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Team Work Aptitude Development in the Field of Concurrent Engineering through ICT Tools: Collaborative Engineering*

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This article explains the results of more than three years working in collaborative engineering learning development, at the master's degree level, in the school of industrial engineers of the UNED, distance university of Spain. The fundamental approach is based on the "distance methodology" and "continuous evaluation" of the students' work and periodic reviews. The need for a teamwork aptitude is assumed an implicit requirement and, therefore, there is a specific methodology for the project. The work is supported by data and statistics that show better results than those obtained in other subjects of the same master's where the teamwork option is not applied, or in other master's and degree subjects in the engineering field or other technical areas. The result is success in the response and participation of the students and a new methodology that could be transferred to other subjects that do not have a specific teamwork requirement, but could use this methodology to improve the results.

Keywords: teamwork; collaborative engineering; concurrent engineering; design; design engineering

1. Introduction

Concurrent engineering is an integrative subject in the field of engineering, and therefore it is normally given in the last years of a bachelor's degree or master's degree.

There are multiple definitions for concurrent engineering [1–4], although perhaps the one that best describes the objectives of this work is the one proposed by Espinosa et al. [5]:

> A work philosophy based on information systems and built on the idea of convergence, simultaneity or concurrence of the information contained in the product's whole life cycle with the product's design phase.

The work philosophy can be approached in three different ways depending on the perspective (Fig. 1):

- Perspective of design, where the approach is to merge the information of a product or service with the design phase. In this area, concurrent engineering is usually given the name of "concurrent design".
- Perspective of work planning. Here it is seen that the activities related to a project under a concurrent engineering approach tend towards a parallel structure. For this reason, in this area it is usually called "simultaneous engineering".
- Perspective of communication, which is essential for the project's development. In this area, concurrent engineering fully relies on the information and communication technology (ICT) tools. When working in this area, concurrent engineering is usually given the name of "collaborative engineering" or "collaboration engineering".

New information and communication technologies open up new perspectives in how to approach this subject matter, and these perspectives should not be ignored when trying to address the subject in an educational, cutting-edge way.

2. Presentation

At the end of the Second World War, the Government of Japan reconsidered its production system and aimed to make the "made in Japan" brand a prestigious trademark.

To this end and after the corresponding analysis, their first goal was to improve the quality of the products manufactured in the country's industrial plants. The proposed improvement in quality required heavy use of written documents and here they encountered the first problem: language. Japanese was, and is, very complex, and most of the workers were illiterate.

In order to overcome this difficulty, they organized what then were called "quality circles", in which an operator read documents on quality and the others listened and made comments.

The first steps in this area, following the guidelines of the Government, were taken by the *Japanese Union of Scientists and Engineers* (JUSE), founded

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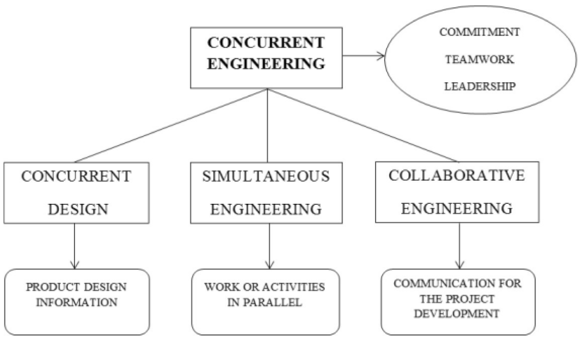

Fig. 1. Development of the concept of concurrent engineering.

in 1946, which organized the *Quality Control Research Group* in 1949 [6–7].

This objective of improving quality resulted in the aforesaid *quality circles*; the philosophy of *continuous improvement of quality* (*Kaizen* is the Japanese word for continuous improvement); the "*just-in-time*" production system, whose bases were developed in Toyota in 1947; the 5S methodology (*Seiri*, *Seiton*, *Seiso*, *Seiketsu* and *Shitsuke*, which translate as: sorting, systematizing, sweeping, sanitizing, self-discipline), which was the starting point of the current *Six Sigma*; process *reengineering*; *total productive maintenance*; and the foundations of what later was called "*robust design*".

It was precisely in the area of robust design where the need for integration between the areas of design and manufacturing arose [8–12]. It soon became obvious that improved communications between these departments could be extrapolated to other areas and that the feedback of information from all a company's departments into the design area could be used as a tool. Thus *concurrent engineering* was born.

With the appearance of *computer-aided design* (CAD), *solid modeling* and *product data management* (PDM/PLM), the work methodology was equipped with computational tools and *concurrent engineering* acquired its current dimensions.

As is known, PDM appeared as a commercial solution in the decade of the eighties and, as to be expected, engineering schools included this technology in the educational content of their different subjects.

In 1994, the engineering school of the UNED began to teach a doctorate course, included in the Construction and Production Engineering doctorate program, which was named precisely: *Concurrent Engineering*.

The research related to this matter led to the first publications [13–14], which include the early results that integrate concurrent engineering into CAD environments.

In 2001, a new Industrial Engineering curriculum was implemented in Spain that lasted for five years (the previous ones were six), and concurrent engineering was included as a major subject in engineering education.

However, when four-year engineering degrees (without specialization) and master's degrees (which replaced the former doctoral courses) were implemented in Spain, the subject was reconfigured.

In bachelor's degree programs, the subject is included in the *Industrial Design* elective, and at the level of master's degree programs, which merge contents of the former second university cycle and those included in the former Diploma of Advanced Studies, the National University of Distance Education in Spain programmed a Master's degree in Design Engineering. This master's includes a series of important subjects in design engineering such as *image* and *solid modeling*, and also *collaborative engineering* as an essential part of *concurrent engineering*, a core requirement of the engineering master's degree.

The first edition of the master's began in the 2009-10 academic year, so at present four editions of the master's degree have already been completed and the fifth is in progress. Table 1 shows the data on students admitted and enrolled in the master's program during these years. These first editions have already provided important data to analyze the students' acquisition of skills, particularly in the field of collaborative engineering.

It is important to note that almost all students combine their studies with professional practice and, therefore, they usually take at least two years to finish the master's degree.

On the other hand, in accordance with current legislation, access to the master's degree is open to students from various degree programs and, for this reason, in addition to industrial engineers among the master's students, we can find graduates of other engineering specialties (mechanical, electrical, telecommunications, topography, civil engineering,

Table 1. Historical of admissions and enrollments in the master's

Edition	Applications	Admissions	New Enrollments	Continuing	Total master's students
2009–10	103	23	21	–	21
2010–11	134	21	20	8	28
2011–12	173	23	21	14	35
2012–13	181	22	20	16	36
2013–14	185	21	18	21	39

etc.), as well as architects and graduates in design, among others.

3. Teaching-learning methodology

When students reach the concurrent engineering subject after having passed other subjects with complex technological contents, they normally have a sound knowledge of traditional engineering. But in this subject, which is obviously based on teamwork, they are found to be lacking in skills because unfortunately they have not previously acquired them, i.e. ''commitment'', ability for ''teamwork'' and ''leadership'':

- When we talk about leadership in collaborative engineering there is no reference to ''foreman'' or ''boss'', as these concepts are fortunately obsolete, but rather to ''coordinator'', ''manager'' of a sports team or ''activator, cheerleader or motivator'' in a working group. This role is currently known as ''coach''.
- When we talk about teamwork, concepts like ''shared decision-making'', ''respect for people'', ''work-sharing'' or ''delegation'' arise. It is not a matter of one person doing everything and the others merely looking on. Nor is there a strict division of work such that each person does only one part and the others know nothing about the project other than their own little area. Teamwork involves active communication between members in such a way that everyone actively does their part [15], but with knowledge and participation in the work by the other members of the group, as if it was a complex puzzle [16].Students make the connection between effective teamwork and essential design activities like open mindedness, collaboration, and innovation [17].
- The aim of commitment is for the engineer to accept and carry out the assigned tasks, to try not to change the rules in the middle of project execution, to not give up at the least little problem or when not in agreement with the team's proposals, etc. It is a matter of undertaking the project with the aim of reaching the end.

None of these skills, which are so necessary in an engineer, are rigorously developed in preceding subjects. They are considered as inherent traits, like creativity [18], and are at the root of many of the difficulties involved in the development of industrial projects. In the field of concurrent engineering, these qualities play a relevant role since the aim of the subject itself is not to solve a specific problem of design, but rather to acquire a methodology and a set of useful skills to tackle any design problem that may arise—a methodology that relies precisely on *commitment*, *teamwork* and *leadership*.

Concurrent engineering as a subject has a series of special connotations in a university like the UNED, where education is distance-based. In this university, the students acquire their knowledge and skills at home and communicate with their tutors or peers by any available method other than the traditional ones. Therefore, the student must use Internet as a fundamental learning tool and electronic mail as a fundamental tool of communication (ICT tools).

In other subjects, the student can study alone, supported only by his/her efforts and communication with the tutor. However, in this subject the student must necessarily communicate with peers and so must rely on social networks, video conferencing and as many possibilities as currently offered by the world of communication [19]. Students must share files and working documents, a reason why they should develop special skills to take advantage of the possibilities of the Internet and ''cloud'' computing to do the exercises assigned to them.

There are not many universities in the world that, like the UNED, have to deal with the problem of having students scattered all over the globe; and who have to work as a team. For example, a group of four students where one is an architect and is in Buenos Aires, another is an industrial designer and lives in Frankfurt, a third is a civil engineer and is in Santa Cruz de Tenerife and the last one is an industrial engineer and lives in Madrid.

Tables 2 and 3 show the worldwide and Spanish distribution of UNED's students, respectively.

3.1 Practical exercises

Concurrent engineering is a practical subject, and it involves a series of exercises of increasing complexity that the students must complete to acquire the required skills. The competencies identified in the subject are shown in Table 4, and the exercises proposed for this subject are:

- E1. Brainstorming for alternatives in product design
- E2. Value analysis exercises
- E3. Cost analysis
- E4. Ergonomic analysis
- E5. Manufacturability analysis
- E6. Environmental studies
- E7. Analysis of synergies
- E8. Manufacture of prototypes
- E9. Studies of the product's lifecycle
- E10. Improvements in design
- E11. Obsolescence and recyclability studies

In this field, dimensioning [20], and the use of rapid prototyping as design [21] are effective methodologies to help students to obtain effective results in their engineering projects.

Table 2. Worldwide UNED'S students distribution

Country	Degrees	Bachelors	Postgraduates	Total
Argentina	110	29	47	186
Belgium	311	70	49	430
Brazil	34	16	9	59
Equatorial Guinea	357	141	1	499
France	268	50	19	337
Germany	464	143	47	654
Italy	60	16	15	91
Mexico	74	18	33	125
Peru	102	27	43	172
Spain	151,909	42,534	6,974	201,417
Switzerland	154	42	6	202
UnitedKingdom	555	152	33	740
USA	99	22	37	158
Venezuela	75	27	63	165
TOTAL	154,572	43,287	7,376	205,235

Table 3. Spanish UNED'S students distribution

Community	Degrees	Bachelors	Postgraduates	Total
Andalucía	23,165	6,643	848	30,656
Aragón	5,205	1,407	252	6,864
Asturias	3,292	896	192	4,380
Baleares	4,102	1,222	126	5,450
Canarias	8,268	1,800	298	10,366
Cantabria	2,316	611	119	3,046
Castilla La Mancha	7,788	1,969	351	10,108
Castilla y León	7,383	2,627	447	10,457
Cataluña	11,951	3,027	448	15,426
Ceuta	590	259	25	874
Comunidad de Madrid	35,020	10,836	1,996	47,852
Comunidad Valenciana	14,181	3,317	443	17,941
Extremadura	3,355	1,158	221	4,734
Galicia	10,146	3,004	398	13,548
La Rioja	1,036	281	60	1,377
Melilla	539	213	33	785
Murcia	4,484	1,111	188	5,783
Navarra	3,752	925	168	4,845
País Vasco	5,336	1,228	361	6,925
TOTAL	151,909	42,534	6,974	201,417

Table 4. Competencies involved in the concurrent engineering subject

Relating to knowledge:
- Knowledge of design management techniques. Dialogue between designers and business strategy.
- Computer-aided engineering. Visualization tools. Documentation generation tools.
- Multimedia tools. Strategic communication of the product.
- Expertise in product data management.

Relating to skills and attitudes:
- Design and corporate communication. Adaptation of graphic styles to the product and market.
- Ability to prepare product design strategies.
- Capability to perform assessments and validations of the design.
- Ability to elaborate a product design and development project.
- Process management techniques. Speeding up conception, production and release times.
- User-centered design. Technical analysis of new demands. Understanding of lifestyles.
- ICT applications. Advanced technologies for the design of new products.
- Ability to develop projects with concurrence of technologies.
- Product engineering methodology. Information management and decision-making.

There are simple projects that students must accomplish alone; there are also more ambitious projects that need to be dealt with in groups of two or three; and finally there are complex projects, which should be executed by multidisciplinary teams with four or five members.

The methodology has been developed based on the difficulty for the student. The specific strategies for each exercise are introduced and the different alternatives available in each case are analyzed.

Table 5 shows a list of exercises assigned throughout the course; the number of students who form the team in each exercise; the relative degree of difficulty of each exercise; as well as the results obtained in

Table 5. List of exercises, level of participation and quality of the results

Exercise	Number of students	Difficulty of the exercise (1–5)	Level of participation (1–5)	Quality of the results (1–5)
E1	4–5	1	5	5
E2	2–3	4	5	4
E3	2–3	3	4	3
E4	1	3	3	3
E5	4–5	4	4	4
E6	2–3	3	4	3
E7	4–5	2	4	5
E8	2	3	3	3
E9	4–5	5	5	5
E10	4–5	5	5	5
E11	1	3	3	3

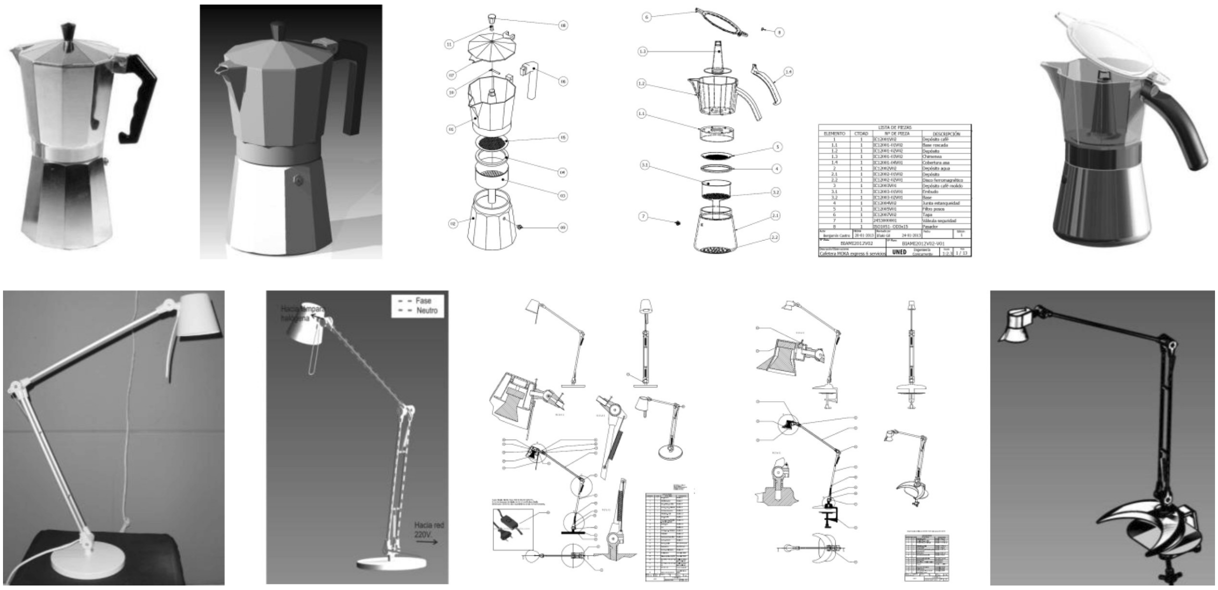

Fig. 2. Design improvement phases.

terms of level of participation and quality of the results.

We can see that, as a rule, the average quality of the results obtained is directly proportional to the number of group members and does not depend on the level of difficulty. In terms of the degree of involvement, we also find a proportional relationship to the number of group members, but here we find a certain dependence on the level of difficulty of the proposed exercise.

As a representative example, Fig. 2 shows the results obtained by the students in a design improvement exercise. Here we can see the phases of development:

(a) Commercial product
(b) Modeling the commercial product
(c) Detailed drawings
(d) Improved design drawings
(e) Photorealistic image of the improved design

3.2 Available technologies

Of course, when taking this subject, the new technologies serve as a good support for the students. Fig. 3 shows a screen display of the *Alf* platform that the UNED makes available to its students, where they can find the basic course documentation, guidelines and exercises, as well as collaboration forums where they can do part of their work.

As for documents, students also have access to online documentation, such as that posted on the *production systems* web (Fig. 4), or recommended books [22–23].These can help students to complete their own professional library in design engineering, which in itself is one of the objectives pursued by the master's course.

3.3 Indicators

The set of indicators that will later enable the analysis and conclusions are:

Dropout rate. Number of students who, having registered, cancel the enrollment or do not attend the exams.

Recovery rate. Number of students who, having dropped out, take up the subject again.

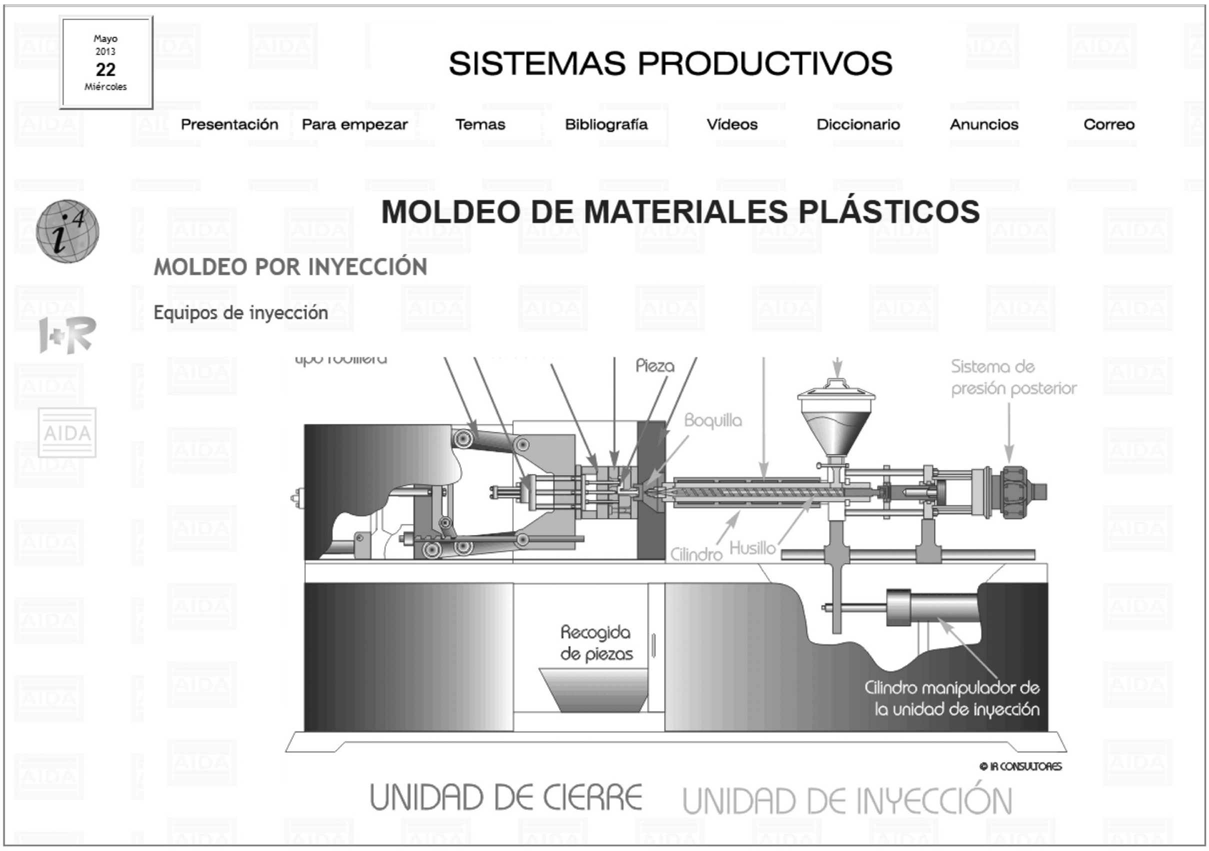

Fig. 3. Web of production systems.

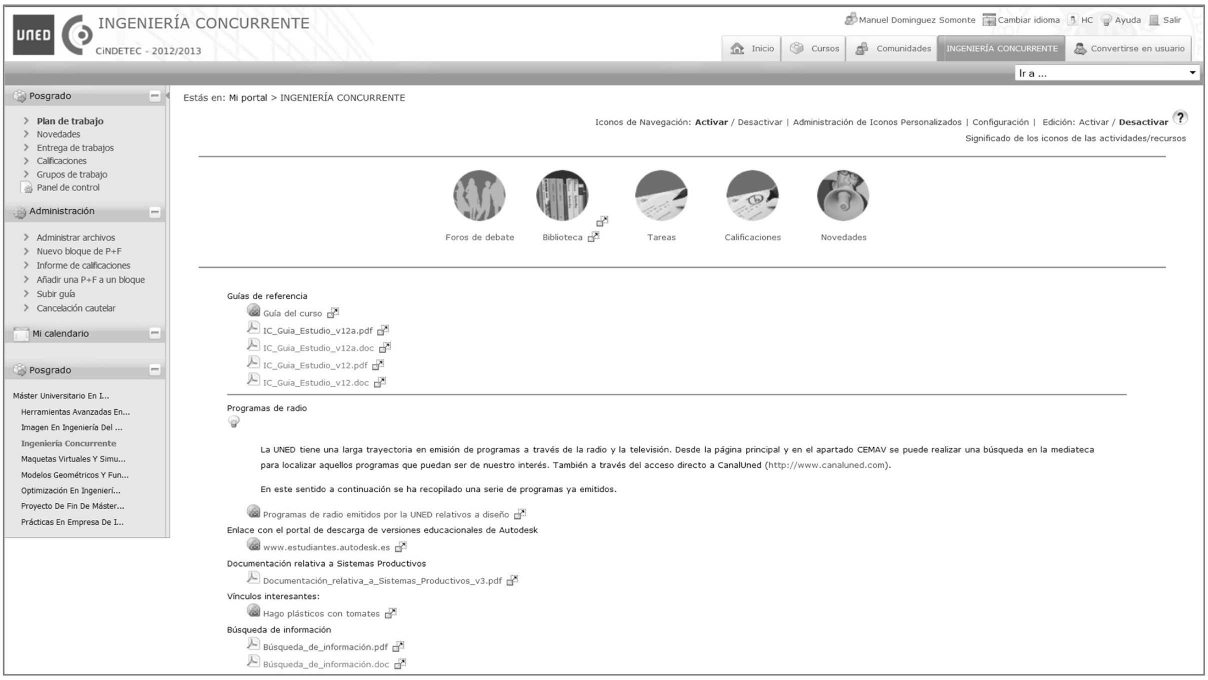

Fig. 4. *Alf* platform.

Success rate. Number of students who pass the exams. This is measured in percent versus those who take the exams (those who have not dropped out).

4. Main results

As indicated above, there are data on the first four editions of the master's which have been completed and on the current edition which ends in September. These data on the indicators mentioned above, which serve as a basis for the analysis, are included in Table 6.

From this table we can see that the number of students who drop out of the studies is high, but it is not as high as the normal dropout rate for undergraduate studies at the UNED.

We can also see that the success rate is high and comparable to any face-to-face University, and quite a bit higher than the average rate of the UNED degree programs.

It should be noted that the results listed here have been obtained from statistics provided by the University and from the tests and surveys carried out by the master's Coordination Commission, as well as from the contributions of different professors or the specific comments made by students throughout the different courses.

4.1 Comparison with related subjects

The comparison with alternative teaching methodologies is not easy because there are not many published data on results in the face-to-face field in which collaborative engineering is not yet fully developed.

In terms of the distance option, correlated with the subjects that have paved the way to the current situation, there are the subject of *concurrent engineering*, included in the teaching period of the doctoral program, and the subject of the same name included in the 5th year of Industrial Engineering studies.

Table 7 shows the data used for the comparison. It lists the three subjects and indicates the duration (year or semester) of each one. It also includes the number of credits for each course, as well as the average number of students annually enrolled in each subject.

The data in the table are based on the average number of students enrolled per year, which enables us to obtain these findings even though the number of students each year has been very low.

We can see that when the option of teamwork is not considered, the recovery rate of students who drop out is very low. On the other hand, although the rate of success compared to students who attended the exams is similar in the three alternatives, when combined with the success rate versus the enrolled students, there is a big difference between the subject methodology proposed in this article versus the traditional approach.

As for the comparison of results with those obtained in other subjects of the same master's program or in courses of other master's degrees included in the school of industrial engineering programs, the values are quite similar to those previously obtained as commented below (Table 8).

As we can see, the success rate over students who attended exams is better, but if we also consider the recovery rate of students, the final success of the students enrolled in the course is much more significant.

Table 6. Enrolled students and success in concurrent engineering

Concurrent Engineering	Enrolled	Early dropout	Early dropout (%)	Recovery	Recovery (%)	Final dropout	Final dropout (%)	Success	Success (%)
2009–10	18	10	55,56	3	30.00	7	38.89	8	72.73
2010–11	21	11	52.38	4	36.36	7	33.33	13	92.86
2011–12	24	11	45.83	6	54.55	5	20.83	18	94.74
2012–13	20	8	40.00	4	50.00	4	20.00	15	93.75
2013–14	18	7	38.89						

Table 7. Comparison of results with related subjects

Subject	Duration	Credits	Enrollments	Early dropout (%)	Recovery (%)	Final dropout (%)	Success over attendance (%)	Success over Enrollments (%)
Concurrent Engineering *Doctorate*	annual	5	2	60	5	57	93	39.2
Concurrent Engineering *5th year Industrial Eng.*	sem.	5	10	55	8	52	88	41.6
Concurrent Engineering *Design Engineering Master's*	annual	10	20	40	45	25	91	68.5

Table 8. Comparison of results with other master's subjects

Subject	Duration	Credits	Enrolled	Early dropout (%)	Recovery (%)	Final dropout (%)	Success over attendance (%)	Success over Enrollments (%)
Concurrent Engineering Master of Design Engineering	annual	10	20	40	45	25	91	68.5
Other subjects Master' of Design Engineering	annual	10	20	40	11	35	85	38.1
Other subjects in other Eng. Masters	sem.	5	40	40	8	33	80	32.9

4.2 Benefits of the approach

The starting points for the analysis proposed in this article include:

- A master's degree subject that receives very heterogeneous students e.g. industrial engineers, architects, civil engineers, aeronautical engineers, surveyors, etc.
- Students of very different ages, ranging from 24 or 25 to 50 or 55 years old.
- High degree of equality between males and females, although this has never been proposed as an objective.
- Students who usually must combine studies with professional work. It is a fact that, when a company requires an additional effort, one of the first choices of the student is to abandon the master's program.
- A distance methodology which requires a significantly different mode of work-study for the students.

With this approach, and thanks to the programming methodology, the following results are achieved:

- When the group is formed in an autonomous way, it works better than when the group is created by tutors, that is, the teams work better if the students organize themselves. Here the "commitment" variable becomes an important value.
- Contrary to what one might think, the groups were not formed by similarity of qualifications but, rather cleverly, the students themselves tended to form multidisciplinary groups. When forming the groups, there seems to be no distinction by age or sex.
- The work teams absorb the external workloads of students and cover for each other, trying to prevent the tutors from finding out. When working in a group, the possibility of abandonment is significantly reduced. The group retains the students.
- Just as there is a natural tendency to help colleagues in trouble, there is also a tendency to shun students who for no obvious reason do not work hard enough and try to take advantage of the work of others.
- Papers presented by a group are usually of a higher quality. They are more rigorously developed and the presentation tends to be better. This is probably because, when there are more people reviewing a job, detection is better and the details are improved appreciably.
- Even when, for reasons of methodology, the leadership of the group has to be rotated, no difference is detected in the results of the work.
- However, it is obvious that some students have more sway over the group than others, regardless of whether or not they are the group coordinators. No doubt they are natural team leaders.
- Students who acquire a commitment to an exercise usually finish the exercise even when they know that they will leave the master's program for external reasons. Few students drop out when the teamwork has begun.
- Students with qualifications previously considered as similar (industrial or mechanical) are not found to be more successful than students with other degrees considered as dissimilar (surveyors, civil engineers, agronomists, etc.).
- Abandonment is directly proportional to the pressure of professional practice. There were not many dropouts due to differences between the group members or other causes. There was zero abandonment of students in a situation of infra-employment or unemployment. Abandonment was detected when students changed jobs and took on a new job that required more time than expected.

It is important to note that the success of the methodology depends on two basic elements: on one hand the students assume that teamwork is positive, as they understand that it is the normal way to work in industrial environments, and on the other hand working together reduces the student dropout rate.

At the beginning of the course, some students show some reluctance towards teamwork, since their inertia as recent undergraduate students and their interest in controlling all the barriers they must overcome in the subject make them think that teamwork will be an additional difficulty. However, this initial difficulty soon turns into an incentive when they discover that the teamwork results are better than those obtained on working alone.

In fact, it is interesting to hear the comments of the students when, for some exercises at the end of the course they are again required to work alone, they argue that they have teams that are performing very well and would like to keep that methodology as far as possible.

5. Discussion

This paper shows the results obtained in a subject given in a master's degree program in which, due to the requirements of the subject matter, it is necessary that students work in a group.

As the University in question is a distance university in which ICT tools are essential, teamwork must necessarily be developed through telematic media, and consequently collaborative engineering skills are developed in an equally valuable way.

The skill of teamwork through collaborative engineering is very valuable for practicing engineering. However, in addition to enhancing that ability for *teamwork*, the proposed methodology has also succeeded in enhancing the skills of *leadership* and *commitment*.

Finally, it was noted that with the methodologies used, as well as promoting teamwork through collaborative engineering, the final results in terms of student success are better than those obtained in other subjects of the master's program or in other master's programs in the field of engineering.

6. Future issues

After four years of experience in teamwork in the subject of concurrent engineering, the teaching staffs of the Design Engineering Master's program are considering the implementation of this methodology in other subjects, e.g. *Virtual models and simulation* and *Image*, because, although teamwork is not an intrinsic competence in these subjects, it is being demonstrated that academic performance improves with teamwork and that it also prepares students for professional practice in a manner very similar to what awaits them in their future professional careers.

7. Conclusions

This paper presents the results related to the need for *collaborative engineering* in developing of the training exercises of the *concurrent engineering* subject in the Design Engineering Master's program of the UNED, where integration of the teamwork, commitment and leadership skills is considered as a fundamental requirement.

The application of concurrent engineering to industrial design tends to require a lot of information, obtained from very different sources, that is capable of boggling the most privileged mind. Thus it is necessary, and essential, to use ICT tools.

The subject stresses the importance that everyone directly or indirectly related to the product be responsible, to the appropriate extent, for the design, from marketing to customer service.

However, for this purpose, classic product development procedures must be reconsidered and adapted to the current technology—information technology—which necessarily involves *concurrent engineering*.

The success of the data shown in the results section is due to the subject methodology and approach, the contents of which require teamwork.

It is important to note that, at times, it seems that students forget that they are studying for a master's degree and rather it seems that they are working for their own company. Curiously, students approach the exercises as a game or a challenge, and they perform better

The results obtained with these methodologies, essential for this subject where teamwork is a requirement, can be transferred to other subjects, because it is clear that good results are obtained. This means that other subjects that are based on individual work, because the subject does not require another work method, would probably yield better results if they used methodologies based on teamwork.

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