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Solving the Problem of Interpreting Views: Teaching the Part Visualization Process*

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Part visualization is a fundamental skill in engineering. It comprises the reading, interpretation and creation of industrial technical drawings, interpreting the different views of a part represented in them. However, engineering students show certain learning difficulties and a high failure rate in subjects such as Technical Drawing and Industrial Design. This paper presents a proposal to provide a learning method in this specific knowledge. In order to solve visualization problems in any kind of industrial part, comprehension indicators have been defined analizing the student's difficulties, the expert's knowledge and literature review. The main lack founded in the traditional teaching method has been the inexistence of a systematic resolution process and not taking into account the factor of spatial visualization in learning. An activity programme has been developed to assimilate the process which puts these comprehension indicators to work together. With the help of dynamic images as well as physical models the visual factor was considered. The programme proposes specific tasks which work through the theoretical contents and procedures involved in part visualization as well as taking into account the students' main difficulties and deficiencies when faced with this kind of problem. After testing the method in the classroom, the results which have been obtained from experimental and control groups have been contrasted, showing a higher improvement in the experimental group. The main conclusion is that it is necessary to work with the student on the process of solving visualization problems, teaching the specific strategies and forms of reasoning which are associated with part visualization, in a continuous feedback.

Keywords: part visualization; teaching strategy; problem solving process

1. Introduction

The ability to mentally visualize and manipulate objects and situations constitutes an essential need in many engineering-related jobs. It is estimated that nowadays, at least 84 careers consider spatial visualization as a fundamental need [1], and in some technical jobs, the ability to visualize has acquired an outstanding importance [2].

'*Visual science is defined as the study of the processes that produce images in the mind*' [3]. The spatial visualization and the visualizations of parts are part of this science. In this study the subject of study is the visualizations of parts, in the multiview projections system, in other words, the interpretation of views of an object represented by its technical drawing.

In the different subjects studied by future Engineers, some difficulties can be observed in the visualization of parts and the development of spatial capacities throughout the course [4]. Educators have often noticed the difficulties of most students in graphic courses when trying to visualize an object using multiview drawings. This is mainly due to the inexistence of a systematic process to analyze complex forms [5]. A review of the literature of technical drawing textbooks has not been successful in finding a clear, concise, and developed method of solving part visualization problems using procedural contents. For example, some books try to help in the improvement of this skill, leaving in the hands of the student the way to resolve the visualization problem, and centre in the development of the spatial capacity. But part visualization has its particular ways of reasoning and they should be developed.

As there is no systematic resolution process, the students confirm not having a problem-solving strategy, and they use the trial-and-error strategy or they rely on intuition [6]. The notion that the knowledge of the professor can be transmitted in its final stages (by stating a problem and showing the solution) is not the best way to help the students' learning process. Teaching scientific knowledge in the final stages in an organized manner does not prevent failure in learning concepts and problem solving [7].

When students reason, different aspects of interrelated knowledge are put to work. A set of general abilities is used and applied to concepts of a subject, creating particular ways of reasoning in that subject. Therefore, the didactic study affirms that, besides the theoretical and conceptual knowledge, content such as procedural knowledge must be considered in teaching [8].

We also find students that have not developed

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their spatial capacity enough and therefore have serious difficulties understanding and manipulating the parts in space. Educators often forget the factor of spatial visualization in learning [9]. A review of most of the text books in the subject show that little is done to improve the development of the spatial capacity. The engineering textbooks often present orthogonal views, static concepts, theories and ideas with little or no explanation, and no interpretation of spatial data. It is assumed that the student will be able to overcome the mental challenge, assembling the spatial puzzle. The part visualization, a fundamental skill in the engineering career, needs the spatial visualization, so this skill must also be borne in mind.

So, there is a learning problem in an important subject that the teacher should try to solve in order to offer the students a better way of learning this knowledge. The goal of this study is to provide a learning method for the visualization of parts which improve the present way of teaching. This study proposes a problem-solving model that we have adapted to the case of part visualization, integrating resolution structure, concepts, procedures and different types of reasoning specific to visualization of parts.

2. Methodology for part visualization problem solving, comprehension indicators and activity program

When planning the teaching of specific content and deciding the design of the learning process through an activity program, it is necessary to define certain aspects. Among these, the intended objectives and the contents, keeping in mind the possible difficulties that can arise in the assimilation of the content by learners.

In a previous study [4, 10] which interviewed and recorded a group of students in order to analyse the resolution process they followed for three different visualization problems, difficulties that the student may find during the learning process were identified. The most important difficulties and deficiencies founded were:

- Lack of knowledge and flaws in the application of projective invariants where studying the part projections.
- Difficulties in relating spatial reality and its representation in the plane, both in perspective and in the multiple view representation.
- Difficulties with plane type identification during the analysis of views.
- Difficulties corresponding projections between views.
- Difficulties in the assessment and use of different resolution methods and strategies.
- Deficiencies in tracing the perspective, not using reference elements or a suitable sketching sequence.

On the other hand, a group of lecturers for this subject were interviewed and asked to define the concept and procedure contents required for visualization and to solve several visualization problems, explaining the reasoning used in their deduction process. Finally, we looked at Graphic Expression textbooks and published research papers in the area, through bibliographical review and analysis of their contents which are relevant to visualization.

These multiple analysis help in the definition of comprehension indicators for part visualization. The activity program can be designed so that the students could work all the indicators needed for part visualization and help them to overcome the difficulties that they might find in the learning process.

2.1 Comprehension indicators of part visualization

In order to solve the visualization problems in any kind of industrial object, the following comprehension indicators had been defined. The first eight indicators basically correspond to conceptual knowledge and the last two indicators, while containing conceptual skills, correspond essentially to procedural knowledge.

2.1.1 Fundamentals of representation systems

These fundamentals consist of a sound knowledge of the basics of the main representation system of the orthogonal cylindrical projection (multi-view), including standardization, and how projections are created (from 3D to 2D) as well as the reason for visible and hidden lines. Another important aspect is achieving a sound knowledge of the basics and main features of the axonometric perspective and oblique projections (3D). To visualize the part in space (3D) it is necessary to proceed in reverse to what has been done to create the views (2D). There should be a good knowledge of the relationship between the systems of representation

2.1.2 Rules of orthographic projection

The rules derived from the type of projection (parallel projection/cylindrical and orthogonal) must be mastered. These are:

1. The projections of a point will be aligned in different views.
2. The dimension between two points (x, y, z) will be the same from different views.
3. Parallel lines in the different views will remain always parallel.
4. The form of flat surfaces remains equal in

different views unless it is seen as a line. In this case, the surface (plane) is parallel to the visual.

5. Two continuous areas separated by a line cannot be on the same plane.
6. The dimension of a feature is in a true scale when it is perpendicular to the visual projection. When it is not perpendicular, it will be smaller than true scale [11].

2.1.3 Types of planes and characteristics of its projections

There must be a sound knowledge of the different types of planes (3D) according to their relationship with the projection (parallel, perpendicular and oblique) as well as the characteristics of their projections (2D).

2.1.4 Types of solid primitives and characteristics of its projections

It is necessary to be very well acquainted with the various geometric main elements (3D) and the characteristics of their projections (2D) both when they are solids or surfaces (prism, cube, piramide, cylinder, cone, sphere, geometries of revolution).

2.1.5 Tangency and intersection between surfaces

This means mastering the tangency between surfaces (3D) and their representation (2D) (lines of contact, finite line) as well as the various intersections between surfaces (3D) and their representation in the most basic areas (plane, cylinder, cone, sphere).

2.1.6 Fundamentals of vacuum (negative geometries)

This involves having a sound knowledge of the existence of vaccum and its relationship with the material (3D), as well as knowing how to represent the existing vaccum in the projections (2D) (hidden lines)

2.1.7 Fundamentals of cuts and different types of cutting planes

These fundamentals consist of a good knowledge of the basics of cuts (3D) and their representation (2D), as well as the different types of cutting planes (normal, staggered, rotated, ½view ½cut)

2.1.8 Fundamentals of the industry's most characteristic features

This means mastering the most common industrial elements of industrial parts (3D), their characteristics and how to represent them (2D) (all kinds of holes, nerves, rounding off, chamfers . . .)

2.1.9 Fundamentals of sketches

These fundamentals involve the process of creating sketches (3D and 2D) keeping the viewpoint, the proportions and the parallels.

2.1.10 Resolution process and strategies for part visualization problem solving

In Fig. 1 you can see the scheme for 'part visualization problem solving'. This involves learning to analyze the data of departure, the type of data,

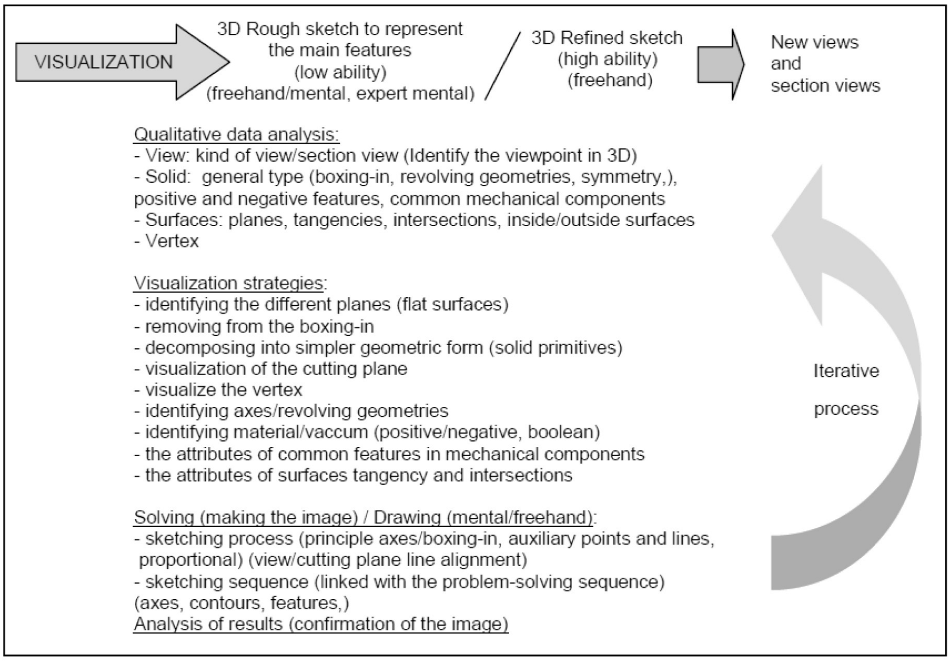


Fig. 1. Scheme of the resolution process proposed for 'part visualization problem solving'.

and knowing how to interpret the obtained information to classify the types of parts (solids, surfaces, vertices, features, outside/inside, intersections). This analysis will allow lead to a solution to the problem solving strategy. This means choosing the most appropriate solving strategy (specific) according to the analyzed data. It also involves knowing how to validate and raise different hypotheses to solve the visualization of the various elements making up the part:

- Elimination of volumes (removing from the boxing-in).
- Decomposing into simple geometric elements.
- Identifying similar shapes (recommended for parts of flat surfaces).
- Identifying the vertex and joining them with the base.
- Identifying the geometries of revolution through circles (centres) and axes.
- Differentiating between solid geometry (positive geometry) and vaccum (negative geometry).
- Interpreting the information derived from the most typical Industrial elements.
- Using the cutting (data) as a reference in the sketch.

In order to solve a part, an iterative process must be followed to solve all the elements of the part in a logical sequence, drawing a sketch and checking its concordance with the data. In an iterative process, all the elements of the object must be solved. Once the whole part is obtained, new views and cutting views can be created using the same method (analyzing the new viewpoint/cut viewpoint and then, solving element by element).

2.2 *Program of activities*

A teaching method has been developed which deals with students learning difficulties, working with the student on the process of solving visualization problems, or in other words, teaching the specific strategies and forms of reasoning which are associated with part visualization. This perspective also affects the curriculum, which was not conceived as a collection of knowledge and skills to introduce in the classroom, but as an activity programme to teach the students the appropriate knowledge and skills. In this case, the theoretic and procedure contents have been integrated into a single construction process by means of problem solving.

As progress is made in the teaching unit and in order to assimilate the knowledge, the corresponding activities marked by the program must be carried out. The degree of difficulty of each activity is directly related to the step to be accomplished in the didactic unit. Different activities have been drawn up which gradually introduce problematic visualization exercises, focusing on different objectives and taking into account the deficiencies or difficulties found, the conceptual contents to be applied or the procedures that students must learn. Specific activities have been proposed in order to work on concrete indicators. On one hand the difficulties increase when increasing the numbers of comprehension indicators that should be dominated in order to solve the part, and on the other hand the level of spatial visualization required.

In Table 1 you will find the defined steps to carry out the activity program. On the second column you will find the specific indicators to work on each step. However on the third column there are other indicators that also take part on each step (these indicators are always necessary on a simple basic level). On the fourth column you can see the dimensions in which the student has to work. So each step of the activity program tells you the level of spatial visualization needed (the level of spatial visualization is higher when you have to draw the sketch in 3D from the 2D views, than when you have to draw the 2D views from the 3D sketch). On the fifth column you can see the highlights of the activities to be carried out on each step (some of which are on Figs. 2, 3, 4 and 5)

The programming has been developed in a flexible way, taking into account curriculum contents and corresponding group requirements depending on the learning development level and on the degree of assimilation of the contents. For this reason, an assessment has been followed, so the lecturer knows his students deficiencies and he can develop the appropriate support for students to continue making progress in the constructive process. At the same time, assessment situations must help the students regarding the knowledge and normalization of their own progress, helping them to understand their own progress and difficulties. Therefore, it provides continuous feedback both for lecturers, to modify and readapt the scheduled teaching activities, and for the students to work harder on the areas where difficulties have been detected. The number of problems to solve in each step will depend on the degree of deficiencies or difficulties which the students encounter and the student's degree of assimilation of the knowledge implicated in part visualization.

2.3 *Computer Tools helping the comprehension of the spatial reality and the resolution process*

In all this process, the 'Spatial Visualization', which can be defined as the skill to manipulate images mentally, is an essential capacity when trying to solve a visualization problem. This teaching unit makes a specific effort to attain the necessary level of this skill.

Table 1

Steps	Indicator to work	Carry out indicators	Dimensions	Types of activity
1	1 Spatial visualization	1, 4, 9 Spatial visualization	2D and 3D From 3D to 2D	Identifying elements from 3D views (points, lines, surfaces, . . .). Identifying points of view (multiple choice quick exercises). Creating projections from 3D views. Drawing simple sketches of easy parts (mirror exercises). Working the spatial visualization (visualization test) [12].
2	2 and 3	1, 2, 3, 4, 9 Spatial visualization	2D and 3D From 3D to 2D	Exercises to work the Plane types and the identification of planes. Box-plane intersections in axonometric and their projections (Fig. 2).
3	10 (correspondence)	1, 2, 3, 4, 9, 10 Spatial visualization	From 2D to 3D	Working on the resolution process with parts with flat faces (Fig. 3). Filling in the given sketch and views with missing lines of parts with flat faces.
4	4,5 and 10	1, 2, 4, 5, 9, 10 Spatial visualization	From 2D to 3D	Working the resolution process of pieces with simple geometric elements. Drawing sketches of parts with curved elements.
5	6,7 and 10 Spatial visualization	1, 2, 3, 4, 5, 6, 7, 9, 10 Spatial visualization	From 2D to 3D From 2D to 2D	Solving of parts with simple vacuums, drilling exercises (Fig. 5). Solving of cutting exercises with new views/cuts. Spatial visualization (cutting) fast exercises (multiple choice).
6	5 and 10	1, 2, 3, 4, 5, 6, 7, 9, 10 Spatial visualization	From 2D to 3D From 2D to 2D	Solving of parts with characteristic intersections with new views/cuts. Working the spatial visualization high level (cutting V T) [13] .
7	8 and 10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10 Spatial visualization	From 2D to 3D From 2D to 2D	Solving of parts with industrial characteristics elements with new views/cuts.
8	10 Spatial visualization	1, 2, 3, 4, 5, 6, 7, 8, 9, 10 Spatial visualization	From 2D to 3D From 2D to 2D	High level exercises (exam exercises) (Fig. 4). Working the spatial visualization (visualization test) [12].

Giving 3 points the box must be cut by the plane that they define. They should draw the projections of the cut box. Box-plane intersection exercise is helped with CAD, physic models and views

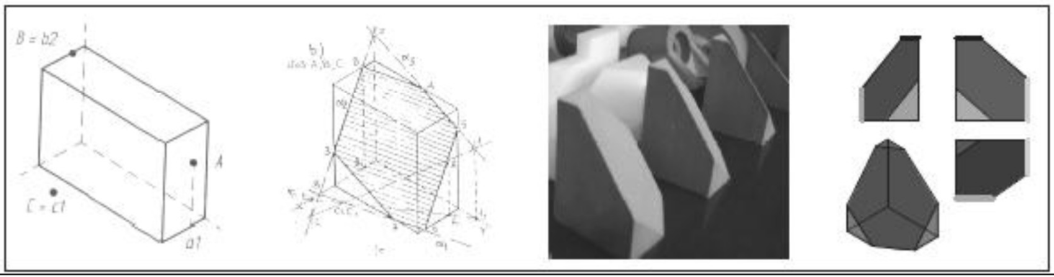


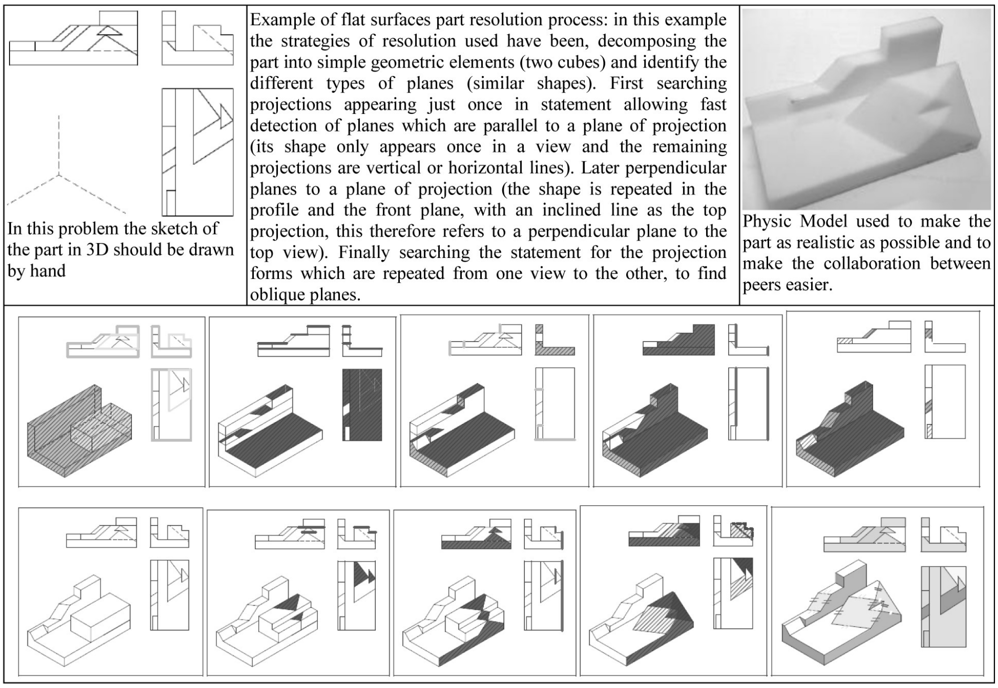
Fig. 2. Box-plane intersection exercise.

Computer tools offer a variety of complementary tools that are very helpful in the teaching/learning of every subject, including the visualization of parts. The apparition of new working tools had enabled the interaction with objects through a virtual world lowering the difficulties of comprehension between the spatial reality of a part and its representation on the technical drawing. As Lellan affirms [14], virtual reality is a cognitive tool that permits the immediate dynamic interaction, making it possible for the student to comprehend the engineering concepts that are spatially dependent. According to Potter [15] the students with a deficient development of spatial capacity, need to learn, by using static, dynamic and transformational images, as well as their combined use in problem solving.

The tools used in this Visualization Didactic Unit are the following:

2.3.1 Slide animation

By using a computer (PC) with a screen output connected to a projector we can easily modify slides and go up and down in the solving process. These slides can also have attached photos and

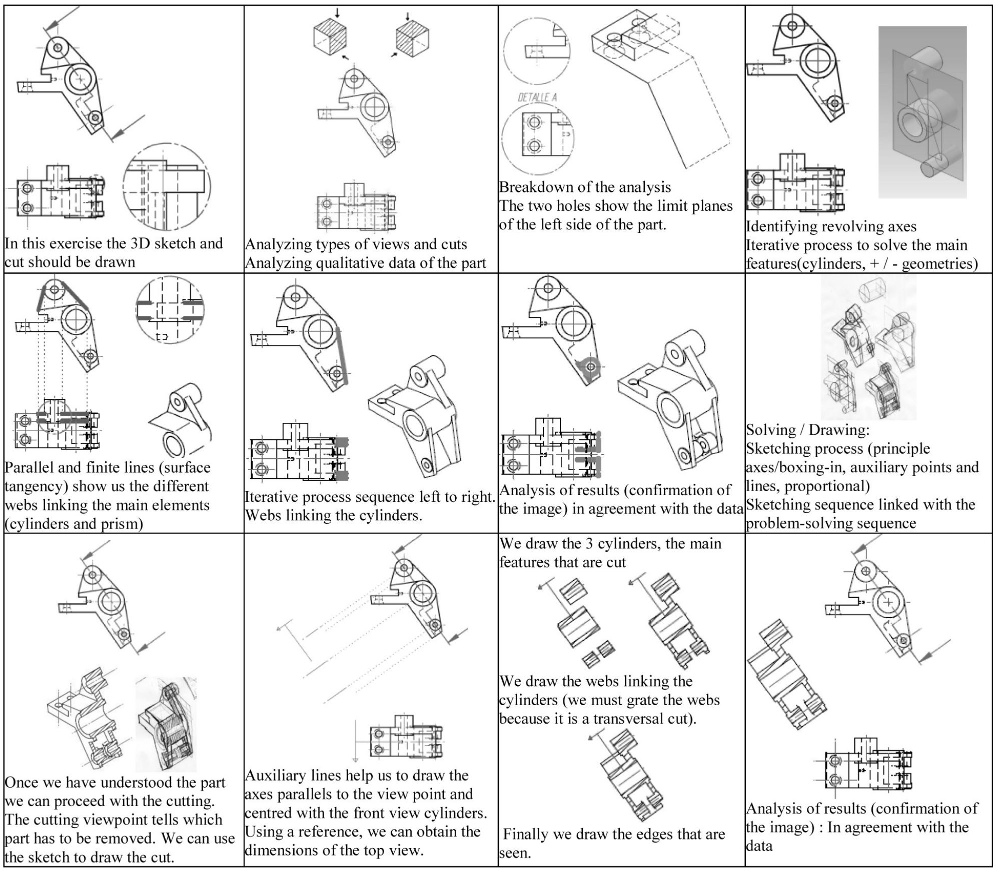


In this problem the sketch of the part in 3D should be drawn by hand

Example of flat surfaces part resolution process: in this example the strategies of resolution used have been, decomposing the part into simple geometric elements (two cubes) and identify the different types of planes (similar shapes). First searching projections appearing just once in statement allowing fast detection of planes which are parallel to a plane of projection (its shape only appears once in a view and the remaining projections are vertical or horizontal lines). Later perpendicular planes to a plane of projection (the shape is repeated in the profile and the front plane, with an inclined line as the top projection, this therefore refers to a perpendicular plane to the top view). Finally searching the statement for the projection forms which are repeated from one view to the other, to find oblique planes.

Physic Model used to make the part as realistic as possible and to make the collaboration between peers easier.

Fig. 3. Flat surfaces part resolution process. Example of identifying similar shapes strategies.



In this exercise the 3D sketch and cut should be drawn

Analyzing types of views and cuts
Analyzing qualitative data of the part

Breakdown of the analysis
The two holes show the limit planes of the left side of the part.

Identifying revolving axes
Iterative process to solve the main features(cylinders, + / - geometries)

Parallel and finite lines (surface tangency) show us the different webs linking the main elements (cylinders and prism)

Iterative process sequence left to right.
Webs linking the cylinders.

Analysis of results (confirmation of the image) in agreement with the data

Solving / Drawing:
Sketching process (principle axes/boxing-in, auxiliary points and lines, proportional)
Sketching sequence linked with the problem-solving sequence

Once we have understood the part we can proceed with the cutting. The cutting viewpoint tells which part has to be removed. We can use the sketch to draw the cut.

Auxiliary lines help us to draw the axes parallels to the view point and centred with the front view cylinders. Using a reference, we can obtain the dimensions of the top view.

We draw the 3 cylinders, the main features that are cut

We draw the webs linking the cylinders (we must grate the webs because it is a transversal cut).

Finally we draw the edges that are seen.

Analysis of results (confirmation of the image) : In agreement with the data

Fig. 4. Example of a resolution process (description of the main steps for the resolution).

giving the views of a part the student has to drill, identifying the zones of material or not. CAD and physic model and the cutting view had help to carry out this exercise.

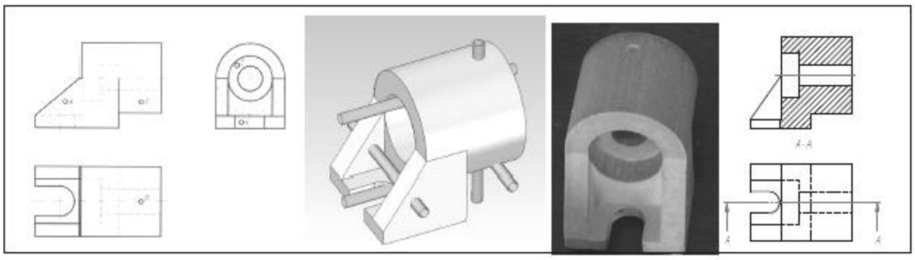


Fig. 5. Example of drilling exercise.

other documents such as videos and CAD models (Figs. 3 and 4).

2.3.2 *Virtual models (CAD)*

Virtual models created by computers with a CAD program can be easily rotated, sectioned and decomposed in any moment depending on the teacher's or student's needs. We can move from a perspective to multi-views or vice versa quickly. In this way, the difficulties arising from the understanding of the relationship between the spatial reality of a part and its representation on the technical drawing are minimized (Figs. 2, 3, 4 and 5).

2.3.3 *Physical models*

In order to increase the spatial capacity of students it is necessary to work in space with 3D models which can be turned, moved, and worked on mentally, for example, by obtaining their projections [16]. Another way of improving the students' ability when visualizing an object or a 3D scene is to make their experience as realistic as possible [17]. These models helped in the interaction peer to peer and peer to teacher. Therefore, real physical models have been used. Some of them are made of cardboard but most of them are made with rapid prototyping machinery in the Product Design Laboratory in Bilbao (www.ehu.es/PDL/) at the Department of Graphic Design and Engineering Projects, University of the Basque Country (Figs. 2, 3 and 5).

2.4 *Traditional teaching method*

Traditional teaching method is used in control groups in our university. In a previous research in which teachers of the University of the Basque Country were asked about their teaching strategies, they used most of the time the stated-solution strategy, without discussing the resolution process [6]. There were not defined comprehension indicators, so the exercises were not sequenced or specifically designed to work on students' difficulties.

Lecturers often immediately link students' visualization difficulties with a lack of practice in solving this type of problems, meaning that these students have not solved a minimum number of problems to develop their 'know-how' skill. So, in many cases, the student is encouraged to solve more problems on their own. The usual result is that the student is still unable to solve these problems and their motivation wanes, occasionally causing them to drop out of the course.

Mathewson [9] comments that engineering texts frequently present orthogonal, static views of concepts, theories and ideas with little or no explanation or focus on interpreting the spatial data. They almost assume that the student will be able to make the mental leap, piecing together the spatial puzzle.

Therefore, we should take into consideration the possibility that the problem will not be solved by simply providing more exercises, but by developing a teaching method which deals with student's learning difficulties, working with the student on the process of solving visualization problems, or in other words, teaching the specific strategies and forms of reasoning which are associated with part visualization.

3. Research methods and data

For two years this activity program had been tested four times, with Industrial and Chemical engineering in the first course at the Basque Country University. The students of the study have been selected randomly and the students do not know that they have been part of a study. The aim was to contrast if there are differences in respect to the traditional teaching group, making a quantitative and qualitative analysis [18–20].

The instruments used to contrast the impact on our proposal and the results are the following:

3.1 *Part visualization exercise at official exam*

Part Visualization problem at official exam have

Table 2. Significant differences comparing control and experimental groups solving visualization problems

Part Visualization exercise	Experimental (n)—average	Control (n)—average	Confidence level (%)	t (t student)	P
Industrial Engineering					
Partial exam 06/07	(46) – **4.09**	(257) – **3.11**	**99**	2.33	0.006
Final exam 06/07	(40) – **2.94**	(231) – **2.54**	**89**	1.22	0.101
Partial exam 07/08	(56) – **2.87**	(279) – **2.40**	**96**	1.75	0.033
Final exam 07/08	(51) – **2.03**	(263) – **1.78**	**94**	1.55	0.056
Chemical Engineering					
Partial exam 06/07	(25) – **3.83**	(20) – **3.43**	**66**	0.41	0.335
Final exam 06/07	(17) – **3.93**	(17) – **3.99**	–	–	–
Partial exam 07/08	(25) – **4.81**	(9) – **3.29**	**98**	2.14	0.015
Final exam 07/08	(24) – **4.39**	(8) – **2.61**	**98**	2.14	0.015

been analyzed, data of 8 official exams were collected for two years from four different groups (Industrial and Chemical Engineering). In Table 2 you can see on the second and third columns the average of the results and group size between the group that has used the described method (experimental group) and the rest of the students (control group), which continued with the traditional teaching method. On the fourth column you can see the level of confidence, to be a significant difference (*t* student statistic). Four out of eight exams the difference is significant (>95), in other two the confidence level is 94 and 89. There are two exams where the difference is very poor, in these two cases the part visualization problem at the exams given by the department was of low difficult level, so most students could resolve the problem.

3.2 Spatial visualization test

The improvement in the spatial visualization test [12] the students who did at the beginning and at the end of the course were compared. The results of the first test confirms that the experimental and control groups have a similar starting point and they are comparable. The improvement is higher in the experimental group in both cases and in one of them the difference is statistically significant (Table 3).

3.3 Qualitative test to analyze the reasoning and indicators employed in the resolutions of part visualization problems

Some special tests have been performed and recorded individually with some students in both groups. These students had passed the course the year before. The aim was to make a qualitative analysis [21] of the resolution process. They had to resolve by hand 3 part visualization exercises while they explained what they were doing and why. It lasted from 1 to 1.5 hours and all the interviews were video recorded.

This analysis shows that the experimental group follows a reasonable method of resolution whilst the control group keeps on basing its work on experience and intuition. So there is a qualitative difference between the groups. Only in the control group appears important knowledge, confidence and method deficiencies. On the other hand the experimental group have understood this knowledge, so they have a resolution method for part visualization problems. They carry out the problem in a reasonable way, they analyze the statement better and they use appropriate arguments. The experimental group students have less deficiency, so they are more efficient than the control group (Table 4).

Table 3. Improvement in spatial visualization

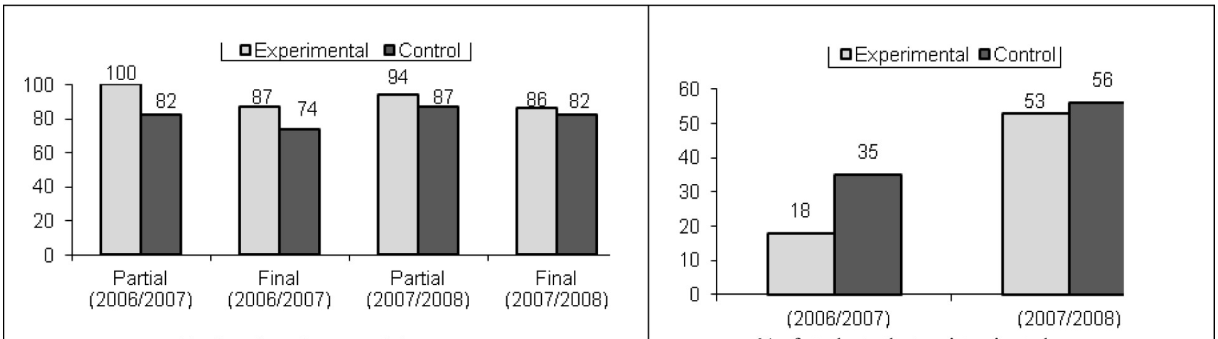
Spatial Visualization improvement	Experimental (n)—average	Control (n)—average	Confidence level (%)	t (t student)	P
Industrial E.	(53) – **6.08**	(292) – **5.37**	**80**	0.84	0.19
Chemical E.	(38) – **7.28**	(14) – **3.25**	**98**	2.18	0.01

Table 4. Examples of deficiencies of both groups (interview extracts)

Experimental group (n=12)	Control group (n = 10)
'The form of flat surfaces remains equal'	'I think it is a flat, square piece that I see as a triangle
'General to detail is the solving sequence I use'	'I draw the views on the box surfaces and if I am right, fantastic'
'I break down the part into elements'	'Experiment-error, trying and trying, I have no method, I can not see'

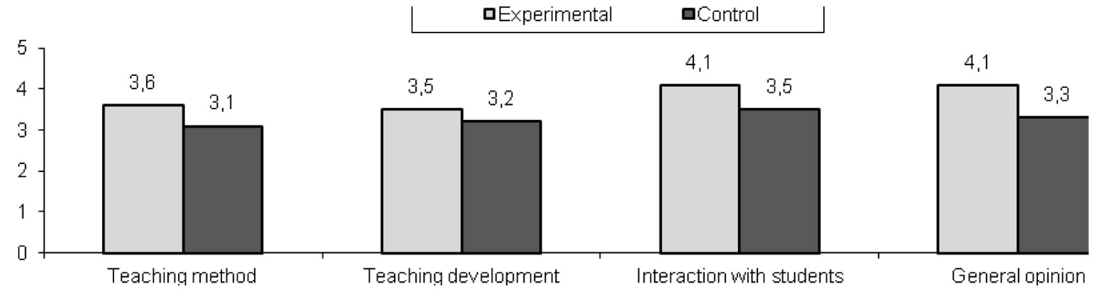
Table 5. Group size for the actitudinal survey

	Attendance to the exams	Experimental N	Control N	Need of private lessons	Experimental N	Control N	Students opinion	Experimental N	Control N
Industrial 06/07		46	309		33	153		26	183
Industrial 07/08		59	318		39	162		41	207



% of student that attend the exam

% of students that assist private lessons



Some items of the Students´ official survey about the teaching received 2006/2007

Fig. 6. Students' attitudinal results comparing control and experimental groups: exam attendance, need of private lessons, and the opinion of the students about the teaching received.

3.4 Students attitudinal survey

Other data collected shows the students satisfaction and motivation: exam attendance, the need of private lessons and the opinion of the students about the teaching recieved. This data have been collected through Basque Country university official questionier and a special test done for this study (Table 5). The university official questionier asks the student about teaching method, teaching development, interaction with students and general opinion of the same. We can see in this paper (Fig. 6) only the data of the industrial engineering (in which the group size is bigger); the results in Chemical engineering are quite similar.

In all the cases a higher attendance to the final exam and a lower demand of private lessons were registered in the experimental group, so more students in the experimental group were able to follow and finish the course with this teaching method. On the other hand the experimental group opinion of the learning method is better than that obtained in the control group.

4. Discussion

In this paper is shown an approach to the part visualization problem solving, an important knowledge for engineers which presents a high failure in graphic courses. This situation could be mainly due to the inexistence of a systematic process to analyze complex forms. A review of the literature of technical drawing textbooks has not been successful in finding a clear, concise, and developed method of solving part visualization.

The didactic study affirms that, besides the theoretical and conceptual knowledge, other content such as procedural knowledge must be considered in teaching. This study proposes a problem solving model, adapted to the case of part visualization, integrating resolution process, concepts, procedures and different types of reasoning specific to visualization of parts. This 'part visualization problem solving' model has been mainly based on three sources:

- The analysis of the students' difficulties when faced with part visualization problems.
- The analysis of the experts' solutions to part visualization problems.
- The analysis of textbooks and published research papers in the area of engineering education.

Ten comprehension indicators have been defined, where the last one is the resolution process for this kind of problems. The way to articulate the learning of this knowledge has been defined through an activity program which is sequenced in order to work the different indicators.

As educators often forget the factor of spatial visualization in learning assuming that the student will be able to assemble the spatial puzzle, this study has also taken into account the level of spatial visualization needed to carry out the activities. The tools that should be used to help the learning process have been also defined: in order to help the resolution process slide and CAD models (decomposing into simpler geometries) have been used, and in order to help in the comprehesion of the spatial reality CAD models and physical models have been used.

Finally, the results after the implementation of this methodology for part visualization in first course of Engineering are explained. The results have been compared with traditional teaching groups.

The data has been collected only in the University of the Basque Country, which forces us to be cautious when drawing general conclusions about the analysis of this data for other educational contexts or countries. Nevertheless, some of the trends noted could be occurring in other places, and so it should be the lecturers who consider the possible implications on their specific teaching.

Results of exams, used arguments to solve a part visualization problem, exams attendance, improvement of the spatial capacity, the need of private lessons, and the opinion of the students about teaching received have been compared. For these comparisons, exams attendance and results have been collected, and video recordered special test have been done for this study. The visualization survey, which quantifies the capacity of spatial visualization, has been used at the beginning and at the end of the course in order to compare the improvement of the spatial capacity. Finally the survey of students' opinion about the teaching has been used to know the students' attitude with this method. All the results are more positive to the experimental group, both in the quantitative and qualitative analysis.

- There has been an improvement in the teaching-learning process. The results of exams are better and the students have a systematic process to solve the part visualization problem, so they have understood the comprenhension indicators. The spatial capacity improvement has also been higher in the experimental group.
- This teaching proposal has provided the necessary knowledge and strategies to follow the course and to learn 'part visualization problem solving' in a better way than using traditional methods. The data of higher attendance and the lower need of private lessons at the experimental group show this conclusion.
- The students have a better attitude with this teaching method, and the students' opinion is better about the teaching received.

5. Conclusions

The results obtained seem to be due to the introduction of certain novelty aspects in the used methodology that could be transferred to other contexts:

- It is important to define the comprehension indicators to design an activity program. These comprehension indicators should be based on the student's difficulties, the expert's knowledge, and literature review in the educational research in part visualization.
- The activity program should be designed so that the students work on all the indicators necessary in the visualization. Designing specific tasks, taking into account, the theoretical contents and procedures involved in part visualization as well as the students' main difficulties and deficiencies when faced with this kind of problem.
- The notion that the knowledge of the professor can be transmitted in its final stages (by stating a problem and showing the solution) is not the best way to help the students' learning process. It is necessary to work with the student on the process of solving visualization problems, teaching the specific strategies and forms of reasoning which are associated with part visualization, in a continuous feedback.
- Spatial visualization should also bear in mind. The apparition of new working tools had enabled the interaction with objects through a virtual world reducing the difficulties of comprehension between the spatial reality of a part and its representation on the technical drawing.

Results are hopeful but upcoming interventions should be improved upon so that results are more conclusive and the methodology is implemented and widespread.

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