IOP Conference Series: Materials Science and Engineering

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Development of a modular kit to improve DFA learning

To cite this article: J Serrano *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1193** 012118

Development of a modular kit to improve DFA learning

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Abstract: DFA (Design for assembly) is an important part of the contents included in some of the manufacturing courses taught at Jaume I University. DFA is a tool to analyse and improve product design from an assembly point of view. Although DFA contents had been covered using different teaching activities (theoretical, problem and laboratory sessions), the results in students' assessment revealed that the expected learning outcomes were not being achieved. In particular, results were especially unsatisfactory in the practical application of DFA. Students misunderstood concepts such as "handling" and "insertion" operations, and failed at identifying assembly problems related to thickness or alignment among others. A learning by doing approach has been proved to improve students' learning and engagement, as they take an active role and have the opportunity of doing things themselves. In a previous work, a specific modular and reconfigurable kit to improve DFA learning by experimentation was designed. Based on this work, this paper presents the analysis of the results obtained in two different courses where the modular kit has been used by students in a new seminar session.

Keywords: Design for assembly (DFA), Modular kits for learning, Learning by doing, Reconfigurability.

1. Introduction

The analysis of the learning outcomes in some manufacturing courses at Jaume I University (UJI) reveals that a significant number of students find these subjects difficult. The main reasons are that the contents are not only dense and varied, but also new for the majority of the students. Furthermore, the instructor must cover all the contents in a quite limited period of time and thus, a rather teacher-centred approach is applied. In particular, the contents related to Design for Assembly (DFA) seem to be troublesome for many students. Although most of the students understand the DFA fundamentals, they do not acquire the appropriate skills for a correct assimilation and practical application.

In engineering, it is well-known that the use of active learning activities may lead to improve knowledge retention and students' engagement, as the students are involved in doing things and thinking about the things they are doing [1,2]. In the literature, educational experiences of learn by doing, generally through project-based learning activities, can be found. Some examples are: CAD-CAM and product management concepts can be taught through the design and manufacture of plastic toys at a laboratory scale [3], mechanisms and machine dynamics contents can be taught through the design of a tower crane for lifting heavy loads [4], or the fundamentals of Design of Experiments can be easily practised through a catapult prototype [5]. Besides project-based activities, the use of physical kits for learning activities has been also addressed. For instance, the use of 3D printing models for learning concepts about Geometric and Dimensional Tolerancing [6], or the well-known use of the Arduino platform for the implementation and validation of programming skills [7]. In all these educational experiences it has been proved that concepts assimilated through experimentation in practical sessions are more long-lasting over time.

Since no specific commercial models for supporting DFA learning have been found, the authors decided to design and manufacture their own modular kit to support experimentation with DFA concepts. A previous work presented in [8] showed the design of a complete modular kit to fulfil the requirements of the experimentation activities related to DFA concepts. In the present paper, the previous work is expanded to include two new issues. The first one is the physical materialization of some of the cases of the modular kit as designed in [8]. The second one is the analysis of the impact of the use of the modular kit in two manufacturing courses during the academic year 2020/21.

The paper is organised as follows. Section 2 and 3 summarise the previous and the new methodology used to cover DFA related contents, as well as the design of the modular kit. The main results of the use of the modular kit are described in section 4. This includes the first physical models and the analysis of user experience from surveys answered by the students. Finally, the main conclusions of the study are summed up and future lines of work are outlined in section 5.

2. Previous learning methodology

DFA is a design tool to analyse, compare and improve product design alternatives from an assembly point of view. Most of the DFA methodologies are based on the application of design guidelines or recommendations [9,10]. The DFA methodology used at UJI is the one proposed in Boothroyd et al. [9]. One of the interesting characteristics of this methodology is that the assembly efficiency of a product design can be quantified. For this purpose, the whole assembly operation is divided into three parts: the handling operation (grasping and orienting a part to be assembled), the insertion operation (placing a part in its final location in the product) and the fastening operation.

Previous to this work, the activities used at UJI to cover DFA contents were: theoretical sessions, problem sessions, laboratory sessions and project-based learning (PjBL). In the theoretical sessions, the fundamentals of DFA, as a set of design rules or recommendations, were explained. In the problem sessions, case studies to analyse part assemblability were solved. Problems to calculate the assembly efficiency of a product and to compare different design alternatives were also solved in these sessions. Graphic-based solutions were used in both cases (figure 1). In the laboratory sessions, students carry out the disassembly of a product and its subsequent assembly to assess assembly difficulties. Finally, students work in small groups on a PjBL basis to redesign a product from the assembly point of view. By the use of all the previous teaching activities, students were expected to have understood and acquired the fundamentals and the skills required to properly apply DFA.

Despite the diversity of teaching activities used in the courses, the learning results were not satisfactory. The learning outcomes related to the basic theoretical concepts were achieved, but students showed many difficulties when it came to the correct practical application of these concepts. More specifically, many students failed at finding and interpreting assembly difficulties, and handling and insertions operations were often misunderstood. Although the PjBL activity was very interesting to apply the previously acquired knowledge, the results obtained were not as expected. According to the authors' opinion, the main reason why these problems arose was the lack of practice. Teachers tried to overcome this fact by using different practical activities. Previous studies carried out by the authors show that the skills acquired through practical learning result in greater knowledge retention by the student in the long term [11]. However, the disassembly of only a single product does not allow students to experiment with different situations. Furthermore, working with finished products greatly limits experimentation. Many of the assembly problems and considerations have already been taken into account during the design of the product, and only the final solution adopted can be seen. Therefore, it is not possible to deepen in the analysis of assemblability and evaluation of the design evolution and alternatives. For this reason, the authors considered the possibility of designing a new learning strategy based on the use of a modular kit. The goal was to design a new teaching activity where students could interact with the kit and could experiment with various design alternatives.

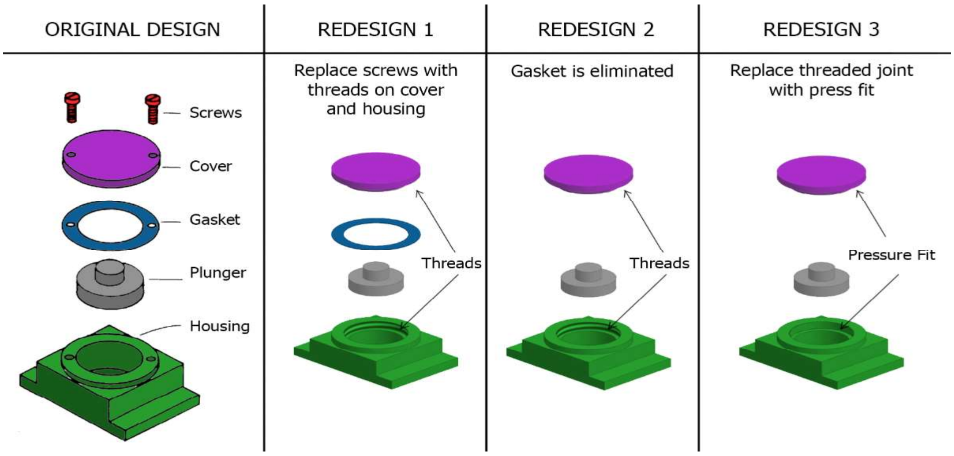


Figure 1. One of the cases solved in the problem sessions. The original design [9 and the evolution of improved designs after applying DFA.

3. Proposal of a new methodology

In this section, the new teaching methodology to support DFA learning is described. First, the basis of the new methodology is briefly summarised in section 3.1. Then, the design of the modular kit is presented in section 3.2.

3.1. Basis of the new methodology

The new methodology is based on the use of a reconfigurable kit as a learning tool. The kit is made up of fixed and interchangeable components to build different design alternatives of the same product. This allows the physical experimentation of DFA fundamentals. For the design of the kit, a simple product made of very few components (5 or 6) was selected. In particular, the simple example of a valve proposed in [9] (figure 1) was chosen. It is a classic DFA application problem that was already being used during the problem sessions.

The physical kit would be used during the seminar sessions. Students could physically check different design alternatives and notice the impact on assembleability, and the instructor could clarify and reinforce DFA concepts. In addition, using the kit in a seminar session would enable students to work in smaller subgroups, so iteration among students would be encouraged. Therefore, a problem session was replaced with a new DFA seminar session, whereas the rest of the activities was kept unchanged.

3.2. Design of the modular kit

To design the kit, the main concepts and skills that had to be reinforced were first identified. Students' answers in previous years' exams and assignments were analysed to identify the most common mistakes related to the application of DFA. The most frequent mistakes found were:

- Misunderstanding "handling", which includes the action of "grasping the part" and the action of "correctly orienting the part for insertion". Many students understood the difficulty of orientation as a problem of "insertion", rather than of "handling".
- Failing at identifying alignment difficulties only from the graphic information in the question.
- Failing at identifying the insertion difficulties of parts without chamfers into small holes or pockets.
- Misunderstanding the influence of part thickness on handling difficulty. Parts with a thickness greater than 2 mm do not usually present handling difficulties, but students usually assigned this problem to any thin part, even if the thickness was 5 or 8 mm.
- Significant problems in understanding the difficulty of orienting parts that are externally symmetrical and internally asymmetrical.

IOP Conf. Series: Materials Science and Engineering 1193 (2021) 012118 doi:10.1088/1757-899X/1193/1/012118

As mentioned before, the example of a valve proposed in [9] and shown in figure 1 was chosen for the kit. The main assembly problems in this product are: unnecessary parts (screws); gasket (difficult to grasp due to its small thickness and flexibility, and difficult to orientate and align); cover (difficult to orient and align); simultaneous alignment of three parts (housing, gasket and cover), as well as the alignment of the two screws. To overcome these problems, several solutions were proposed: to ease the grasping operation of the gasket by increasing the thickness and reducing the flexibility; to use two locating pins to ease the alignment of the gasket and the cover; to remove parts by replacing the screws with a threaded cover; to ease the threading operation of the cover by providing chamfers; to ease the location of the cover by providing a flat. According to the solutions proposed, five different design alternatives (cases) were developed. To materialise these alternatives, three covers, two gaskets, five housings, in addition to the two screws and the plunger, were necessary. To simplify the number of different components required, all of them were analysed to identify the reconfiguration possibilities. The goal was to modify key features of the components by replacing portions of the same component (modular and reconfigurable kit). This strategy avoids the use of a large number of different components and simplifies the process. In addition, this approach allows students to assimilate the idea of modifying a characteristic of a component, rather than replacing it.

As a result of this analysis, the only component with reconfiguration possibilities was the housing. In particular, only the upper portion of the housing had to be modified to interact with the gasket and the cover in different ways. The housing was divided into two parts: a fixed base including most of the geometry, and an interchangeable insert to obtain different configurations. Three different inserts were designed. Figure 2 shows all the different component variations designed for the kit. Figure 3 shows the different combinations of the components to create 5 alternative design cases altogether.

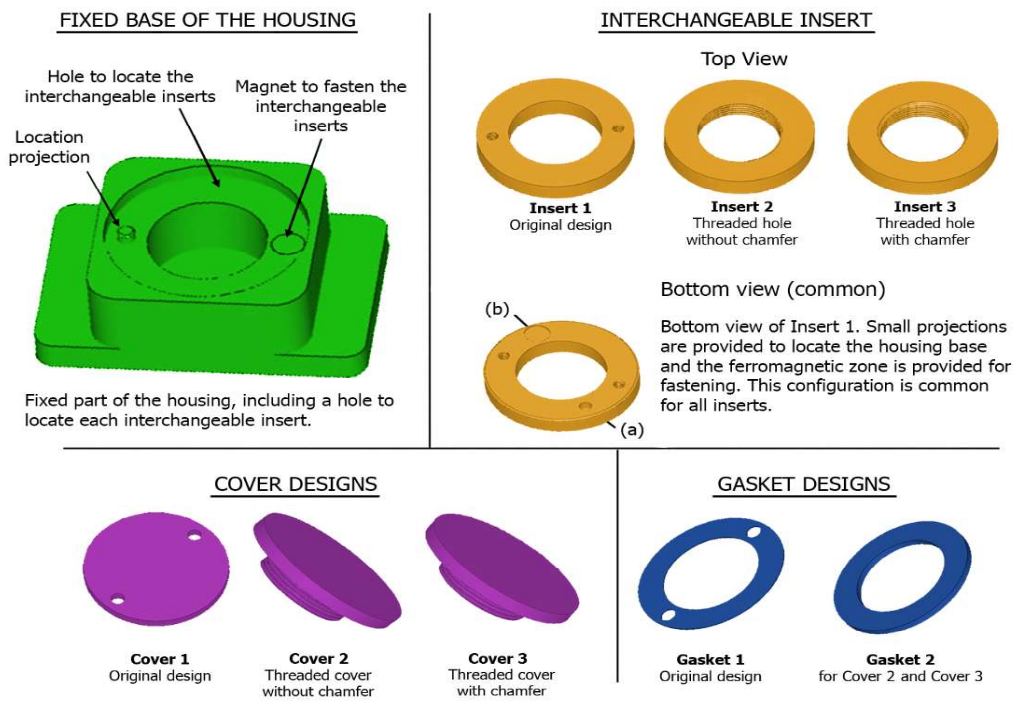


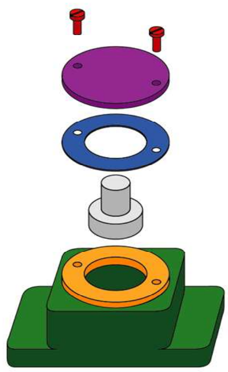
Figure 2. Design of the main components of the kit, showing different variants for eacl component.

Study cases configuration

COMPONENT	CASES				
	Case 1	Case 2	Case 3	Case 4	Case 5
INSERT	I1	I2	I2	I3	I3
COVER	C1	C2	C3	C2	C3
GASKET	G1	G2			
OTHER	Screws	----			
BASE	Fixed base				
PLUNGER	Plunger				

(a)

Example Case 1



(b)

Figure 3. (a) Combinations of elements for the configuration of each of the five possible case studies. **(b)** Example of configuration and assembly sequence for Case 1.

4. Results and discussion

The main outcomes of the work are examined in this section. First, the manufacture of the DFA kit is briefly (section 4.1) described. Second, the results of the practical use of the DFA kit in a seminar session of two different courses are analysed. This analysis is based on students' opinion obtained in a survey (section 4.2).

4.1. DFA modular kit

Once the design of the kit had been fully defined, each component was manufactured with appropriate materials according to its functionality. The fixed base, the inserts and the covers were machined from aluminium. The gaskets were made of rubber. The plunger was manufactured using silicone and phenolformaldehyde resin. The complete kit is shown below (figure 4(a)), as well as the set of parts used for case 1 (figure 4(b) and figure 4(c)).

(a) (b) (c)

Figure 4. (a) Physical elements of the DFA kit. **(b)** Elements of the configuration for Case 1 **(c)** Assembly of Case 1.

4.2. Use of the modular kit and assessment

The new proposed methodology (based on the use of the DFA kit in seminar sessions) has been applied in two UJI courses during the first semester of the academic year 2020/21:

- Design for Manufacturing: Processes and Technologies II (DFM:PT). This is a third-year core course of the Bachelor's Degree in Engineering in Industrial Design and Product Development (DEIDPD). The group in this course is large (140 or 150 students approximately), which results

in large work groups in the seminar sessions (around 25 students). In addition, this subject has a high percentage of repeating students.
- Design for Manufacture and Assembly (DFMA). This is a fourth-year optional course of the Bachelor's Degree in Mechanical Engineering (DME) and it is fully taught in English. The group in this course is usually small, less than 10 students.

To evaluate the impact of the implementation of the new methodology, a survey was designed to be answered by the students. The aim of the survey was to assess the impact on students' academic training, as well as students' experience using the kit. The survey included 12 questions related to the activity carried out in the seminar session. The questions could be answered on a 1 to 5 scale (1: "Totally disagree"; 5: "Totally agree"). The most relevant questions according to the results obtained are listed below:

- Q1 - This activity has helped me to better understand and differentiate what the "handling" and "insertion" operations involve.
- Q2 - This activity has helped me to better understand the influence of a small thickness on part handling.
- Q3 - I consider the activity relevant for my academic training.
- Q4 - The time devoted to this activity is appropriate.
- Q5 - I think it is important to carry out this type of activities for this course and I think it should be repeated in following years.

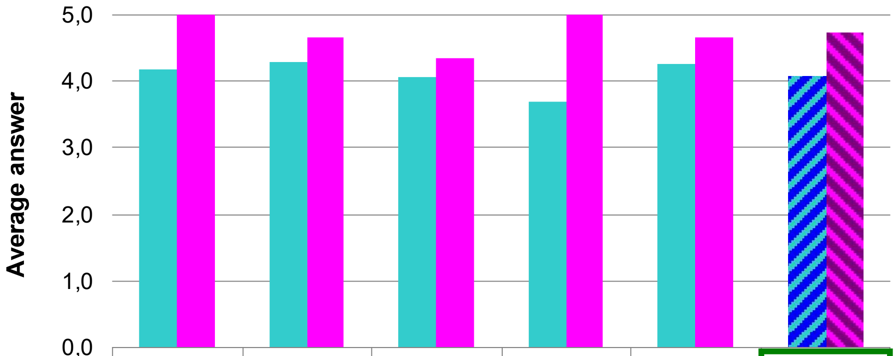
After finishing the DFA seminar session, students were asked to answer the survey voluntarily and anonymously. A total of 60 answered surveys were collected (57 from DFM:PT and 3 from DFMA). The main results of these surveys are shown in figure 5. A clear difference can be observed in the behaviour of the results obtained in each of the courses.

As can be seen in figure 5, the results obtained are clearly higher in the case of DFMA compared to those obtained in DFM:PT, both on average (4.73 versus 4.10 points) and in each of the questions individually. Moreover, the questions with a better and a worse result are different in each case. The reasons for this can be several, such as:

- Age of the students and degree the subject is taught in.
- Previous basic training, both in former degree courses and in high school. It is more common for students of DME than of DEIDPD to have completed a scientific-technical training at high school and more technical courses in the degree.
- Profile of the students. DME students show, in general, a greater interest and ease in learning technical aspects than DEIDPD students.
- Type of subject: core or optional. Students who choose a specific optional subject are more likely to acquire such knowledge.
- Work group size. Very large groups make it difficult for students to participate and interact with available resources, whereas very small groups encourage active participation

For all these reasons, a separate analysis of each course is next presented. Firstly, the results of DFM:PT will be discussed. The results obtained in this course show an average of 4.10 points in the overall survey, which is a satisfactory result. A deeper insight in the different questions shows that one of the aspects valued most negatively is the planning of the session, both regarding the duration and the moment within the course schedule (Q4). This issue is closely linked to two key factors in this course: the high number of work groups and the group size. The number of groups directly affects the scheduling of the seminar sessions. Sometimes, the seminar related to a topic is given one or two weeks after covering this content in the theoretical sessions, which makes it difficult to consolidate these contents.

Large groups and the limited number of DFM kits available makes it difficult for all students to be able to interact with the parts in an appropriate way.



	Q1	Q2	Q3	Q4	Q5	Mean
DFM:PT	4,19	4,30	4,08	3,69	4,26	4,10
DFMA	5,00	4,67	4,33	5,00	4,67	4,73

Figure 5. Comparison of the average answers in each question and for each subjec considered.

Questions Q2 (influence of thickness) and Q5 (importance of activity and repetition in later years) have been the questions best valued by students. These results suggest that the activity has clarified one of the most frequent problems: handling difficulties related to part thickness. Students value the session very positively and they even recommend repeating it in following years. It should be mentioned that a large number of students had not revised the DFA theoretical contents prior to the seminar session, which hindered the development of the session.

Focusing on the results in the DFMA course, the average of the evaluation of all the questions is 4.73 points, a very satisfactory score and higher than the results in DFM:PT. The results obtained in the DFMA survey show that the worst valued question was Q3 (“This activity has been relevant to my training”). This low assessment of Q3 can be influenced by the optional nature of the subject, which can be interpreted as an accessory complement in the global training of DME students. Questions Q1 ("handling” and "insertion" operations) and Q4 (duration and scheduling of the session) were the best rated, with a unanimous maximum score. In contrast to the DFM:PT results, Q4 has achieved a remarkably higher evaluation in the case of the DFMA subject. Once again, the number of work groups and group size have a significant effect on results. In DFMA, with only one very small group, the seminar session could be placed closer to the corresponding theory session, thus resulting in a better schedule and fostering students’ participation.

5. Conclusions

The use of modular kits by students makes possible the physical assessment of the fundamentals of DFA, thus improving the understanding of the problem and the development of solutions. The kits developed to support DFA learning are made of few reconfigurable components. The reconfigurability allows the evaluation of the assembly efficiency of different design solutions by changing some key features of the components instead of replacing the component.

The new methodology using the modular kit had a significant positive impact on the students’ opinion. Students have highly valued the experience of using the physical kit and found it very useful to practice the main DFA concepts. The application of the new methodology and use of the kit has been analysed in two different courses and the results obtained show noticeable differences. Some of the main reasons for this are the number of work groups and the group size. The number of work groups mainly affects the proper scheduling of the sessions. In larger groups, participation and interaction of students with the physical kit is hindered and the user experience is more limited.

As a future line of work, the study will be extended to the analysis of the results in the exam specific DFA questions and the comparison with previous years' results. Additionally, new case studies will be developed to include new configurations in the modular kit. In a longer term, the use of a similar learn by doing approach based on the use of modular kits will also be explored to support learning activities in the field of Geometrical Product Specification.

Acknowledgements
This work is part of the 3574 project funded by the Educational Support Unit of Jaume I University.

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