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Teaching Part-Visualization: an Approach Based on Problem-Solving Strategy Knowledge*

MIKEL GARMENDIA, JENARO GUISASOLA and EGOITZ SIERRA
Dept. of Graphic Expression in Engineering, Polytechnical College, University of the Basque Country, Plaza Europa 1, 20018 Donostia-San Sebastián, Spain. E-mail: mikel.garmendia@ehu.es

Part visualization, which refers to read and understand any technical drawing, is a fundamental skill in engineering. However, engineering students show certain learning difficulties and a high failure rate in subjects such as Engineering Graphics. The main aim of this study is to introduce a new teaching strategy for part visualization. A problem-solving model for visualization has first to be designed. Teaching strategies may then be applied, by drawing up a programme of specific tasks which takes into account the theoretical contents and procedures involved in part visualization and students' main difficulties and deficiencies when solving this kind of problem. After testing the method in the classroom, the results which were obtained from test and control groups were contrasted, showing an important improvement.

Keywords: part-visualization; teaching strategy; problem-solving model

INTRODUCTION

VISUALIZATION CAN BE UNDERSTOOD as the ability to study the views of an object and to form a mental picture of it, so visualizing its three-dimensional shape. In other words, visualization is the understanding of visual information.

Engineers should be able to read and write in this graphical language. This reading skill is fundamental as any person involved in the technical industry should be able to read and understand any drawing easily [1].

The Polytechnical College, University of the Basque Country, has a high failure rate among first year Engineering Graphics students, with about 50% of enrolled students not taking the final exam, and only about 25% passing it. Even students with proved intellectual skills in other areas had problems understanding the mechanisms which related the representation of 3D objects with the objects themselves [2].

In a previous study [3] which interviewed and recorded a group of students in order to analyse the resolution process they followed for three different visualization problems, most of the students admitted that they had not learned the methodology required to solve these problems and tended to use the strategy of trial and error and intuitive methods.

Mathewson [4] comments that educators commonly neglect teaching visual-spatial thought. An assessment of most of the paper-based material reveals that they do little to foster developmental growth of spatial abilities. 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.

In the new European context, visual reasoning is to be considered, in terms of the learning outcomes and competences, as a capital aspect of future engineers' education. But, at the same time, it must be introduced in a very efficient way [5].

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MODEL FOR SOLVING VISUALIZATION PROBLEMS

Several sources of information were consulted to answer these questions. First, we looked at Graphic Expression textbooks, through bibliographical review and analysis of their contents which are relevant to visualization. Then, 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, the existing teaching research bibliography was consulted covering problem solving in Science and Engineering.

Nickles [6] explains that solving a problem adequately requires a general method and specific programmatic knowledge.

Research into problem solving maintains that different areas of knowledge interact during reasoning processes: general skills and abilities are applied to a subject concept giving way to the forms of reasoning applied for the given subject.

Consequently, teaching research leads to the idea that in addition to theoretic or conceptual knowledge, there are other contents, such as procedures, that must be taken into account while teaching [7] [8].

This research proposed a problem-solving model [9] [10] [11] [12]. We have adapted this model to the case of object visualization, integrating into this resolution structure, the concepts, procedures and forms of reasoning which are specific to visualization.

This model cannot be considered a rigid resolution algorithm, but more like a compilation of general recommended steps, with resolution criteria and strategies that must be assessed every time and used according to the part's statement.

First, it is recommended to perform an in-depth quality analysis of the visualization exercise's views before developing it, taking into consideration all the different variables:

Volume analysis, determining the total volume taken up by the part and considering the possibility of carrying out part solid analysis, in other words, if it may be counted as being made up of volumes or different basic geometrical shapes, therefore decomposing the part to be able to analyse each element independently.

Surface analysis, paying special attention to variables such as projection forms, edge configurations (parallelism), visibility, etc., to identify the plane types making up the part, depending on the features of its projections (Figure 1).

In this sense, one of the analysis strategies consists of searching the statement for the projection forms which are repeated from one view to the other, to find oblique planes (the triangle shape appears in the three views, so, this is an oblique plane), or perpendicular planes to a plane of projection (the shape is repeated in the profile and the front plane, with a inclined line as the top projection. This therefore refers to a perpendicular plane to the top view).

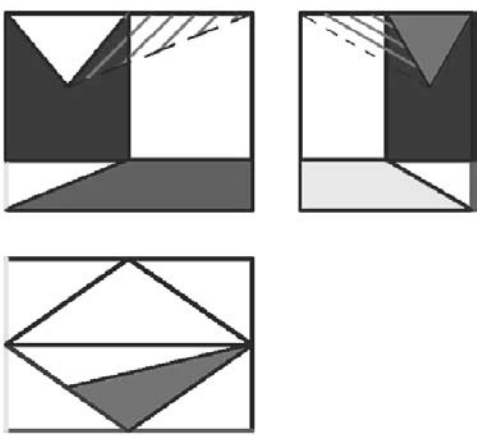


Fig. 1. Surface analysis.

The opposite strategy would be 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. These projections are typical of parallel planes to a plane of projection in which the projection is an area).

Vertex analysis, particularly those in which inclined lines corresponding to oblique planes converge, as the correct copy of the coordinates of these points to the perspective is fundamental for the trace.

Quality analysis generates several hypotheses, allowing us to focus and direct the problem resolution, assessing possible resolution strategies. This refers to selecting existing resolution strategies and developing the most convenient one, depending on the statement's features.

In the bibliographical review, several authors propose the method of elimination of volumes from the prism derived from the part and the composition of solids or the consideration of the part as a combination of primitive solids.

The solid composition method is valid for some types of industrial parts and pursues the strategy which involves breaking down the problem into different sub-problems. The analysis of each of the solids, or when the part shows inclined or oblique planes, generally requires a surface analysis method [13].

Tracing perspective requires assessment of the convenience of using support and reference elements, such as the wraparound prism, using reference points, resorting to approximate circumference-tracing methods or following the appropriate tracing sequence, for example, by first drawing the normal surfaces (planes parallel to a plane of projection), followed by inclined surfaces (perpendicular to one plane of projection) and leaving the oblique planes until last.

Finally, it is appropriate to carry out result analysis, verifying consistency with the statement. Some authors advise labelling the surfaces and vertex as a way of checking the accuracy of the solution [13].

TEACHING STRATEGIES FOR PART VISUALIZATION

Lecturers often immediately link students' visualization difficulties with a lack of practice in solving this type of problem, meaning that these students have not solved a minimum number of problems to develop their know-how. So, in many cases, the students are encouraged to solve more problems on their own. The usual result is that students are still unable to solve these problems and their motivation wanes, occasionally causing them to drop out of the course [3].

We shall 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 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 theoretical and procedural contents have been integrated into a single construction process by means of problem solving.

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, a process assessment system has been followed, so the lecturer may know student deficiencies and 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 areas where difficulties have been detected.

Several assessments have been performed throughout the academic year: students solve problems individually and collectively in the classroom. This gives the lecturer an idea of general group progress, to readapt the teaching activities according to this progress. Weekly homework done by students is also assessed to detect possible difficulties and provide the appropriate personal support.

The following table (Table 1) displays general aims planned for teaching part visualization and the possible difficulties that the student may find during the learning process.

Different activities have been drawn up which gradually introduce 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.

The number of problems to solve in each activity will depend on the degree of deficiencies or difficulties which the students encounter and their degree of assimilation of the knowledge implicated in part visualization.

The proposal for the visualization teaching sequence appears in the diagram (Table 2), assigning a code for each activity (A1: Activity 1).

The guideline for proposed activities follows the logical structure above. The first activity (A1) determines the students starting level, or their previous knowledge, detecting deficiencies coming from their secondary education, through group problem solving among the students in the classroom, with the teacher acting as leader and moderator in the process.

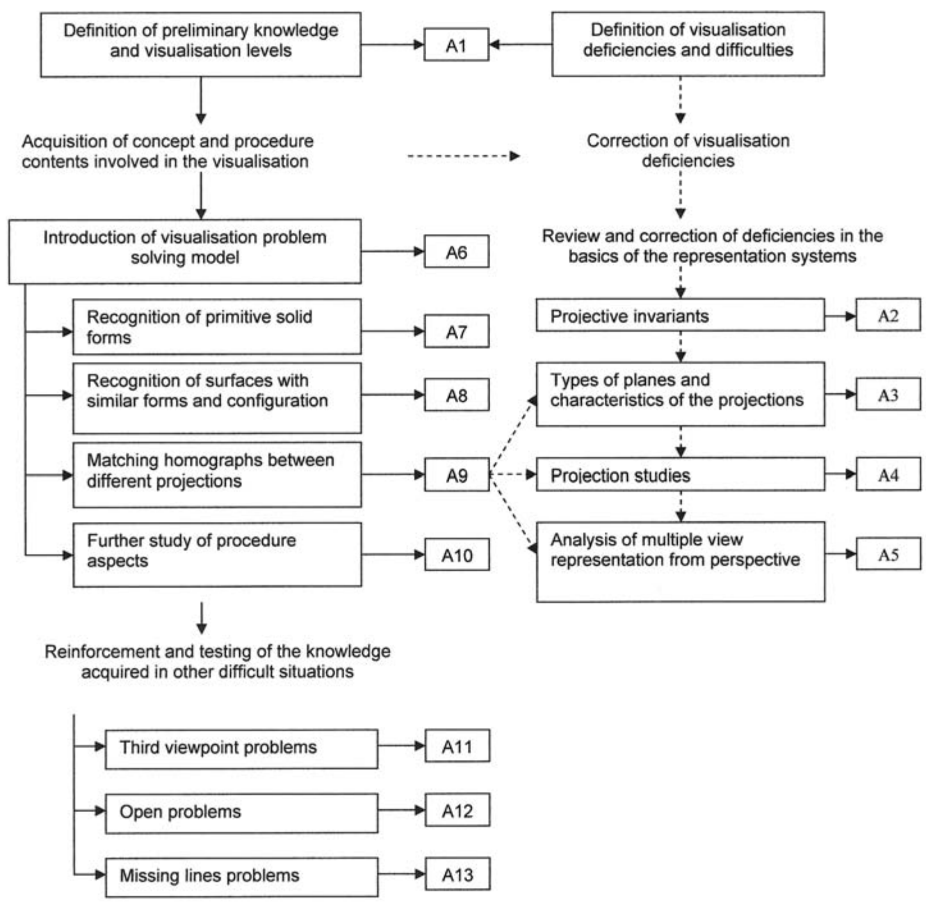
The students' starting level and deficiencies may change from one group to another or even from one student to another. This first activity is proposed as a tool to be able to adapt the main activities programme to a specific group of students, and even propose different variations for the programme to customize it to the students' requirements, designing and selecting from among the different activities, those that will be done by the whole group in the classroom and those proposed to student subgroups with specific requirements.

Various activities will be proposed for students who have deficiencies, or as consolidation and review of this knowledge for the whole student group, giving the student several problems to

Table 1. Aims and difficulties in visualization

AIMS	DIFFICULTIES
The student correctly applies the basics of the perspective and representation systems in parts visualization.	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.
The student knows and can identify different types of planes which appear in the parts and the features of their projections.	Difficulties with plane type identification during the analysis of views.
The student knows about and can correctly apply the different methods and strategies to solve visualization problems and their limits and convenience of use depending on the part's features.	Difficulties in the assessment and use of different resolution methods and strategies. Deficiencies in the surface analysis method.
The student knows the corresponding conditions between projections from one view to other, as result of projective invariants.	Difficulties corresponding projections between views.
The student acquires process knowledge for solving visualization problems: quality analysis, generation of hypotheses, resolution strategies and analysis of results.	Lack of knowledge of problem solving models. Difficulties with quality analysis of statements, errors in hypothesis generation and deficiencies in planning suitable resolution strategies.

Table 2. Activity programme sequence structure



question and check the assimilation of fundamental concepts (A2, A3) along with two additional activities (A4 and A5) in which these fundamental concepts must be applied and analysed on the representation of several industrial parts. When a group of students shows no deficiencies in the starting activities, then activities A2 to A5 can be skipped.

The proposed sequence consists of first presenting the resolution model for problems which we introduced early, applying it to one or two practical example exercises (A6).

Taking into account that it is possible to solve a visualization problem by using different methods depending on the part's features, three different activities (A7, A8 and A9) have been developed to teach the students these resolution methods.

The following activity (A10) is focused on procedural aspects involved with part visualization. Different problems are proposed in the classroom with the idea that the student will solve them both individually and interacting with their classmates and with the lecturer, in a participative process of continuous interaction.

It deals with the different phases involved in solving visualization problems: initial quality analysis, hypothesizing, evaluation of different problem-solving methods and strategies, explaining in detail the reasoning used during the solving process and results analysis, putting particular emphasis on the initial quality analysis of the statement and the final analysis of the errors made during the problem-solving process, trying to find their causes as a result of some deficiencies.

Finally, the three activity types are proposed to test the knowledge acquired by means of different problems (A11, A12, A13) searching for a metacognitive objective.

Potter [14] (2003) states that perception and mental imagery can be developed through various applications, which include modelling and sketching, representing objects in three-dimensional models, working from three-dimensional models to represent their different dimensions on paper, as well as experience in working with different perspectives of objects and models as represented on paper or on the computer screen. In this sense, Okudan [15] proposes solid modelling to design and to interactive visualization of parts and assemblies.

These considerations have been taken into account when designing the activity programme and implementing it in a multimedia system (Figure 2). It basically consists of offering the

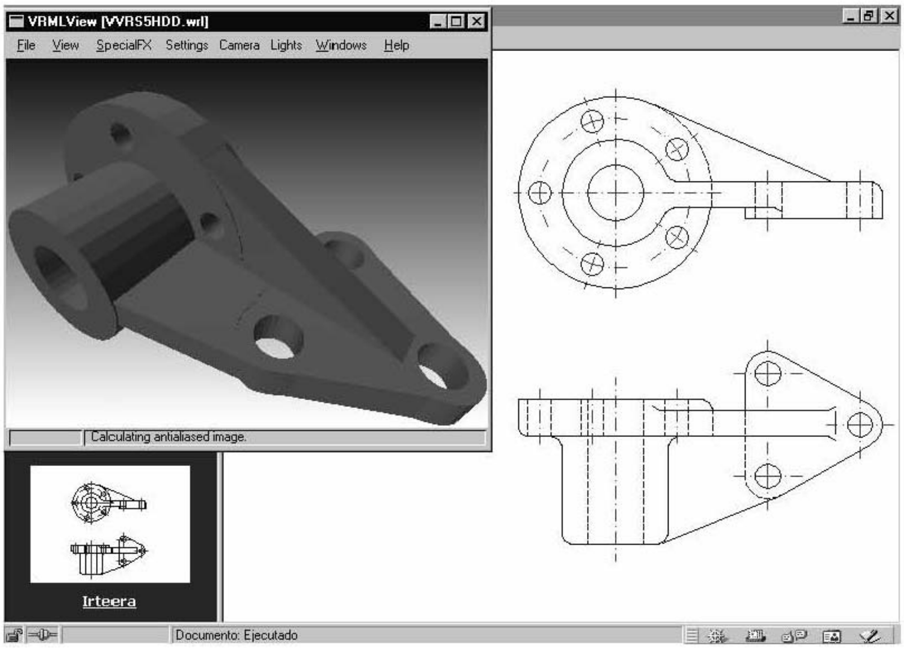


Fig. 2. Possibility of interaction with virtual reality.

possibility of interaction with the parts proposed through the different activities in VRML (Virtual Reality Modelling Language). According to Bertoline et al. [13], there is another way to improve a person's skill in visualizing a 3D object or scene: by making that experience as realistic as possible.

Some students may have difficulties related to an object's spatial reality and its corresponding plane representation. There are even students with difficulties in understanding the solution of a visualization problem given in perspective, particularly if the given part contains oblique planes. By interacting with the part, these comprehension difficulties are reduced.

RESULTS

To demonstrate if better results are obtained in learning visualization skills by working in the classroom on the activity programme developed in our proposal compared with the models which are habitually used, the experimental and control groups have been contrasted.

The model employed in usual teaching to visualize parts can be differentiated from the model followed in the experimental group in two aspects. First, the type of activities which the student carries out has been reduced to three, following this sequence: obtaining part projections using statements in perspective; obtaining perspectives using statements with multiple views; viewpoint problems.

Second, the usual teaching strategy consists in resolving an example of a visualization problem, and then students have to solve visualization problems by themselves. Volume and surface analysis methods are commented upon, but there is generally no interaction with students using these methods. Strategies and forms of reasoning followed during the resolution process are not explained and multimedia systems allowing students to interact with the parts are not used either. Instead, students are only given solutions to the problem statements so they can correct their own work.

A test was designed to prove the success of the alternative proposal which was implemented in order to improve part visualization. The test consisted of asking the students to solve two different visualization problems, so they had to draw the perspective of the part using multiple views representations. These exercises were given at the end of the programme's activities included in the final exam.

Two problems to solve in the questionnaire were of intermediate level, but the type that any engineer should be able to solve without making any mistakes. The objective would be that students do not pass the subject if they are not capable of interpreting these statements without making mistakes. The aim of the test was to determine the percentage of students who found the correct solutions without any errors. These students would have the basic concept and procedure knowledge required to visualize the parts. Therefore, the indicator to contrast would be the percentage of students that achieve it.

The following table (Table 3) shows the percentage of correct answers obtained by test and control groups for the problems given.

It also displays the statistic value of χ^2 obtained from the aforementioned percentages and the P value for the probability that a random variable with one degree of freedom will take a value which is higher or equal to the statistics.

As the statistical comparison between control

Table 3. Contrast between test and control group

	% of correct answers Test group (N = 146)	Control group (N = 98)	χ^2	P
Exercise 1	45.2 %	18.6 %	16.3	<<0.01
Exercise 2	52.1 %	20.9 %	21.0	<<0.01

and test groups shows, all the students belonging to test groups reach the final correct solution for the problems in higher percentages ($p < 0.01$), so it has been proved that the proposed alternative teaching method improves the results in learning achieved by the students compared with the models which are normally used.

CONCLUSIONS

Educators commonly neglect teaching visual-spatial thinking. An examination of most paper-based materials reveals that they do little to foster developmental growth of spatial abilities. Engineering texts frequently present orthogonal, static views of concepts, theories and ideas with little or no explanation or focus on interpreting the spatial data. Almost assume that the student will be able to make the mental leap, piecing together the spatial puzzle.

We thereby propose the possibility that dealing with this educational failure could consist of developing a teaching strategy which deals with the learning difficulties, working with the student on visualization problem-solving processes, explaining the methodology and forms of reasoning behind part visualization and taking into account in their teaching concept and procedural contents, stressing the reasoning followed in the deduction process and in detecting errors and deficiencies which are produced in them.

We designed and implemented a varied programme of activities, such as recognition of primitive solid forms, recognition of surfaces with similar forms and configuration, projection studies, analysis of multiple view planes, further study of procedural aspects, missing lines problems, or open problems. The activity programme which was drawn up obtains better learning results from students than the usual models.

The teaching strategy will consist in proposing these activities in the classroom with the idea that the student will solve problems set individually and interacting with their classmates and with the lecturer, in a participative process of continuous interaction. It deals with the different phases involved in solving visualization problems: initial quality analysis, hypothesizing, evaluation of different problem-solving methods and strategies, explaining in detail the reasoning used during the solving process and results analysis, putting particular emphasis on the initial quality analysis of the statement and the final analysis of the errors made during the problem-solving process, trying to find their causes in terms of some deficiencies. This gives the lecturer an idea of general group progress, to adapt teaching activities according to this progress.

In this sense, we consider interactive work with students to be critical in order to solve visualization problems and that we must take both conceptual and procedural process contents into account in our teaching, particularly emphasising the logic involved in the deduction process and error detection process and the deficiencies which occur in them.

Our experiment shows that it is possible to obtain better results from visualization teaching, by changing some teaching strategies.

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Mikel Garmendia is an assistant professor at the University of the Basque Country, Spain. He earned his Ph.D. in Engineering Design Graphic Education at the University of the Basque Country. His current research interests include engineering education and approach for classroom innovation.

Jenaro Guisasola is a professor of Physics in the Applied Physics Department and he has been a faculty member at the University of the Basque Country for the last 12 years. He earned his Ph.D. in physics education at the University of the Basque Country. He is the author or co-author of 13 books and numerous journal articles. His current research and publication interests are diverse and emphasize the role of cognitive psychology and the history and philosophy of science in Physics education and in approaches for classroom innovation. His interests also include scientific literacy and science museums.

Egoitz Sierra is an assistant professor at the University of the Basque Country, Spain. He is doing his Ph.D. in Engineering Design Graphic Education.