Methodology for Part Visualization Problem Solving - the Importance of the Process -

E. Sierra Uria[1] and M. Garmendia Mugika[2]

[1]Faculty of engineering of Bilbao, The University of the Basque Country, Bilbao, Basque Country, egoitz.sierra@ehu.es;

[2]University School Technical of San Sebastián, The University of the Basque Country, San Sebastián, Basque Country, mikel.garmendia@ehu.es

Abstract

Part visualization is a fundamental skill in engineering. It comprises the reading, interpretation and creation of industrial technical drawings, understanding the different views (multi-view) of an object/piece represented in any technical drawing.

The ability to mentally visualize and manipulate objects and situations is an essential need in many jobs and careers. It is estimated that at least 84 majors consider visualization a fundamental need, and in technical jobs, many of them related to the different types of engineering, the ability to visualize has a crucial importance.

Educators have often pointed out the difficulties of most students in graphic courses when trying to visualize an object using multi-view drawings. This is mainly due to the inexistence of a systematic process to analyze complex forms.

A thorough review of the literature in technical drawing textbooks has not been successful in finding a clear, concise, and properly developed method of solving visualization problems by means of procedural contents.

In collaboration with several experts and for the first time, a problem solving model for visualization has been designed and developed for all kind of industrial objects **(Methodology for Part Visualization Problem Solving)** within a constructivist didactic framework. This Problem Solving model is the key to all technical knowledge and is an application of the scientific method.

In order to solve visualization problems in any kind of industrial object, comprehension indicators have been defined and a Teaching Unit has been developed with the help of dynamic images (power point and CAD files) as well as physical models. They may be applied by drawing up a programme of specific tasks which takes 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.

This teaching strategy has been applied over the last two years in the first year of Industrial Engineering at the Department of Engineering in Bilbao at the University of the Basque Country with good results.

Topics covered by the book include, but are not limited to:
Research and Innovation in Education
Curriculum Design and Innovation

1. Reasons for this Teaching Strategy?

There are three main reasons supporting this new teaching strategy:
First, in the different subjects studied by future Engineers, some difficulties can be observed in the visualization of parts and the development of spatial capacities (Sierra Uria, Egoitz, 2005) [1]. Second, 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 majors consider spatial visualization a fundamental need (Smith, 1964) and in some technical jobs, the ability to visualize has acquired an outstanding importance (Maier, 1994)[2].
And third, the need for this new strategy arises from the educator's need to analyze and continuously assess their own ways of teaching in order to become more effective educators (Fernando Hernandez, 1992) [3].

2. Didactic Framework

There is a need to analyze the specific difficulties arising from the learning of visualization. Educators have often pointed out the difficulties shown by most students in graphic courses when trying to visualize an object using multi-view drawings. These difficulties are mainly due to the inexistence of a systematic process to analyze complex forms (Luzzader and Duff 1986) [4].
The didactic strategy followed in most classrooms seems to be one of the main reasons for these difficulties. This didactic strategy consists in a visualization of the problems followed by the solutions to those problems, without providing students with a clear explanation on how to solve them; this is, the necessary reasoning during the problem-solving process (Garmendia, 2004) [5]. Students themselves confirm this lack of a problem-solving strategy. Instead, they use the trial-and-error strategy, or they simply rely on intuition.
Didactic research in problem-solving states that when students reason, different aspects of inter-related knowledge are put to work. A set of general abilities is used and applied to the different aspects of a subject, thus creating particular ways of reasoning in that subject. This proves that in teaching, besides the theoretical and conceptual knowledge, other contents such as procedural knowledge must be taken into consideration (Guisasola et al. 2003) [6].
Certain aspects must be defined when planning the teaching of specific contents and deciding on the design of the learning process through a program of activities. The intended objectives and the contents are among these aspects that ought to be defined, keeping always in mind the possible difficulties that may arise from the assimilation of the contents by the students. But at the same time, it is necessary to define the strategy that will be followed to achieve a meaningful learning, defining a logical sequence of activities specifically designed for the learning process, as well as the type of assessment that will be used to guide the students and help them improve in their learning. We also come across

students who have not developed enough spatial capacity and therefore, they have serious difficulties in understanding and manipulating the parts in space (Navarro,2004) [7]. Mathewson (1999) [8] affirms that educators often forget the importance of the spatial-visualization factor in learning. A review of most text books in this subject shows that little has been done to improve and develop the students' spatial capacity. Engineering textbooks often present orthogonal views, static concepts, theories and ideas with little or no explanation, all of this together with a lack of interpretation of spatial data. It is assumed that the student will be able to overcome the mental challenge and assemble the spatial puzzle.

According to Potter (2003) [9] students with a deficient development of spatial capacity need to learn by using static, dynamic and transformational images, as well as the way to combine them in problem solving. Spatial perception can be developed in many ways. For instance, by practicing the modelling and freehand drawing of objects, representing objects in 3D models, manipulating objects in 3D in order to recreate their representations dimensionally, and finally, by experimenting and working with different perspectives or views of the represented part or object both on the blueprint and in the computer image.
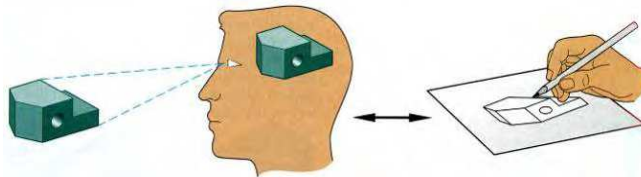

Fig. 1. Bertoline 2003 [10]

On the other hand, a thorough review of the literature in technical drawing textbooks has not been successful in finding a clear, concise, and fully developed method to solve visualization problems using procedural contents. (Sierra Uria, Egoitz, 2005) [1]

2.1 Didactic Framework

This Visualization Didactic Unit, together with the programme of task based on the new **Methodology for Part Visualization Problem Solving** has been developed under a constructivist view and within the European Higher Education Framework. The highlights of this framework are the following:

- The student builds up his knowledge
- The new knowledge has to be significant to the student
- The student's previous knowledge must be taken into account
- The teacher must guide students in their learning process
- In the learning process, some "cognitive conflicts" are bound to arise
- The learning process will promote "zone of proximal development" [11] between the students
- The student's work is measured by the ECTS (European Credit Transfer System)
- The students will know at all times the result of their effort and their progress in the learning process, as well as the reward corresponding to their effort (evaluation)
- The student holds the main responsibility for his own learning

2.2 Used Tools

Nowadays, ICT (Information and Communication Technology) offers a variety of complementary tools that are very helpful in the teaching/learning of every subject, including the visualization of parts. The tools used in this Visualization Didactic Unit are the following:

2.2.1 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 other documents such as videos and CAD models.
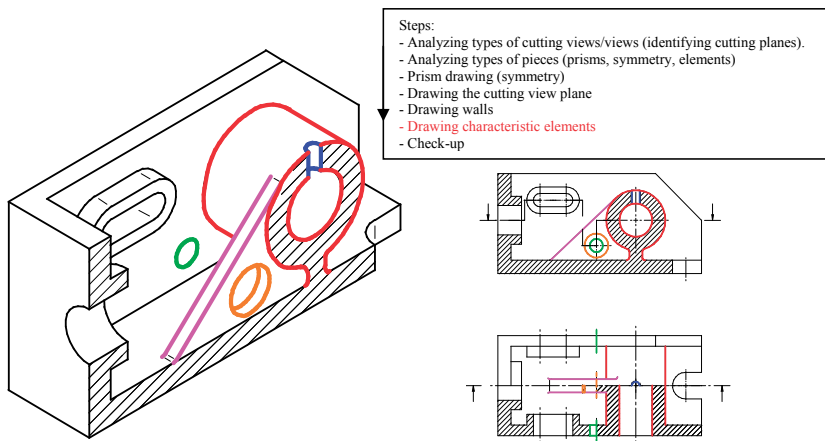

Fig. 2. Slide 6 of 7 from the solving process

2.2.2 Virtual models (CAD)

Virtual models created by computers with a CAD program can be easily rotated and sectioned 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.

Fig. 3. CAD virtual model

2.2.3 Physical models (CAD)

According to a number of authors, 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 (Devon et al. 1994). [12]

Following Bertoline et al. (1995) [13], another way of improving the students' ability when visualizing an object or a 3D scene is to make their experience as realistic as possible.

Fig. 4. Physical models

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.

3. Methodology for Part Visualization Problem Solving, Comprehension Indicators and Activity Program

This newly developed Methodology for Part Visualization Problem Solving is mainly based on three sources:

- The analysis of the students' difficulties when faced with Visualization problems
- The analysis of the experts' solutions to Visualization problems
- The analysis of textbooks and published research papers in the area of Engineering Graphics and Engineering Education

In this new Methodology [14] the Problem Solving model has become the key to articulate all the necessary knowledge for the the solving of this kind of problems. The Problem Solving model, which is an application of the scientific method, constitutes the basis of all technical knowledge.

When faced with a Visualization Problem, the data (multi-views) must first be analyzed and, according to these analyzed data, a strategy must be decided on. The problem can be solved element by element (sub-problems), by 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 object is obtained, new views/cutting views can be created using the same method (analyzing the new viewpoint / cut viewpoint and then, solving element by element).
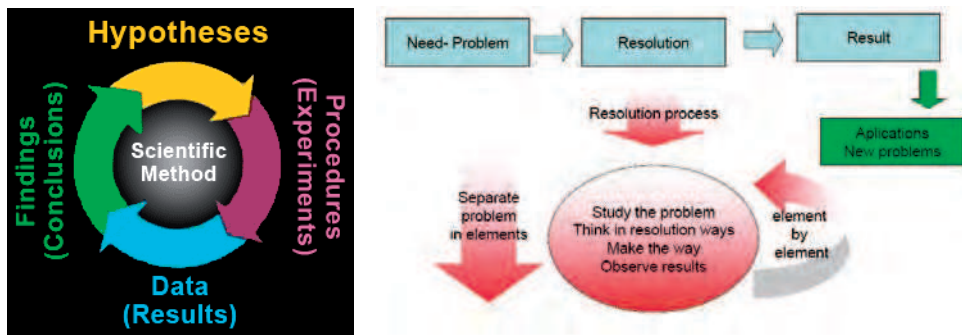
Fig. 5. Scientific method and Problem Solving Model

3.1 Comprehension indicators

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

3.1.1 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 piece 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.
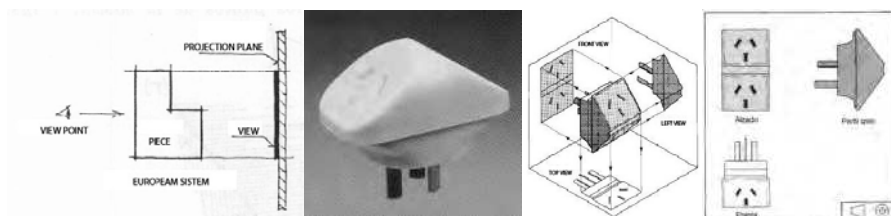

Fig. 6. Fundaments of multiview representation [18]

3.1.2 Conditions or rules of correspondence (6 rules)

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

1. The projections of a point will be aligned in the different views.
2. The dimension between two points (x, y, z) will be the same for different views

3. Parallel lines in the different views will remain always parallel.
4. The form of flat surfaces remains equal in the different views unless it is seen as a line. In this case, the surface (plane) is parallel to the visual
5. Two contiguous 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.
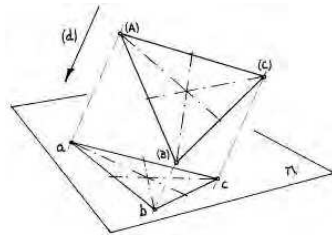

Fig. 7. The form of flat surfaces remains equal but the dimensions are not in true scale unless the feature is parallel to the projection plane

3.1.3 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, project planner and oblique) as well as of the characteristics of their projections (2D).

3.1.4 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, cylinder, cone, sphere, geometries of revolution).
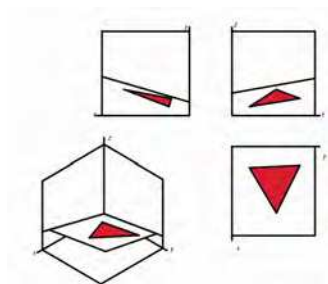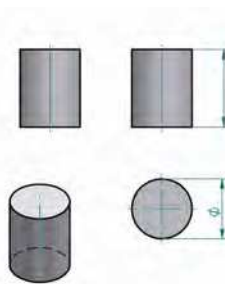

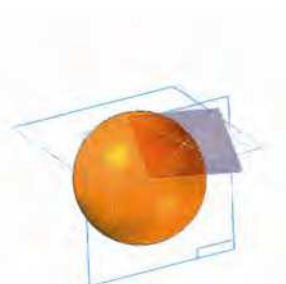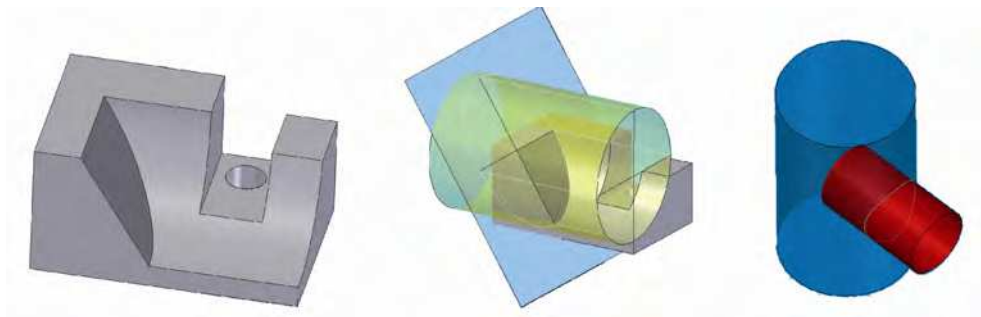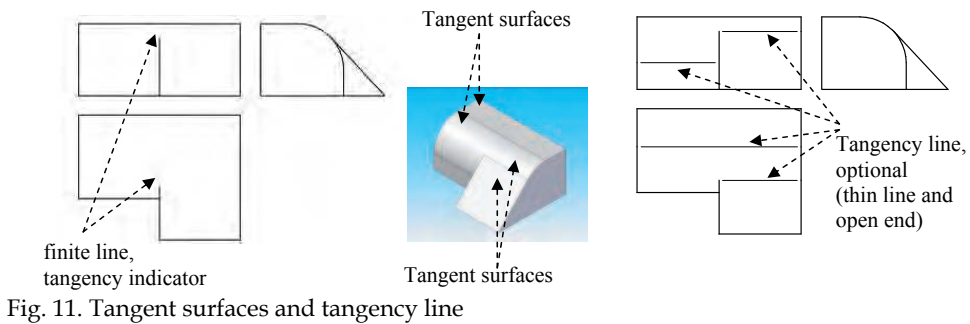Fig. 8. Oblique plane   Fig. 9. Cylinder   Fig. 10. Sphere
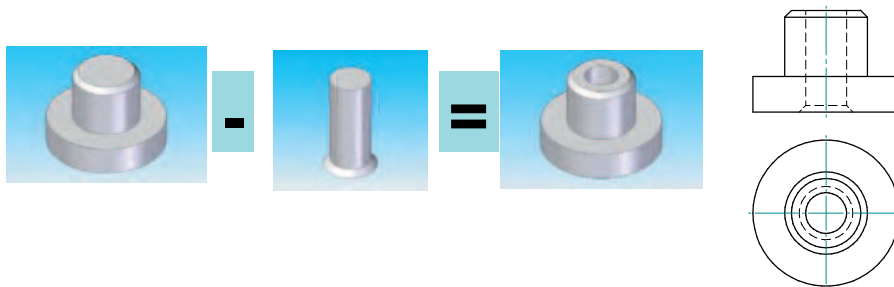
3.1.5 Tangency and intersection between surfaces
This means mastering the tangency between surfaces (3D) and their representation (2D) (lines of contact, finite line) as well as the various intersections between surfaces (3D) and their representation in the most basic areas (plane, cylinder, cone, sphere)

Fig. 11. Tangent surfaces and tangency line

Fig. 12. Intersection between cylinder and plane and between cylinders

3.1.6 Fundamentals of vacuum (material -)

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

Fig. 13. Vacuum = material (+) - material (-). The vacuum is always surrounded by material

3.1.7 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, aligned, //view //cut)
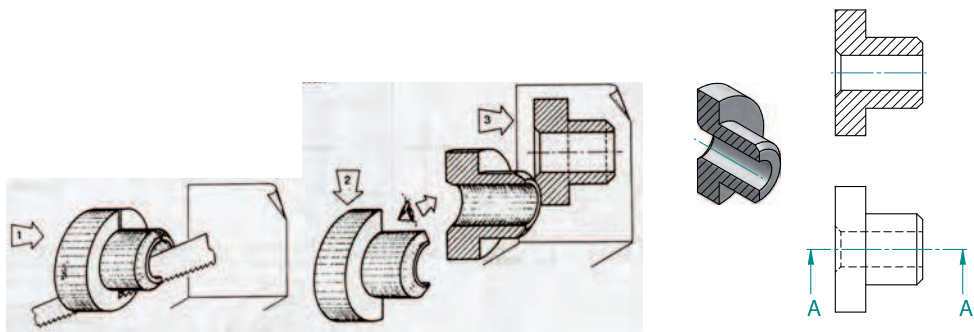
Fig. 14. cutting plane

Fig. 15. Example of different cuttings: aligned section, offset section view and broken-out section view

3.1.8 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...)

Chamfer

Vacums
(reducing the weigh
of the piece)

Rib and webs

Filled and rounded corners

Fig. 16. Piece with several industry's characteristic features

Fig. 17. Holes (drilled, countersunk, counterbored, blind and threaded holes)

3.1.9 Fundamentals of sketches

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

Fig. 18. Sketching process [15]

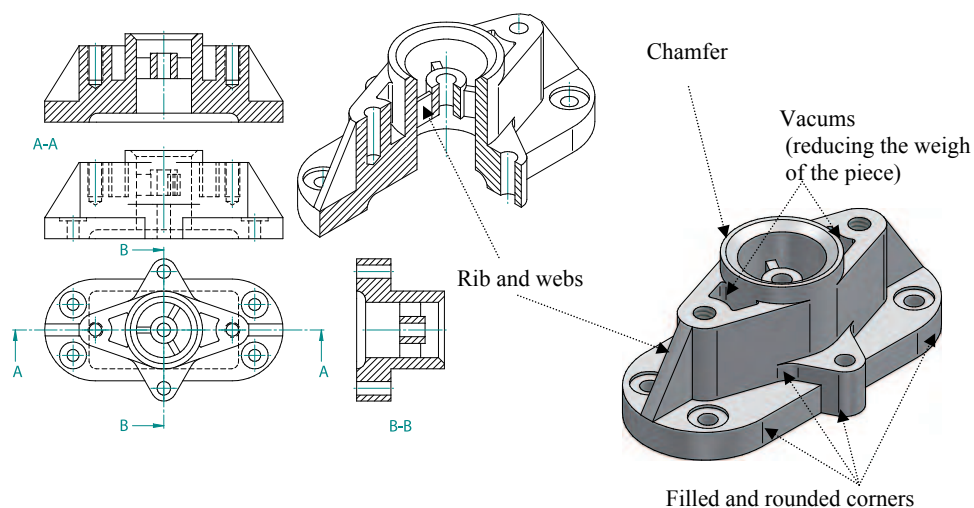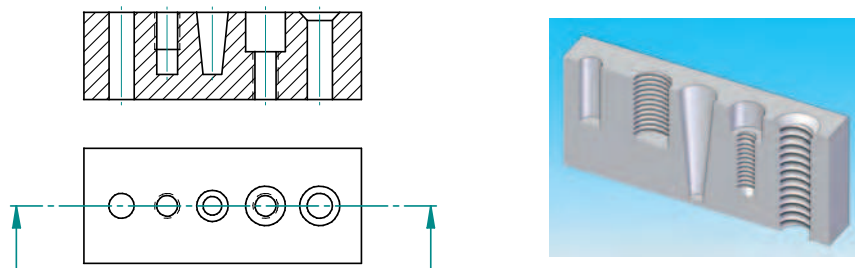Fig. 19. Cylinder intersection sketching process   Fig. 20. Bertoline 2003[10]

3.1.10 Methodology for Part Visualization Problem Solving and strategies

Qualitative data analysis. This involves learning to analyze the data of departure, the type of data and knowing how to interpret the obtained information to classify the types of pieces (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 piece.

- Elimination of volumes
- Decomposing into simple geometric elements

Fig. 21. Elimination [10] and descomposing [21]

- Correspondence Method (identify the different planes): pieces of flat faces

Fig. 22. First steps of solving process, identifying the planes which are paralell to the projection planes

- Identifying the vertices and joining them with the base (figure 23)

Fig. 23.

- Identifying the geometries of revolution through circles (centers) and axes figure 24)

Fig. 24.

- Differentiating between solid geometry (material +) and vacuum (material -) figure 25)

Fig. 25.

- Interpreting the information derived from the most typical Industrial elements (figure 26)

DETALLE A

A

DETALLE B

B

Analysing the left side of the piece, we can identify two holes which show as the upper and lower limit plane.

Fig. 26.

- Using the cutting (data) as a reference in the sketch (figure 27)

Fig. 27.

In order to solve the piece, an iterative process must be followed to solve all the elements of the piece in a logical sequence.

3.2 "Spatial Visualization"

This capacity, 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 very specific effort to attain the necessary level of this skill.

Fig. 28. Spatial Visualization fast exercises[10]

Steps:
- Analyzing types of cutting views/views (identifying cutting plans).
- Analyzing types of pieces (prisms, symmetry, elements)
- Prism drawing (symmetry)
- Drawing the cutting view plan
- Drawing walls
- Drawing characteristic elements
- Check

METHODOLOGY FOR PART (multiview drawing) VISUALIZATION PROBLEM SOLVING

FRONT VIEWPOINT

LEFTSIDE VIEWPOINT

TOP VIEWPOINT

VISUALIZATION

3D Rough sketch to represent the main features (low ability) (freehand/mental, expert mental)

3D Refined sketch (high ability) (freehand)

3D

New views and section views (low ability, freehand)

MINIMUM REQUIRED KNOWLEDGE

1- understanding the fundamentals of multiview, axonometeic and oblique projections
2- understanding the principles of orthographic projection (rules)
3-understanding the different types of planes and their projection
4-understanding the different solid primitives and their projections
5-understanding the different types of surfaces, the tangency and intersection between surfaces and their projections
6-understanding the fundamentals of the vacuum (- material, boolean)
7-understanding the different types of cutting planes and their attributes
8-understanding the main features commonly found in mechanical components (rib, web, holes, lug, chamfers, □)
9- understanding the fundamentals of sketching (multiview, axonometric, oblique)
10- understanding the different strategies of visualization

Breakdown of the analysis (subproblems)

Sequence (general-to-detail left-to-right top-to-botton outside-to-inside)

Qualitative data analysis:
1.- View : kind of view/section view
2.- Solid :
    - the general type of the component (main feature) linked with the visualization strategy : (boxing-in, revolving geometries, vacuums, symmetry, □)
    - analyzing positive and negative solid primitives of each feature
    - analyzing the common features of mechanical components
3.- Surfaces:
    - type of planes, contours
    - type of curved surface, tangencies, intersections
    - inside/outside surfaces
4.- Identifying the vertex

Visualization strategies :
    - identifying the different planes (flat surfaces)
    - removing from the boxing-in
    - decomposing into simpler geometric form (solid primitives)
    - visualization of the cutting plane
    - visualize the vertex
    - identifying axes/revolving geometries
    - identifying material/vacuum (positive/negative, boolean)
    - the attributes of common features in mechanical components
    - The attributes of surfaces tangency and intersections

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

Analysis of results (confirmation of the image)
    - The concordance with the data

Iterative process to solve the main features (breaking down the elements)

Analyzing
-Identify the viewpoint in 3D

Solution/Drawing (freehand, mental):
- Sketching process (view/cutting plane line alignment, auxiliary lines, proporcional,
- Sketching sequence (axes, contours, features,□)

Results analyze
- the concordance with the data
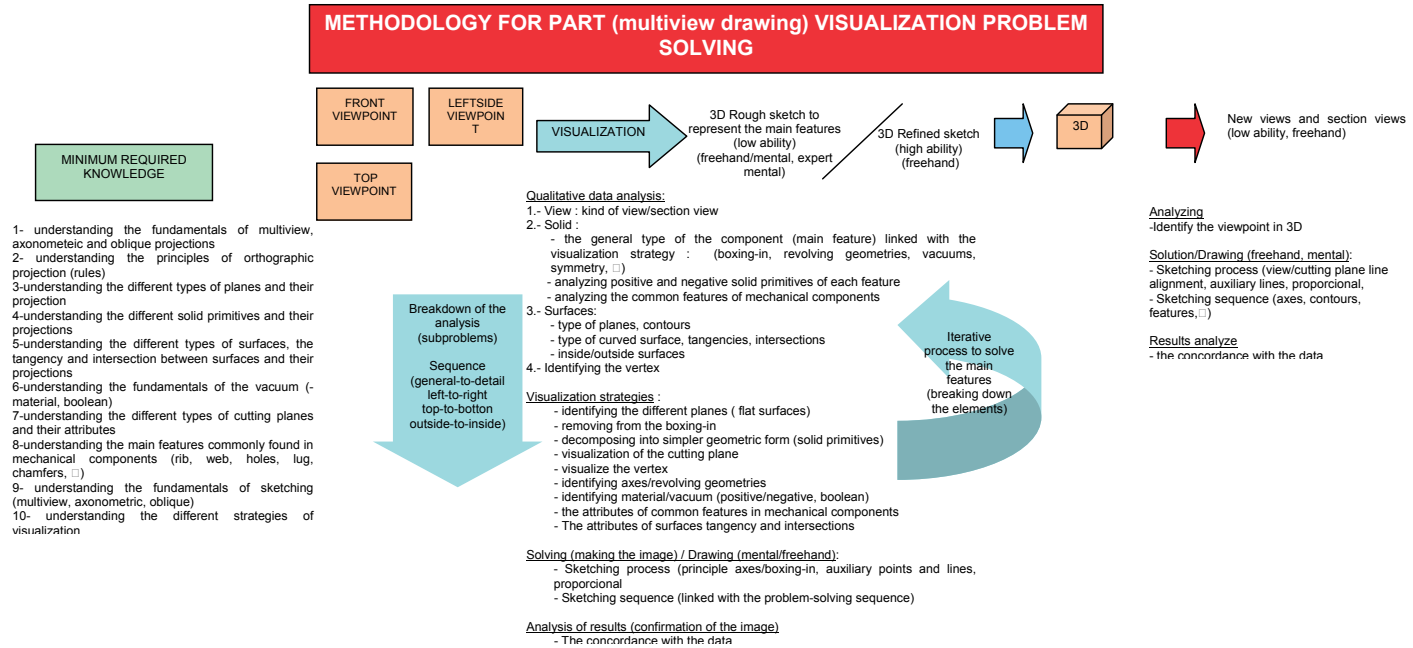
Fig. 29. Methodology for Part Visualization Problem Solving

4. Program of Activities

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 the activities is directly related to the step to be accomplished in the corresponding didactic unit.

Steps to follow

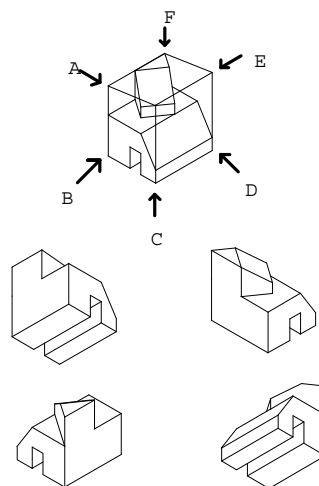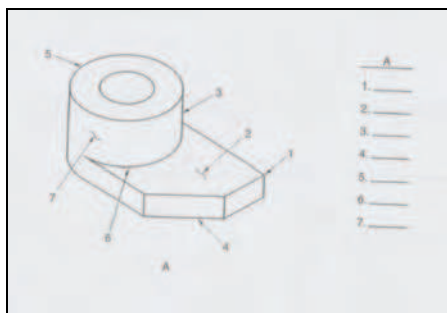| Step	Indicator to work	Carry Out Indicators	Dimensions	Types of activity
1	1 Spatial Visualization	1, 4, 9 Spatial Visualization	2D and 3D From 3D to 2D	Elements (points, lines, surfaces...) Identifying points of view, creating views, simple sketches Working the spatial visualization (Visualization Test) [16]

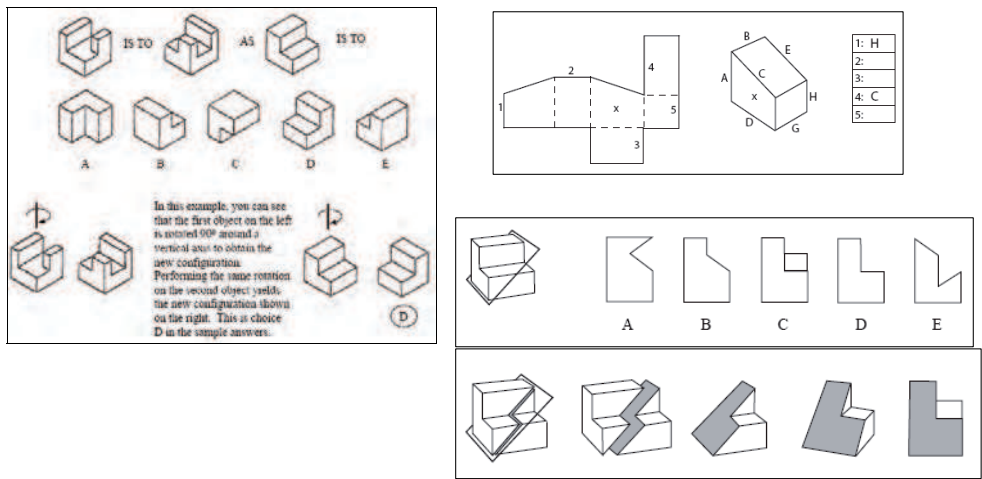Fig. 30. Identify elements [10] Bertoline and viewpoints

Fig. 31. Rotations, develops and sections from Visualization Test [16]

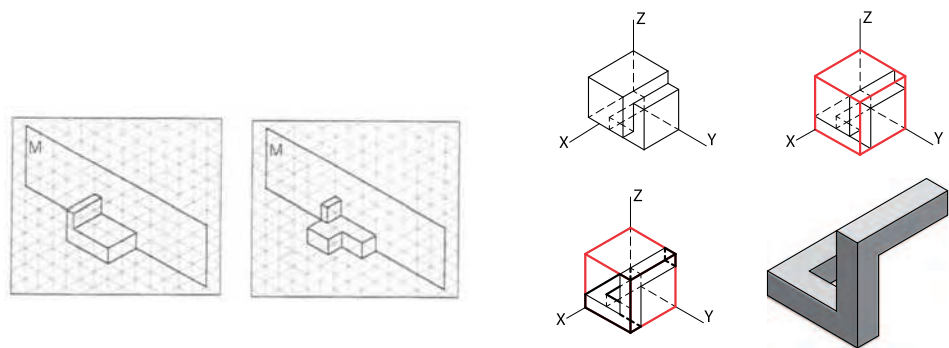Fig. 32. Easy sketches: mirror [10] and box-in it

Step	Indicator to work	Carry Out Indicators	Dimensions	Types of activity
2	2 and 3	1,2,3,4,9 Spatial Visualization	2D and 3D From 3D to 2D	Plane types, identification of planes Box-plane intersections in axonometric (Sketches)

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