adjustment systems between parts to be assembled. It was developed by means of another TFG written by a student following the same degree course as mentioned earlier and who had a special interest in the area of teaching. He was a unique student because he was considerably older than the rest of his classmates, had extensive experience of the world of work and showed a very high degree of involvement with the subjects in the area, in which he obtained very good grades.

INTERACTIVE TRAINING MATERIAL

The teaching material produced is an interactive document in PDF format that includes a large number and variety of multimedia elements. The cover page of this material can be seen in figure 3. It shows an image with the GPS acronyms made with LEGO parts which has been included to express, using a single visual reference, the idea of the assembly of pieces in a way with which everyone will be familiar. It has a structure that makes the search for content in the order and level of depth desired easy, figure 4. As in the previous case, this has been completed in Spanish. In this section we will describe the didactic material developed, the use that has been given to it and the evaluation process that has been followed to measure the impact of its introduction on learning outcomes.

Figure 3. Cover of the new didactic material

Figure 4. Structure of the document contents

Description

The work behind this new didactic material was aimed specifically at searching for resources that would improve the appeal of the didactic material and raise its degree of interactivity with the student, since the content had already been approached in a broad way in the previous work. We had the help of a professor from another department who specialises in the design of information systems and who knew and had analysed with a certain level of detail the previous work. The work began with a broad and detailed bibliographical analysis of the development and evaluation of didactic materials, to understand in depth what is considered didactic material and what the essential requirements were that needed to be addressed. The need to establish a homogeneous, well-founded structure with a clear objective was evident. The main characteristics to fulfill were, among others: to motivate students, to provide adapted information, to stimulate and facilitate learning, to use skills and to guide the teaching-learning process. These characteristics are achieved by carrying out different operations; some related to the content and others to the form or aspect of presentation, and, of course, with the interactivity of the presentation-medium chosen (Careaga & González-Videgaray, 2008).

Taking into account all these ideas and positions, special emphasis was placed on establishing a homogenous organisation of the information, both of text and other resources that were included in an intensive manner such as: images, graphics, plans, tables, videos, and interactive graphic windows. All this information is accessed quickly and easily through an interactive navigation menu, always present at the top of the screen, and icons with direct access to a summary of the contents, help and usability pages. A system of colour-coding was also established to identify all aspects related to the types of shaft or hole more easily, and to facilitate the understanding of the concepts that are applicable to them. A clearer and more homogeneous terminology has been introduced, in line with current standards, which avoids ambiguity in the definitions of several terms that still appear in some of the standards yet to be updated. The tables included in the standards, where the standardised values of amplitude and position of the dimensional tolerances are collected, were drawn out so that they can be consulted at any time, in a direct and agile way in the same didactic material, and could be used to clarify any doubts that arise when studying.

The course content included in this document begins with an introduction to standardisation and the need for its implementation, to show some brief historical references that have given rise to the ISO GPS system and to briefly describe how this system is structured, figure 5. The second section deals in detail with the main issue of dimensional tolerances, describing everything from the basic notions of the ISO coding system to the tolerances recommended by the standards, figure 6.

This second section also includes a detailed description of the standardised ISO adjustment system, from the different types of adjustment that can be made between two components to be assembled, to the adjustments recommended by the standards (Figure 8). The third and last section of content of the didactic material includes examples of the application of the ISO GPS system. The aim here is to integrate content addressed in other areas of the different subjects with the corresponding laboratory practices programmed in them. The aim is to achieve a common thread between the different content blocks that clearly reflect their interrelation, and ensure that students are aware of what it means to establish demanding dimensional tolerances, both from a technical and economic point of view.

Figure 5. Unit Introduction page

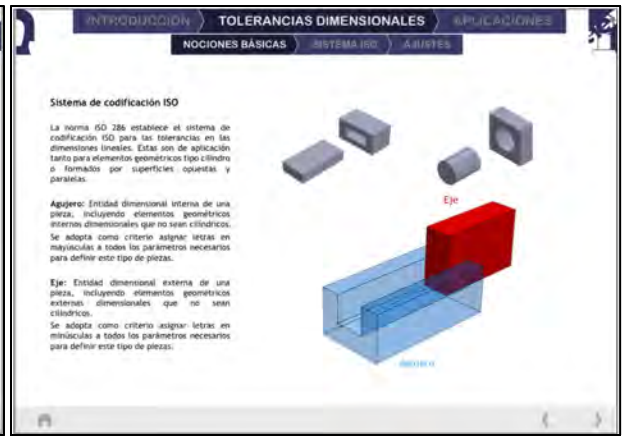

Figure 6. Page from the main section

Figure 7. Page with interactive graphics window

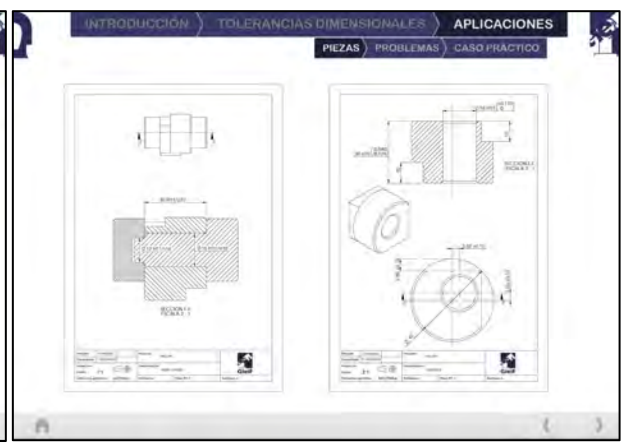

Figure 8. Page with assembly plans

Firstly, a practical task involving the assembly of a simple set of pieces that the students have to manufacture in laboratory sessions was presented. This teaching material includes detailed plans for the manufacture and assembly of all the components, accompanied by videos and an interactive graphic window which allow us to analyse all the components of the product from any point of view (figures 7 and 8). The task consists of three pieces which need to be fitted together to build a cylindrical mechanism. They fit together and need to be tightened to assemble the product. In the practical laboratory sessions in this section of the course, students manufacture these parts through milling, turning and drilling operations using conventional machine tools, with the aim of getting the product to work properly. These parts have some geometric characteristics that allow us to evaluate deviations of shape such as roundness, flatness, parallelism, perpendicularity or concentricity. This demonstrates the need to complement the dimensional tolerances with other types of tolerances such as geometric and surface finish.

Also, in this third section two of the recurring problems seen in this section of course content are resolved in a detailed manner. These problems are like those that have to be solved in the exams. In the detailed working of the key problems in the analysis of normalised adjustments and tolerances, both technical and economic considerations are introduced. These justify the decisions taken to solve these exercises. Problem type 1 focuses on the complete definition of a standardised adjustment that is given in the wording of the problem. The student must learn how to use the tables that show the specifications, from which he needs to extract the necessary information to determine the maximum and minimum admissible values for each one of the component parts. With these values the student must identify the type of adjustment that is needed between those pieces and determine the values necessary to complete the assembly. To do this, the student must use simple mathematical operations, addition and subtraction, although to apply them correctly they must understand the basic concepts which govern the system of standardised tolerances ISO GPS, figure 9. Problem type 2 is solved in reverse order to the previous one and a solved problem can be found in the didactic material. In the wording of the problem there are some minimum technical specifications of the type of adjustment that two pieces must have to be assembled, and the student must determine the standardised tolerances for the two types of parts that have to meet the aforementioned specifications. To solve this type of problem, the student must make multiple decisions based on the recommendations indicated by the specifications. To be able to do this it is essential that the basic concepts mentioned above are mastered, as this problem has several valid and viable solutions.

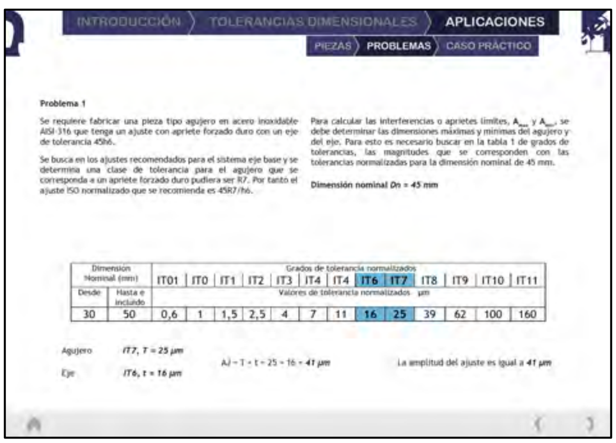

Figure 9. Page with solved problems

Figure 10. Page with information of batches of parts.

Finally, the third section includes the information required to be able to undertake a specific laboratory trial related to the analysis of measurement, manufacture and verification of batches of parts, which consist of a set of 100 pieces including shaft and hole. They are divided into 5 batches with different specifications of manufacturing tolerance, figure 10. The shaft-type parts are made of AISI 304 stainless steel, while the hole-type parts of a 6061 aluminum alloy, all manufactured in a CNC lathe in the Mechanical Technology Laboratory and subjected to a measurement process in the Metrology and Calibration Laboratory, both belonging to the Mechanical Engineering Department. All the information relating to the measurement process such as measurement equipment, measurement uncertainties and the different readings for each piece is included in a series of tables. Students can physically handle these pieces and see the different types of adjustments that can be made. In this trial, the inherent concepts of the ISO GPS tolerance system can be seen with greater clarity, thus allowing the knowledge necessary for the application of dimensional tolerances to be consolidated. With this additional resource, analysis of the variability of the manufacturing and measurement processes can be made, as well as the processes of proof of compliance with the design specifications. With these analyses students can understand the close relationship between manufacturing processes, dimensional measurement and quality control of a production batch. This batch of parts allows advanced complementary trials in specialised areas of study, both in the classroom and the laboratory, as well as more detailed optional work.

Use

This material has not been developed for completely autonomous use by the student, but as a support for the teacher in the face-to-face sessions that are considered absolutely necessary. The recommended methodology consists in a first session of approximately 1 hour for a brief introduction to the contents, while describing how the material is organised, the resources available therein and the basic guidelines to be able to use the document. In this session, students are shown how to access the didactic material through the institution's archives ACCEDA-ULPGC (Hernández-Castellano et al., 2016). It is recommended that a period of 1 or 2 weeks is then left for the students to prepare the basic concepts in an autonomous way before the problem-solving sessions, thus introducing a Flipped Classroom methodology. To adequately prepare and understand this basic knowledge an average of 6 to 8 hours is needed.

Two additional sessions of 1.5 to 2 hours are suggested for the practical application of the course content by solving the two types of problems described in the previous section. In the first of these sessions an assessment test of the basic concepts is recommended, with the aim of forcing the students to look at these before moving on to problem-solving. The rest of this session would be devoted to solving several Type 1 problems to reinforce understanding of these basic ideas. It has been estimated that the maximum time required by students to complete this type of exercise would be around 15 minutes.

The aforementioned evaluation test was designed using ten test questions with four possible answers, of which several could be correct, allowing multiple variants with minimal changes in the wording of the question and in the answers. The test is completed by completing two exercises in which the students fill in tables with the values that define two normalised adjustments from pre-determined values given in these tables. The two exercises differ in the type of information provided for their resolution. After several trials of this evaluation test model, a maximum time of 20 minutes was given. After a trial phase the test was considered appropriate for evaluating mastery of a specific skill using the standardised tolerances. To this test we would add the resolution of a type 2 problem, with a weighting of 40% and 60% respectively.

In the second of these practical application sessions, several Type 2 problems are solved, analysing in detail the multiple possible valid solutions based on the decisions taken, considering possible modifications and viability, both technical and economic. To do this, it is very important that the student has a good understanding of the basic concepts, because in solving these problems they must justify all the decisions taken to reach a valid solution, which allows the level of mastery of the aforementioned concepts to be identified. The final result is not the only thing evaluated. A meaningful mark is also given to the process followed to reach the final outcome. It has been estimated that the maximum time required by students to solve this type of exercise would be around 30 minutes.

The use of this teaching material has allowed the transfer of experience in the classroom from veteran teachers to younger teachers, helping them to avoid the typical problems that may arise the first time that certain content is taught, especially when this course content has proved difficult in the past. This experience coincided with two young teachers starting in the department who had to take charge of a subject area that was used to evaluate the impact of the introduction of the teaching material. Neither had previously taught this content, nor had they participated in the preparation of the teaching material. Their impressions in relation to the use of the material are the following: starting with the colleague who, for the first course, was responsible for the control group that used the resources that had been used in previous years.

Teacher 1 comments

"In relation to the new teaching material, I have seen the first main effect to be that students show a greater predisposition to study and pay attention to the content than with the old material, which is a good starting point at the beginning of the topic, especially when dealing with a totally unknown unit and without most students having any previous experience of the topic.

Also, it seems clear that it allows them to reach a more complete and deeper understanding of the most difficult concepts and of the dynamics of the calculations in a shorter amount of time, allowing them to achieve the objectives more efficiently. This can be seen not only in the initial content of the topic, but in the procedures for analysing and calculating the different types of adjustments and tolerances. All this, I believe, is reinforced by the clarity of the contents, the layout and quality of the images and the interactive contents.

It should be noted that it has been possible to observe that the level of consultations and tutorials in which the students take part, through the different communication channels available, have become both fewer and also more focused on less relevant issues.

Finally, I would add that exam results show two distinct student profiles. The two groups display different characteristics when tasked with solving adjustment and tolerances problems: some solve the problems almost entirely and with a high score and others that leave them out or do no more than start the problem, which suggests that students who tackle the problems do so without difficulty or with a very high degree of understanding, unlike the other large group where it seems that they have not wanted or could not address the topic."

Teacher 2 comments

"The teaching material conveys the importance of standardisation in engineering. The overall message that the student gets in the introductory part is that standardisation allows the improvement of communication between designer and manufacturer, providing the designer with more resources with which to specify the particulars that the final piece must meet.

However, the greatest strength of this material lies undoubtedly in the clarity with which the basic concepts about linear dimensional tolerances and adjustments are explained, as well as the ISO standardisation system. The images and colour-coding system used greatly facilitate the teaching work. In addition, the didactic material follows an ordered structure that facilitates the assimilation of concepts.

Although the material includes a specific section on problems, it has been observed that this material must be complemented with the resolution of problems by the teacher or with other additional material that includes more solved exercises."

Evaluation

The impact of the introduction of this teaching material has been measured in two subjects of different degrees, different years of the course and with different values of ECTS credits.

First assessment of the impact

The first trial was carried out in a topic in the first semester of the second year of the Degree in Mechanical Engineering, worth 4.5 ECTS that had two theory groups and 93 students enrolled on the 2015/16 course. The teaching material was used with one of the groups while the other acted as the control group using material from previous years. At the same time, the trial group was divided into two subgroups, one where the teaching material would be used completely autonomously by the students and the other where it would be used as support in face-to-face sessions.

The students in both trial subgroups and also the control group voluntarily completed the assessment. Following the analysis of the control test results, it could be seen that in the test subgroup; students that had the support of face-to-face sessions in the classroom, 83.3% of the students had understood the concepts analysed to a sufficient level, compared to 28.6% in the subgroup that did not have the support of face-to-face classes. For the control group this level was reached by 58.3% of the students. These results clearly showed that the impact of the teaching material had been positive and significant, and that it was essential to have complementary face-to-face support sessions for better understanding of the contents.

To avoid any unfair advantage between both groups it was decided that all the students enrolled in the subject should have access to the teaching material before the assessment of the content. The results obtained in this assessment by the students of the test subgroup with face-to-face support showed that 70.6% of them passed and of those passing there was an average overall score of 7.9 and a score in problem solving of 8.2, of passed students. For the test subgroup without face-to-face support, the percentage of students passing dropped to 35.1%, although the comparative scores were very similar at 7.3 and 8.1. For the control group, the respective values were: 71.4%, 7.6 and 8.1. This confirmed that the results of the evaluation had been reasonably good and consistent for all students enrolled. Slightly higher mean scores and greater consistency were observed in comparison with the results obtained in previous years. They also reinforce the idea that the support of face-to-face classes is essential for better understanding of the contents. As mentioned above, the aim was not to use the teaching material completely autonomously as there are always problems teaching the content as it is difficult and tough to understand. This objective was not even considered. That said, we decided to explore this option so as to analyse the degree to which the content in the teaching material was understood and learned by the students. On the whole, the results obtained for the test subgroup without face-to-face support are clearly worse than those obtained in the previous year, with the exception of some specific students, whose results were very similar, or even better, than those obtained by students of the group that had face-to-face support.

The following academic year 2016/17 the same methodology was applied to both groups. This resulted in a very similar pass rate of 70.3%, with an average score in the problem solving of 8.8. The general feeling was that the level of understanding of the contents was better than the previous year. In the last year group to be studied, 2017/18, the same methodology was used again and 73.7% of students passed with an average score of 7.5 in the problem about adjustments and tolerances. The average overall grade in the subject across the different content was 6.9. From this it could be concluded that the level of learning and understanding of the content of the Adjustments and Tolerances topic is above the average of the rest of content of the subject. This was with a starting point of clearly identified difficulties with learning this material. Therefore, the impact of introducing the teaching material in this subject has been seen to be very positive. It was also the first time that the content was taught independently to other year groups and the first time that the course was taught by the two aforementioned young teachers.

Second Assessment of the Impact

The second assessment of the impact of this teaching material was made in an area of study in the third year of the Degree in Engineering in Industrial Design and Product Development. This subject takes place the second semester, has 9 ECTS and has a single group of theory and two groups of classroom practicals. This subject was selected as it was possible to have comparable learning results from the previous academic year, 2014/15, and the analysis carried out during 2015/16, 2016/17 and 2017/18. The students were informed that the unit of work on Dimensional Tolerances was going to be delivered using this new didactic material and that would require extra commitment outside the classroom, studying independently, in order to complete the unit. In the first year, only two face-to-face sessions of two hours of classroom practicals were devoted to each group in the first four weeks of the semester. The first session was devoted to the introduction to the ISO GPS system and to give some basic notions of the ISO tolerance standardisation, informing students that, in the next session to be carried out after 15 days, they would undergo an evaluation test; the same test as was used in the assessment in the previous section. The main objective was to encourage students to work through the teaching material in advance of the next session. The students had a maximum time of 20 minutes to complete the test, with most of them handing their tests in after around 15 minutes.

The results of this test, for the units of work analysed, showed that most students achieved a sufficient level of knowledge in the conceptual aspects of the content, but also that most did not know how to apply them in practice. Therefore, a face-to-face session was proposed as an essential element of the learning process so that students could work through the practical application of the content – this was mentioned in the previous section. Before they sat the test the students were asked to say how much time they had spent working independently with the teaching material. It was considered that the reliability of the information provided was reasonable and it was observed that there was a medium to high correlation between the hours spent working with the material and the grade obtained; the students obtaining the best grades having spent the most time on the teaching material. They had spent between 8 and 10 hours completing independent work. No significant differences were observed between the results of the two different practical groups in the three year groups, despite the fact that one of them had the teaching material for an extra week, and that they could have received additional information from peers in the other group about the test. The level of difficulty of the tests for both groups was the same as they did not differ in content. They did, however, differ in the order of the questions and answers and in the numerical values of the exercises. The students were informed of their results and also that they would be assessed on the content in another similar but shortened test.

The second face-to-face session was dedicated to solving problems with the support of the teaching material. A first, straightforward, problem was written in which students had to define a standardised adjustment and reinforce the basic ideas seen in the teaching material. This was used in the classroom to clarify some concepts and consult the values of the tables taken from the UNE-EN ISO 286-1. The second problem, unlike the first, could have multiple solutions and required decision-making, both technical and economic, to justify the solution chosen. Different alternatives were analysed and the correct ones were chosen, taking into account possible restrictions of the problem. As in the previous case, the teaching material was used as support for the consolidation of basic concepts and to extract the necessary information to solve the problem. In the sessions, one for each group, the students were more active and participated more in the classroom, no doubt motivated by having the required concepts fresh in their minds. This meant that the second session was much more profitable. However, it was noted that the second session had a lot of content which reinforced the need for a specific session for the solving of this second type of problem in order to analyse the many valid alternatives that were available.

It is in the first test where the impact of the introduction of the teaching material can be evaluated with greater reliability. This is because it is the first time the students are assessed on this content. This assessment consisted of three separate parts; one of them corresponding to Dimensional Tolerances, and the other two parts being theoretical, based on the Metrology and Moulding Process Units. Although there were some slight changes in the subject made before the introduction of the teaching material it is thought that a reasonable comparison of the results can still be made, especially in the analysis of course content. It was assumed that a student who had achieved a grade 4 or above in this exam had demonstrated sufficient potential to be able to pass the next assessment with relative ease. They were also asked to indicate how many additional hours they had devoted to preparing this part of the course independently and with the help of the teaching material. It was seen that the students who passed the exam had spent between 8 and 10 hours studying.

Table 1 shows the most relevant results of the analysis that has been carried out. There is a consistently high number of students doing the first partial exam of the different academic courses analysed. Several indicators have been calculated as reference points for various different parts of this initial assessment as they are more precise with regard the course content. In block A, indicators for the theory element of this exam have been included so as to provide a complete overview of the assessment. This part shows that in the academic year 2015/16 there was a significant drop in the percentage of students passing due to the introduction of a new independent assessment system for the different thematic blocks. It can be seen that in the 2016/17 academic year these indicators returned to normal with values similar to those of 2014/15, although they fell again in the academic year 2017/18. This fluctuation has been attributed to the proximity of this test to that of other subjects, and to the fact that cohorts vary significantly from one year to the next.

Block B presents the Dimensional Tolerances indicators, where results show that with respect to the reference year group there has also been a significant decrease in the percentage of students passing. This is most acute in the most recent academic year analysed. It is thought that this is because the level of challenge in the assessment of this unit has been raised with respect to that of the 2014/15 reference year group. This may be due to the introduction of the assessment test on concepts and due to the greater rigour in the assessment of problem-solving. When analysing the results specifically within problem-solving, block C of table 1, you can see that the difference in the number of students passing between the reference year group and the ones that followed them is considerably smaller than the other blocks analysed. There is a very significant drop in the average grade obtained in problem-solving in the different years, but mainly due to the greater rigour in its assessment.

To complete this analysis, we have compared the cumulative overall results, specifically the Dimensional Tolerances section in block D of table 1, following completion of the assessment during the standard exam period. The assessment of this content in the examination during this period was of the same type and level of difficulty as the one completed in the first, shortened, assessment. In all the year groups analysed we see that the number of students taking the course is very similar. There are also almost identical numbers of students passing and similar average grades in the years 14/15 and 15/16. In the 16/17 academic year, a significantly higher percentage of students passed, around 20% higher, which has meant a transfer from an additional exam period to the standard exam period. This was also seen to a lesser extent, in the previous course. For the last year group analysed 17/18, there was a fall in the percentage of students passing during the standard examination session, although the overall percentage of students passing following the supplementary examination session reached 68.5%, a result very close to those of previous years. The average mark was somewhat lower due to the lower average mark obtained by those passing in the problem-solving section of the first initial assessment. In general terms, these results are considered positive, taking into account the higher level of demand in the assessment of this content block since the introduction of the teaching material, as already mentioned.

Some qualitative aspects have been introduced into the analysis because, although the numbers of students in the groups in the different years are almost the same, it doesn't follow that the students themselves will be similar. Specifically, the opinions of several teachers who teach other subjects to the same year group and to the same students agree that the least homogeneous group of those studied were those in 2015/16 and 2017/18. There is also a perception among the teachers that the degree of understanding of the content is not always reflected in the marks scored. In the years prior to the introduction of the teaching material, although the results were not bad, it was thought that the students were able to pass this unit without having understood the concepts fully and with some small changes made in the wording of the problems they were unable to solve them correctly. This has changed with the last few year groups where generally we have observed that they now have the skills required when faced with these same problems.

		Years			
		Control Year	New teaching material used		
		14/15	15/16	16/17	17/18
Students enrolled on the course		60	69	70	65
INITIAL ASSESSMENT					
Students taking the exam		49	51	53	62
	Theory				
A	Students passing	25	11	33	11
	% Passes	51,0%	22,2%	62,3%	17,7%
	Average Mark	6,13	5,70	6,76	5,83
	Students scoring more than 4	36	26	38	27
	% of students scoring more than 4	73,5%	51,9%	71,7%	43,5%
	Dimensional Tolerances				
B	Students passing	27	16	17	11
	% Passes	55,1%	31,4%	32,1%	17,7%
	Average Mark	7,04	6,71	6,44	6,43
	Students scoring more than 4	37	31	29	20
	% of students scoring more than 4	75,5%	60,8%	54,7%	32,3%
	Problem				
C	Students passing	16	13	12	13
	% Passes	32,7%	25,5%	22,6%	21,0%
	Average Mark	8,36	7,56	5,61	6,15
	Students scoring more than 4	18	13	14	14
	% of students scoring more than 4	36,7%	25,5%	26,4%	22,6%
OFFICIAL ASSESSMENT					
	Cumulative results in the Dimensional Tolerances Unit				
D	Students taking the exam	55	53	51	54
	Students passing	31	29	39	25
	% Passes	56,4%	54,7%	76,5%	46,3%
	Average Mark Unit	7,18	7,10	6,69	6,68

Table 1. Results of the impact analysis of the introduction of the teaching materials

For all these reasons, we consider both that the impact of the introduction of this teaching material has been positive and also that there is still much room for improvement to achieve better results. We should also take into account the fact that this will be done with fewer contact hours, which will encourage more independent work. This will be work that the students themselves direct as a result to having up-to-date teaching material that can be used across different subjects.

SOLUTIONS AND RECOMMENDATIONS

Students from each of the year groups were asked to evaluate the teaching material according to: ease of use, graphic information, multimedia sections and practical examples, amongst other things. They were also asked to report any problems they found while learning, errors, and any suggestions for improvement that they considered appropriate. Below are quotes from the students' feedback grouped together by year.

Comments 2015/16

> *"I think the teaching material is pretty good, maybe the best I've seen during the academic year. The fact that the main index is interactive helps a lot so that you can get where you want when you want without having to remember which page it was on or where in the topic. The format is simple and formal, and the colours and visual structure are suitable for studying and encourage you to read. The most troublesome content for me was the Singular Positions section."*

> *"I liked the format of the teaching material a lot, because it was easy to move between slides and the content was well-planned. The material caused me no problems at all when I was studying; the only thing would be that when I was studying I have to make notes, because learning straight from the digital presentation makes my eyes tired and I find that difficult."*

> *"The program is quite intuitive and is a useful source of information bringing together all the required concepts for the topic, tolerances and adjustments in this case."*

Comments 2016/17

> *"The format of the teaching material is good, it makes it much easier when searching for a section. It also seems a good idea to me to have the summary section in which the topic is explained. You are therefore able to study in a simpler way without having to read large amounts from which then only a third or less is what really counts. In the case of the tolerances units, they are sometimes somewhat confusing."*

> *"Regarding the teaching material for classroom sessions, it seems very good that the student doesn't just read slides one after the other. As this is interactive it is more comfortable and less confusing. As for the content, it is well-structured and has the correct information to successfully understand the subject."*

> *"The teaching material seems to me a rather successful way to make studying more manageable. The fact that we can move through it easily to search for what we want in each case without having to go through page by page like with a conventional PDF is very interesting. Some of the content is somewhat confusing, although I also suppose that that will be because we do not have a sound base knowledge in the subject and we can get lost in it."*

Comments 2017/18

> *"The material is quite good and it was not difficult for me to study. The exercises were quite clear but at first it was a bit difficult to interpret them because I didn't yet have a good understanding of the theory. There is a section in the exercises in which there are some incorrect values but then the final result is correct."*

> *"At first the teaching material on dimensional tolerances was quite complex to the point where I did not understand how an axis behaved in relation to its hole and what this meant. Once I understood these concepts more clearly I found this topic really interesting. We do not always recognise the importance that the relationship between two parts has. If one part fails, the end goal might not be achieved. I'd highlight the fact that presenting the table of positions of both parts*

together, helps us to visualise more quickly whether the product requires tightening or loosening. Although I found the first test very difficult, I think it is a good method for students to try to understand the teaching material themselves without having everything explained by the teacher, even if at first it seems like a waste of studying time."

"In my opinion, the teaching material on Dimensional Tolerances was very practical. Not only due to the look it has, especially the tables and graphics, but also due to the clear and concise way of presenting the theory and the problems to solve. In my case, it was very useful because it allowed me to fully understand the unit on Industrial Processes. As a suggestion for improvement, I would suggest adding other examples of practical cases since they are very useful when studying."

These comments allow the authors to conclude that some of the objectives that they sought to achieve have, in fact, been achieved because the teaching material has pleasantly surprised the students, is intuitive in its use and facilitates studying by allowing students to navigate through the different sections they need thanks to the interactive elements. Content appeared to be well-structured and presented in a straightforward way, with a simple format and appropriate visuals that helped the students to understand the content. The vision that the student has of the course, contributed by one of the authors of the didactic material, was considered of vital importance so that the content could be interpreted and learned more easily. Some errors have been detected, thanks to the cooperation of the students. These have been corrected which has then avoided students making mistakes in their interpretation. It has also meant that the general quality of the teaching material has improved.

FUTURE RESEARCH DIRECTIONS

After the experience of using this teaching material over the last three years, the next proposed step is to deepen the implementation of adaptive learning, in this and other topics of subjects. To this end, work is being done to convert this material into a SCORM format to integrate it into LCMS platforms (Moodle-type) and to take advantage of the adaptive capabilities of these systems (Sein-Echaluce et al., 2015).

On a content level, an interactive graphic module is being developed that allows the student to enter values and graphically represent several tolerance intervals. In this way you can compare and visually observe the differences between them and also identify the type of adjustment that occurs in the assembly of two parts.

A module consisting of automatic and random assessment generation is also being considered as this would support students in preparing for their exams and, at the same time, help the teacher to create, review and mark the tests.

Having a central bank of solved problems that encompasses a wide variety of types of situation that can occur in the adjustment of parts is also thought to be a very useful development within the material. These solved problems can help the students, who study them carefully, to achieve the level of confidence required to sit their exam with greater guarantees of success because they can better interpret the connection between the results obtained and correct any possible errors.

CONCLUSION

The main conclusions that have been obtained are:

- This didactic material improves the process of teaching and learning, promoting autonomous work activities, freeing up face-to-face hours in the classroom to study other, more important content in depth.
- A better integration between the theoretical and practical contents of several thematic blocks of the courses has been achieved, achieving a more active and participative attitude in the student during the practical sessions, both in the classroom and in the laboratory.

- The teaching experience of experienced teachers has been taken advantage of so that younger colleagues can develop their teaching more effectively. It has become aware of the importance of the development of these materials that facilitate and homogenise the teaching work between groups of different degrees.
- The students have shown a high degree of satisfaction with the didactic material developed, which translates into greater motivation and better learning results. This was the case also with students considered to be extraordinary or special cases who, in these special circumstances, used it completely autonomously.
- The collaboration of students in the development of these materials has been very positive, because in addition to doing a high quality work, they have also shared their vision and experience as students, which has enabled a better assimilation of the content.
- The number of hours required to impart this content in the classroom was worked out, distributed between theory sessions and practical problem solving sessions. With the information provided by the students, it was possible to estimate the average amount of non-contact time required to complete this part of the course
- Complementing this teaching material with an interactive module for the graphic representation of tolerance intervals has been proposed. It is considered necessary to introduce self-assessment questionnaires and a greater number and variety of problems solved. The aim is to enhance the adaptability of the contents to the student's profile by developing a web version of the teaching material on a Moodle platform.
- The impact of the introduction of this didactic material is considered to have been positive and that there is still a wide margin for improvement with which to achieve better results. To this, we must add the aims of achieving success with a smaller number of contact hours, encouraging autonomous and guided work by the student by having up-to-date and useful teaching material for a range of courses.

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