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A Strategy for Teaching and Learning Technical Drawing*

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The present study describes a strategy for teaching and learning technical drawing, by enhancing students' skills in spatial perception. This strategy was proposed by means of literature review, which identified the strengths and weaknesses of technical drawing concepts up to date. This study allowed to construct a framework in which contains a general guide to address this strategy. It is a method in which students play an active role, initially manually sketching and on the drawing board before proceeding to the computer. The manual drawing was supported by origami systems, and Piaget's pedagogy to understand the space-plane relationship. From another point of view, it was used the problem-based learning on the drawing by computer to draw components that were drawn by hand. The research was conducted over two years in the course of industrial engineering. Purposive sampling was used to select 32 students participating in this research. The principal findings of this research concern the evolutionary learning of the orthogonal projections that enable students to draw objects in the plane that they first saw in the space.

Keywords: technical drawing; strategy; learning; spatial perception; framework

1. Introduction

Before a product can be manufactured, it must first be designed. This requires technical drawing, a skill in which images on computer screens are replacing those once crafted on drawing boards. A prerequisite for affecting a successful transition is the manual learning of technical design at the undergraduate engineering level. This is a process in which students play an active role, with media gradually supplementing—not replacing—the professor's contributions [1]. There is a dearth of reports on ways used to teach technical drawing to undergraduate students. There had been changes in the school curriculum in Scotland to suit the needs of education and industry. However, the manual technical drawing survived several revisions of the education curriculum (from 1972 to 1999). Circular 1101/1983 of the Scottish Education Department proposed that drawing courses be phased out and introduced into technical courses. The reaction of the Technology Teachers' Association in Scotland, backed by industry, reversed that decision [2]. These aspects in Brazil were different and ended up harming the teaching of technical drawing. In 1971, law 5,692/71 provided guidelines for primary and secondary teaching and on December 1, 1971, geometric drawing was relegated to a component of mathematics. In 1975, opinion 4,833, further vitiated educational mandates regarding drawing, and two years later, the university eliminated the drawing exam from its entrance examination for engineering school. In sum, drawing education has been reduced to a supplemental level in Brazilian education [3].

The devaluation of geometric drawing and descriptive geometry in Brazilian education has hampered its teaching, beginning in elementary school and continuing in secondary. As a result of such fragmentation, drawing education in engineering schools has also suffered and engineering students encounter difficulties in constructing orthogonal projections. To meet this ongoing challenge, this study describes a teaching framework experiment and it inspiring the development of this work. Hence, this study poses the following research question: What is the appropriate method for teaching and learning technical drawing in Brazil? To address it, an effective strategy was searched and conducted in the course of industrial engineering that supplements its curriculum with lectures on technical drawing using descriptive geometry devised by the teacher. The student should start the technical drawing on the drawing board using instruments (ruler, squares and compass), and the student moves to the drawing on the computer after demonstrating that its spatial perception has been perfected.

The origins of the geometric drawing can be traced from Plato (bC 428–348) to Monge (aC 1746—1818, descriptive geometry). Plato's renown pupil Aristotle (bC 364–322) founded the Lyceum. Later came the school of Alexandria, the world's first university; where Euclid (bC 330–260) introduced geometric theory set forth in The Elements

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[4]. Geometric drawing depicts lines, surfaces, and volumes, and can be defined as the science that researches the shapes and dimensions of physical object. Form is an aspect of a particular object, while size denotes its dimension. Plane geometry studies forms devoid of volume, i.e., figures drawn in a plane. It was born from man's desire to understand what is around him and to create a representation of that which previously could only be seen in one's immediate environment. Plane geometric figures include as example: the triangle, which can be equilateral, isosceles, or rectangular, a polygon formed by three sides; the square, a figure with four equal sides at right angles; the circle, a figure with a single line with a 360° circumference [5].

Solid geometry studies spatial figures; i.e., those having more than two dimensions, such as: the prism, a polyhedron composed of two parallel faces, which can be triangular, square, pentagonal, or hexagonal, and joining its edges in the shape of a parallelogram; the pyramid, a polyhedron comprising a base which can be triangular, square, rectangular, or pentagonal, with a vertex that combines all triangular sides; the tetrahedron, a regular polyhedron with four triangular faces; the cube, a regular hexahedron with six quadrangular faces; the sphere, whose sequential alignment points in all directions an equal distance from its center [6].

Descriptive geometry involves a pictorial space designed in two perpendicular planes, horizontal (top) and vertical (front) observed from infinity by means of linearly projected directions [7, 8]. It featured elements include (Fig. 1): epures projected orthogonally in the plane, which represent the drawing board; dihedrals, whose angle corresponds to a three-dimensional space between two half-planes, not contained in the same plane, and originating from a common edge.

Technical drawing (Fig. 2) entails the creation of a graphic representation of an engineering product that conveys its form, size, and other characteristics including material, roughness, tolerance, and

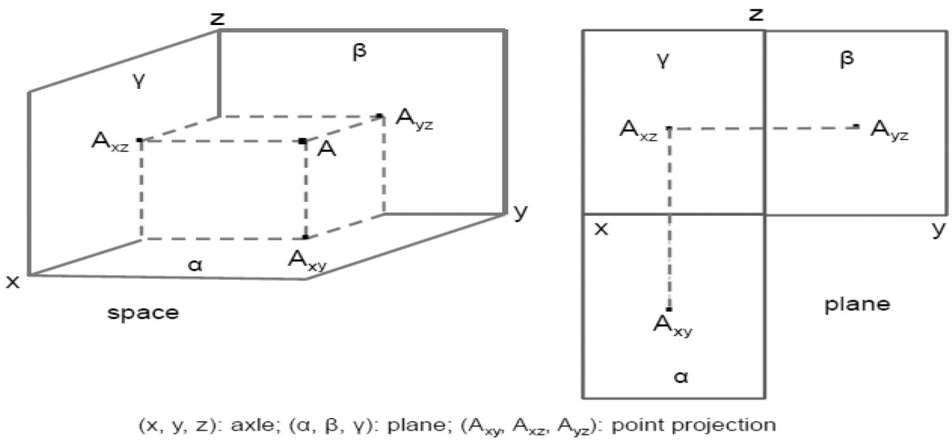

Fig. 1. Elements of descriptive geometry [6].

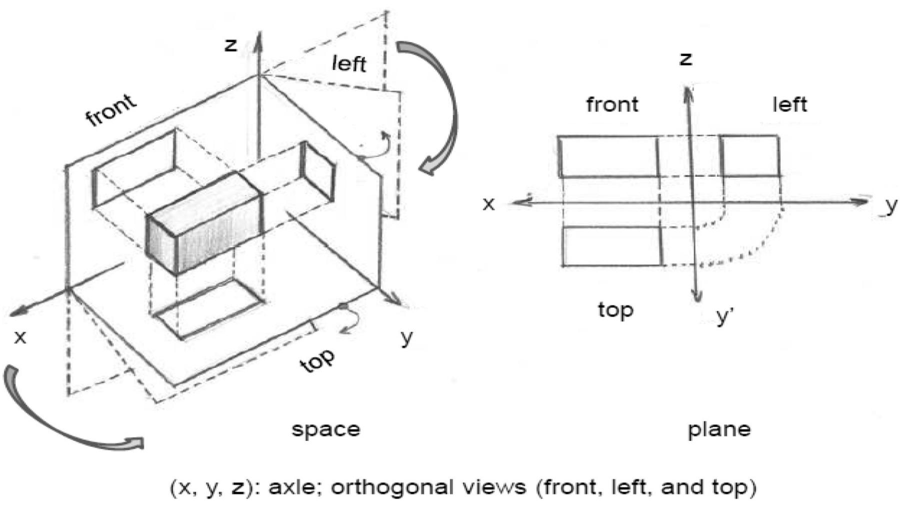

Fig. 2. Technical drawing.

adjustment [9–12]. It uses isometric perspective (solid geometry) that has three axes forming between them angles of 120° and oblique axes forming a horizontal angle of 30° degrees [11–13]. And, it uses the orthographic views, in the United States, on the third dihedral, and in Brazil and Europe, on the first dihedral, and are designated front, top, and left view, resulting from orthogonal cylindrical projections (plane geometry), aligned with each other, thus enabling the perception of their relative position (descriptive geometry).

This paper is structured as follows: section 1 presents the fundamental question addressed by the study and section 2 defines the teaching strategy from the research methodology. Section 3 provides ways of teaching and learning technical drawing and section 4 reports the strategy's evaluation. Section 5 presents the discussion and section 6, the conclusion, summarizes the results and provides recommendations for further research.

2. Literature review

2.1 Research methodology

The research methodology in this study can be divided into three stages, as shown:

- definition of the problem and research question was established in an introduction;
- a literature review from 2000 to 2018 regarding drawing concepts was conducted, using the ISI web of knowledge, scopus, and google scholar databases. The initial screening used the keyword "technical drawing", and the results were further refined, using the keyword "spatial perception" and "problem-based learning"; the remaining articles were reviewed, and a teaching and learning technical drawing framework were proposed;
- discussions and conclusions.

Table 1 presents a literature review (25 articles) in which the transformation of this experience with students was leveraged via the following: sketch, drawing board, orthogonal views, block models, spatial perception, adaptation, CAD and PBL.

Manual drawing is important today for students in engineering school. In this way, they know how to draw using ruler, straight edge, and compass in a world in which designs are done by computer [2]. At the University of Debrecen, Hungary, the basic studies have difficulties, due to the difference between the level of knowledge of the high school teaching, as the number of geometry classes is being reduced the education becomes profuse. One of the way to solve this problem, full-time engineering students have seminars on descriptive geometry [14]. At the University of Pittsburgh in Johnstown, USA, all engineering students have the engineering drawing course. The first goal is to interpret and communicate with technical drawings and sketches, only then use computer-aided graphics software [15]. At the Technical University of Valencia, Spain, 2D freehand sketching application is used that can generate 3D drawing. The purpose of this application is to develop the future engineer in spatial visualization, in the sketch, and in the front, left and top views [16].

Orthographic projections for the determination of objects are a method developed to obtain 3D models of prismatic pieces used in 2D technical drawings [17]. An innovation in the teaching of technical drawing to improve the spatial visualization of objects through orthogonal views was applied in engineering at Polytechnic Montréal, Canada. The result of this research is a 2D/3D tutorial that teaches students how to visualize the orthographic projection exercises solution [18]. The major difficulty of technical drawing is to represent an isometric solid in orthographic views. In order to succeed in this direction, engineering students must be able to compile the spatial properties of objects on flat paper [19–20]. Block model is a system that represents a solid inside a glass box. In this way, students draw the front, left and top views on the faces of the glass box [15]. A simplified way is the concrete representation with blocks of wood to be drawn by the student, which can be observed and touched. In this situation, the student will practice the passage from the orthographic views into isometric perspectives [21].

Adaptation is a biological mechanism of transformation deployed by the body for its conservation. For Piaget, knowledge is based on this process, highlighting structural and functional intellectual environments, with structure involving the nervous system and sensory organs and function serving as a means of intelligence. Intelligence has an hereditary functional relationship with biological organization, which, in turn, is related to adaptation [24–27].

Table 1. Characteristics from articles

Characteristics	Articles	Characteristics	Articles
Sketch	14–16, 29	Adaptation Piaget	22–27
Drawing board	2, 14–16	Spatial perception	2, 14–16, 19–24, 28–29, 37
Orthogonal views	15–21, 29	CAD	2,15, 17–19, 22, 27, 29, 34–37
Block models	15, 20–21, 37	Problem-based learning	27, 30–33, 36

Adaptation forms the mental or cognitive inferred structures, processes of knowledge attained through perception, association, memory, reasoning, and imagination [24]. Cognition is the way the brain perceives, learns, and thinks about data received through the senses. More than simply the acquisition of knowledge, it is an effective way to interact with our peers and the environment in which we live without losing our existential identity [24].

At Tshwane University of Technology, South Africa, the engineering design course teaches communication in the form of drawing. In this course, students have difficulties in spatial visualization. Thus, to mitigate this problem, during the teaching of drawing, it was used the perception of Piaget [22]. The spatial visualization is fundamental for understanding technical drawing. The knowledge is not a copy of reality based on Piaget's theories, for knowing an object is not simply looking at it. You have to understand it [15]. Spatial visualization is very important for the engineer when drawing and interpreting technical drawing. This fact translates thinking and modeling into product development. The correlation of the orthographic projection and the isometric perspective are fundamental for technical drawing. In this way, students without skill had problems to understand fundamental concepts of engineering drawing. One way to aid the visualization is to begin by drawing manually, and later draw on the computer [14, 15]. This is the question, the environment can be perceived in two stages. Initially, through drawing using manual instruments (ruler, straight edge, and compass) on a drawing board. And subsequently via computer application (CAD), a progression [2], which is the focus of this study. This will affect spatial perception, i.e., the mental visualization of a spatial form [16, 20–23].

This is a way of perceiving the object without seeing it. Spatial perception guides the transition between two-dimensional depictions and three-dimensional objects and vice versa with the help of brain through vision. A beam of light rays pass through the iris and retina. This light energy is transformed into bioelectric energy, which through nerve stimulation travels along the optic nerve, reaching the brain [20–21]. The current higher education is a function of skills. Spatial ability is a basic skill to develop decision making, teamwork, creativity, others. At the La Laguna University, Spain, a workshop on three-dimensional creative modeling (Stella 3D) was carried out to improve spatial ability, skills and creativity [28]. Visualization is a fundamental skill in engineering, because it understands the reading and creation of technical drawing. However, engineering students show learning difficulties in this subject. For this, when the teacher presents the solution to a technical drawing problem, whether manual or computational, he/she will not be helping the students in the learning process. Then, he/she must to work with the student in the visualization process [29].

Engineers should be able to acquire new knowledge and find solutions on their own initiative. This requires a capacity for individual and team work. Problem-based learning is a pedagogical concept that emphasizes learning over teaching and focuses on solving concrete problems with the teacher serving as tutor and students working together as a team. It is the student who decides to study and is an active participant in the learning process. Students collaboratively evaluate the statement of the problem and through brainstorming systematize ideas to plan solutions and set goals. In subsequent meetings, they will assess whether the plan's objectives are being achieved, review the problem statement, and revise the plan as needed to attain a final solution [30–33].

Technical drawing encompasses the construction of form and dimension using the ruler, straight edge, and compass. Alternatively, it can be accomplished with the aid of computer-aided design (CAD), which simulates the manual techniques of the drawing board and its instruments [14–15, 34]. Engineering design was created under the aspect of art and science, while drawing was created to represent the product. In its design, the technical drawing can have manual or CAD origin. The definition of technical drawings was then adopted from British Standards (BS ISO 6707: 2004): "Technical information, given on an information carrier, graphically presented in accordance with agreed rules and usually to scale" [35].

The globalization of international recognition of engineering qualifications reduced the time available at Malaysian universities to teach a range of practical skills. In Australia, the students developed skills in industrial design of assemblies with sizing of the elements of machines. Internationally, engineers must have competence in Europe and the USA to draw and interpret drawings. There is a tendency to create freehand drawing (2D) and then move to software (3D), which are automated designs [36]. Spatial ability can be enhanced through the students' hobby as a valid training strategy without academic exercises. The use of video games playing Nintendo Tetris, in intensive drawing training courses, develops the ability to imagine rotations of 2D and 3D objects, improving the development of spatial skills [37].

2.2 *Wilcoxon rank sum test*

The Wilcoxon rank sum test, which is nonparametric, is used to measure the position of two samples. Consider two samples of size n coming from X_i and Y_i. In this case, the observations are paired. Set to $D_i = X_i - Y_i$, for i = 1, 2, . . . , n. Thus, one obtains the sample $D_1, D_2, \ldots, D_n$, resulting from the differences between values of each pair. For testing purposes, one must first establish the null hypothesis, which has the same position: H_0: $X_1 = X_2$. Another hypothesis pertains when the median of the difference is not zero, in which case, the populations differ in location, or X_1 distribution is shifted to the left: X_2, $H_{1:}$ $X_1 < X_2$ [38]. The measurement and distribution of the X population of industrial engineering students is assessed through a questionnaire: How does one assess the student's ability to perceive spatial objects drawn in the plane? Does isometric perspective assist in spatial perception? [39–40].

3. Method proposal

Figure 3 presents a proposed framework for application. It was developed in three phases and seven steps.

Phase 1: Planning
Planning has established the population of the study. It was intentional because it was a class of students in the course of industrial engineering. These students did not have descriptive geometry in high school.

Step 1: Activities
Activities and their programming were included in the study (Table 2).

Step 2: Subjects
The study was conducted in the course of industrial engineering of the University Sao Paulo. The subjects comprised 32 students in a first-year industrial engineering class. Subject were interviews as follow:

- age: 17 (8%), 18 (82%), 19 (10%);
- gender: male (86%), female (14%);
- city: Sao Carlos, Sao Paulo, Brazil (23%), other (77%).

The environment can be perceived in two stages:

- initially, through technical drawing using manual instruments (ruler, straight edge, and compass) on a drawing board;
- and subsequently via computer application (CAD).

Change on curriculum depicts different periods in the history of the school of engineering where the new technical drawing course was introduced in Table 3. Geometry descriptive was an integral part of the high school curriculum at that time and remained so until the close of the 1970s. During 1980s–1990s, the first year of undergraduate engineering education included geometry descriptive and technical drawing. In the second year, additional technical drawing was added for an aggregate of 180 hours in these related disciplines. In the 2016 academic year, in which this study was conducted, the time allotted these courses was reduced by a third to 120 hours. However, these hours were offset by the introduction of the CAD system. Another observation, before the introduction of the computer, students should first begin learning on the free-

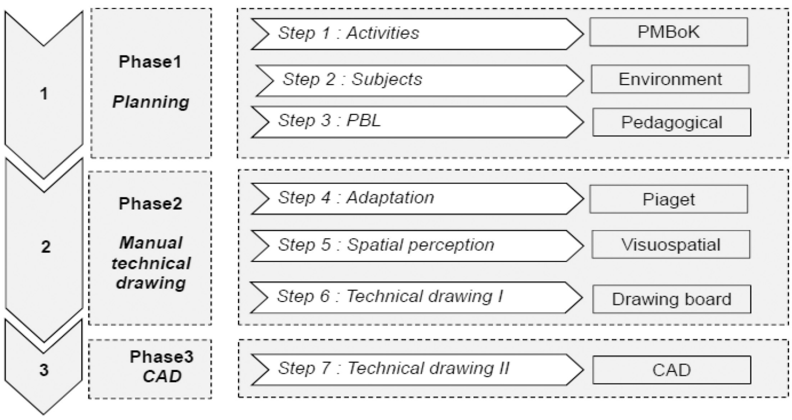

Fig. 3. Technical drawing framework.

Table 2. Scheduling activities

Processes	Initiating	Planning	Executing I Drawing board	Executing II CAD	Controlling	Closing
Schedule	2015, 10 2015, 12	2015, 10 2016, 03	2016, 02 2016, 06	2016, 07 2016, 12	2016, 02 2016, 12	2016, 12 2017, 03

Table 3. Effect of teaching technical drawing

	Before	After
Discipline	Department of civil engineering teaches to civil, electrical, industrial, and mechanical engineering	Department of mechanical engineering teaches to aeronautics, industrial, materials, mechanical, and mechatronics engineering
	Drawing board 1st and 2nd semester geometry descriptive and technical drawing	Drawing board 1st semester technical drawing
	Drawing board 3rd and 4th semester technical drawing	CAD 2nd semester technical drawing
	3 hours / week / 4 semesters (180 hours)	4 hours / week / 2 semesters (120 hours)

Obs: 1 semester = 15 weeks.

hand drawing board. After that, students will draw with instruments in drawing board. Students should perform a lot of exercises on orthographic projections. They should also apply origami systems to develop spatial perception. Following will present a framework that will elucidate this method.

Step 3: Problem-based learning (PBL)
The PBL process applied to the technical drawing is described as follow:

- students are encouraged to take responsibility for organizing and directing the learning process with the tutorial support of the teacher;
- this pedagogical concept is used to enhance their acquisition of knowledge and accelerate their development of communication, problem-solving, and self-learning skills. Teaching descriptive geometry through technical drawing using exercises in a didactic sequence was largely an inferred strategy, not simply induced;
- this process is abstract, proposing that teaching and learning binomial theory and practice should be tutored by the teacher;
- there must be a link between the concepts introduced in the lecture and their concrete application, systematically disseminated in models that facilitate students' assimilation of the theory underlying them.

Phase 2: Manual technical drawing
This will affect spatial perception, i.e., the mental visualization of a spatial form. This is a way of perceiving the object without seeing it. Spatial perception guides the transition between two-dimensional depictions and three-dimensional objects and vice versa. And, the Problem-based learning supports the transformation of the orthographic views into isometric perspectives.

Step 4: Adaptation
Through adaptation of the technical drawing discipline:

- represented by the drawing board, and supplemented with exercises using cognitive and constructive psychology, e.g., Piaget's;
- students are engaged in learning and motivated to learn drawing in view of its critical application in their professional careers.

Step 5: Spatial perception and origami system
The following factors were established at the onset:

- identification of student needs, including potential obstacles to learning and their remedial diagnosis, as well as establishing the dimensions of instructional areas;
- the hardware selected for the study was the drawing board, in the first semester, and students were motivated by the simulation of three-dimensional objects via wooden blocks, origami systems (Figs. 4 and 5).

Figure 4 shows the origami systems, as follow: (1) to draw isometric-solid (wooden blocks); (2) to draw orthographic views in the paper; (3) to cut the paper; (4) to fold the paper (α and β); (5) to put β under α and folding paper; (6) to hold on the object ("in the air") in front of views. Fig. 5 shows, as follow: (1) orthographic views (plane); (2) origami system (space); (3) solid in front of views.

Step 6: Technical drawing I (drawing board)
The strategies on drawing board are the following:

- environment: 45 drawing boards, PC computer, air conditioning, good lighting, 200m^2;
- didactic materials: orthographic, quote, tolerances; drawing solid, wood block objects; spatial vision; drawing front, left, top views of solid object;
- PBL application.

The study entails sequential instruction in manual technical drawing in the classroom:

- students learn the concepts of descriptive geome-

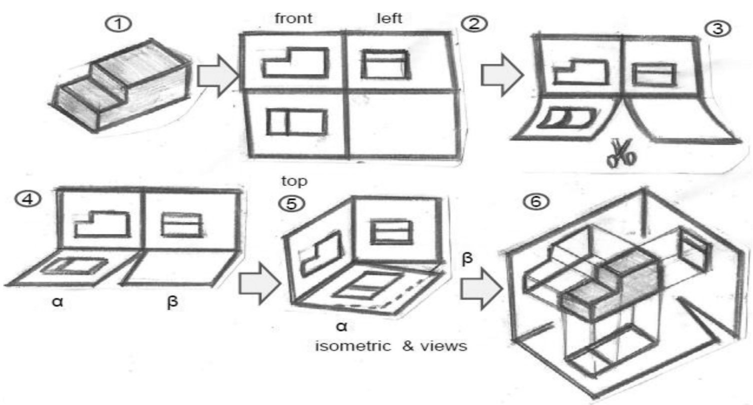

Fig. 4. Origami systems.

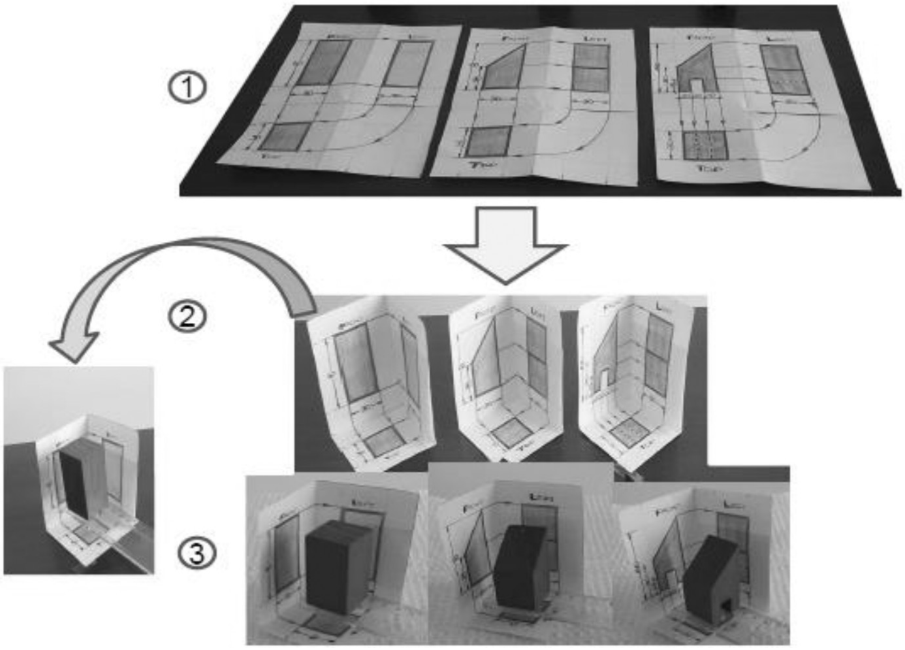

Fig. 5. Wooden blocks and origami systems.

try through systematic exercises in spatial perception;

- they first manually draw three-dimensional objects on the drawing board. Recommended pedagogical strategies include solving a series of exercises;
- the teacher will guide students by PBL to prepare traces, thick and thin, continuous and dotted lines, initially without using CAD, to integrate with other disciplines, e.g., by visiting metrology laboratories to identify instruments of measurement and their relation to dimensional and geometric tolerance in the technical drawing;
- and to understand the role of machine tools and how they relate technical drawing to manufacturing (www.prod.eesc.usp.br/numa);
- at the onset of the first semester, a system provides students classroom access to a university web site (www.simulacao.eesc.usp.br/dtm) replete with educational materials, including a work development power point, with technical assistance available in person at established times.

This step encompasses the following exercises using PBL: drawing solid objects from an isometric perspective, correlating diverse views with their corresponding objects by enumerating their vertices and perceiving their relations. The students should repeat several times, as deducing from two views the remaining third. The development of teaching materials as found on the previously noted university web site (see Fig. 6). The Fig. 6 illustrates the figures corresponding to the solids by using the following rules: ‘‘the projections of a point will be aligned in different views; the dimension between two points

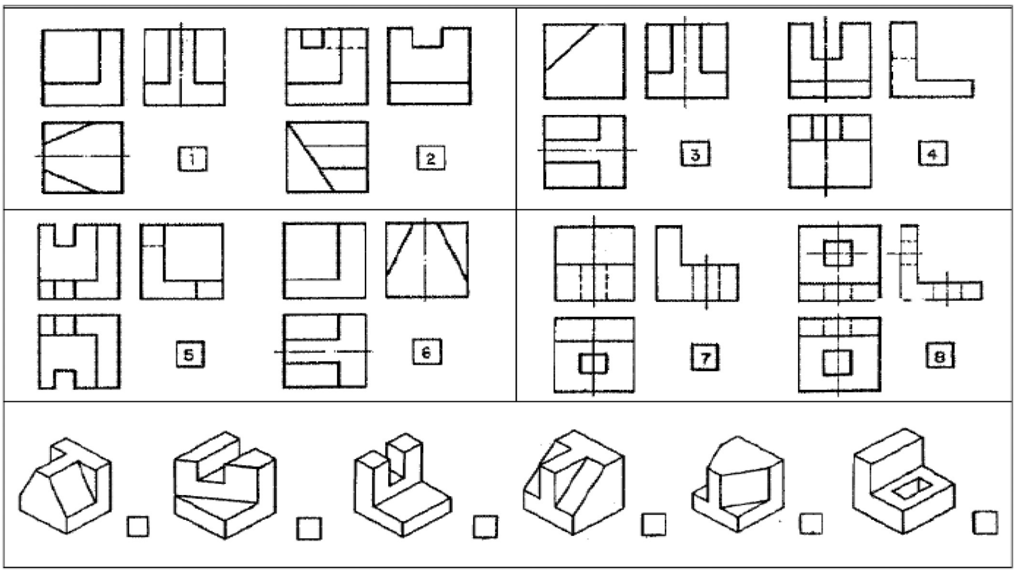

Fig. 6. Views and solids: relationship (www.simulacao.eesc.usp.br/dtm).

will be the same from different views; parallel lines in the different views will remain always parallel; 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; two continuous areas separated by a line cannot be on the same plane; 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" [29].

Phase 3: Computer technical drawing

Students begin technical drawing on paper in sketch form and continue, using the instruments of ruler, straight edge, and compass, to eventually arrive at the computer screen. There, they gradually progress beyond the model to take advantage of the greater capacity for abstraction and maturity provided by display's three-dimensional orthographic views using problem-based learning within CAD.

Step 7: Technical drawing II (CAD)

The strategies on CAD are the following:

- environment: 45 workstation, air conditioning, 100m^2, Solid edge ST8 (licensed);
- didactic materials (sub-routine): rectangle, circle by center point, extrude, remove, connect, parallel, concentric, smart dimension;
- PBL-CAD application.

The application of the PBL-CAD in the computational technical drawing was developed as follows:

- tutorial$_1$: at the onset of the second semester, students are instructed to download software (Solid edge) on their personal computers and to complete tutorial$_1$ which involves drawing a cylinder pin. In the next class, students perform the same tutorial in the CAD lab in the presence of the teacher (www.simulacao.eesc.usp.br/dtm);
- tutorial$_{2-3:}$ the process is reiterated through tutorial$_{2,3}$;
- tutorial$_{4-16}$: Beginning with tutorial$_4$, students work in groups in the CAD lab, provided that they have already completed the tutorial individually at home;
- in the final phase of the second semester, students depict the same objects previously drawn on the drawing board during the first semester (Fig. 7), using CAD;
- drawing on the board and CAD (Solid edge) fixture assembly and six components;
  - including material, roughness, dimensional and geometric tolerance, adjustment, and manufacturing route;
- in Figure 7, in order to draw the named shaft component (number 6, Fig. 7);
  - on paper, it was necessary to draw left view of circumferences, using the compass and to draw front view of rectangles, using a straight edge and ruler;
  - in the computational (Solid edge) drawing, using the ISO part, base reference plane, view orientation, circle by center point, smart dimension (diameter), extrude (height).

4. Results

Students arrived at university with few experiences of spatial perception of three-dimensional depictions and thus encountered difficulties in drawing

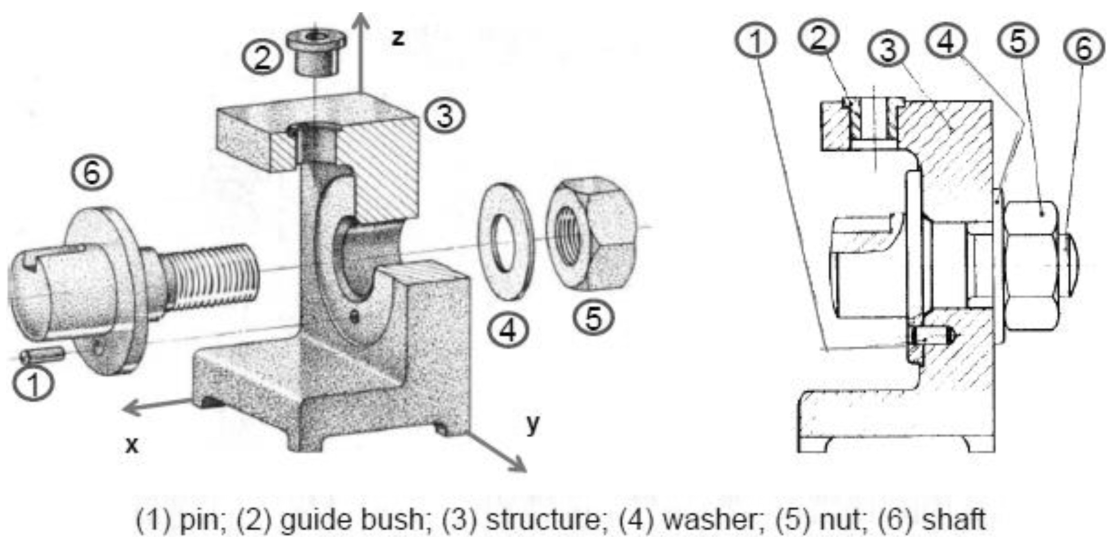

Fig. 7. Assembly and exploded-view (adapted from [41]).

Table 4. Study evaluation, using Wilcoxon rank sum test

	Median			
Question	**Before**	**After**	**p-value**	**Discussion**
1. Dihedral	1	8	0.00019	Good performance, although students lacked knowledge of descriptive geometry knowledge.
2. Plane	3	8	0.00025	Good progress, students could perceive spatial objects in the plane.
3. Space	1	8	0.00019	Students attained enhanced spatial perception.
4. Isometric perspective	3	8	0.00022	Starting views, students perceived isometric perspective.
5. Orthographic view	1	9	0.00019	Excellent, students used front and left views to deduce top view and solid object.
6. Dimension	2	8	0.00021	Students had no difficulty in correlating metrology and measurement.
7. Assembly	1	8	0.00018	Students learned how to represent an object, using its frontal view.

Obs: Purposive sampling was used to select 32 students participating in this research.

orthogonal projections in the plane. This condition has been strategically assessed through the introduction of simulations with physical objects supplemented by exercises and teacher mentoring and monitoring. The transformation of this experience with students was leveraged via motivation, PBL, and cognitive experimental methodology. The results were evaluated using a Wilcoxon rank sum test questionnaire. Table 4 indicates that the Wilcoxon rank sum test evidences a significant difference, p-value < 0.05, for all seven questions.

5. Discussion

To answer the research question and to conduct the study without affecting current courses, the department of mechanical engineering began teaching technical drawing in all semesters to first-year students that addressed its application to aeronautic, industrial, material, mechanical, and mechatronic engineering. The study features the use of the drawing board, including complementing a descriptive geometry lecture with wood block exercises associated with drawing front, top, and left orthographic views, which, when folded as origami systems, facilitates spatial perception of the plane. In Brazil, the number of credits allotted technical drawing courses has been reduced, making it even more essential to adopt an effective pedagogical strategy to put this limited time to its best use. The approach described in this study enables students to actively participate in the learning process with tutorial support and guidance from their teacher. Its primary contribution was the design of a didactic sequence in technical drawing that progresses from use of the drawing board to use of computer-assisted design. Fig. 8 represents the technical drawing guide that begins with the literature review, and use other practices (origami, problem-based learning), which aids the teaching and learning of technical drawing.

Technical drawings define an engineering product before it is manufactured. Topics such as orthographic views, dimensions, and perspectives

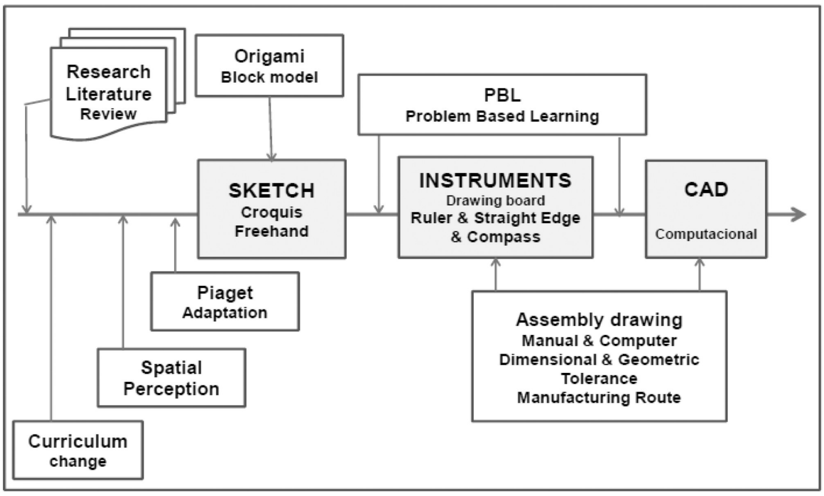

Fig. 8. Technical drawing guide.

are part of the curriculum of every technical drawing discipline. Although the fundamental principles of technical drawing remain the same, the increasing use of computer-aided design has created a rupture with past models for teaching this discipline. Methodologies to tailor the curriculum to the new graphical tools available to the designer and to motivate engineering students to study technical drawing remain unresolved. The development of computer technology has facilitated the imaging of three-dimensional objects, but the reasoning ability of the student remains the key to interpreting technical drawings and, even more important, for creating and disseminating new ideas. Thus while computational resources offer numerous advantages to technical drawing, their full benefit can only be attained if the engineer has accurate spatial perception, the ability to think in three dimensions, and the capacity to perceive the plane as a spatial object.

Table 5 lists a framework proposal versus literature review, in which, the transformation of this experience with students was leveraged via motivation, and cognitive experimental methodology. The new method proposed in this paper emerged from a synthesis of successful 23 studies described in the literature review. This body of knowledge has revealed significant common points, such as spatial perception, wood block and origami, which continue to help to identify opportunities for implementation in improvement. The method proposes to initiate a drawing in the plane and in the space in the sketch format and only later perform it with instruments. In this way, it can be understood with a perception to begin the knowledge of integrating space with the plane. The teacher motivates engineering students to learn technical drawing in such a way that they can perceive a physical object from its depiction in the plane.

In Brazil, descriptive geometry teaching has been increasingly neglected in high school [3], likewise in Malaysia [36] and Hungary, where students have difficulty seeing in space [14]. This fact is also observed in South Africa, for this it was introduced the perception of Piaget [22]. In Canada, the spatial view was improved with training in orthographic projections [18]. In Spain, students can use the software to draw [16, 28]. At the University of Coimbra, Portugal, the course of drawing is supported by orthographic projections, and then pro-

Table 5. A framework proposal (P) versus literature review

	Articles																							
Characteristics	**2**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**35**	**36**	**37**	**P**
Sketch		x	x	x																				**x**
Drawing board	x	x	x	x																				**x**
Orthog. views				x	x			x	x															**x**
Block models			x					x	x														x	**x**
Origami																								**x**
Adaptation										x		x	x	x										**x**
Spatial percep.	x	x	x	x			x		x	x	x				x	x								**x**
CAD	x		x			x															x	x		**x**
PBL														x			x	x	x	x		x		**x**
PBL-CAD																								**x**

gress to the technical drawing. At the University of Oviedo, Spain, students begin with technical drawing interpretation and orthographic views, and then proceed with 3D software. In the School of Madrid, Spain, the students develop the skill of spatial visualization using informatics. At the University of Quebec, Canada, the course is developed in the computer-aided product design. At the Faculty of Engineering of Milano, Italy, the course relies on instruments for drawing, visualization and spatial application [42].

Knowledge, according to Piaget, does not copy reality, but rather understands space, whose construction begins with perception [15]. Perception collaborates with decision making and creativity. The teacher does not solve the problem, but rather plays the role of tutor [28]. Students can use tutorial to understand the space-plane relationship [18]. The application of cognitive psychology is an important methodology in the construction of skill tests. Spatial perception is one of the most studied skills in human cognition. Today, the interest that awakens with verbal aptitude and reasoning can explain the variance of the scores in tests. Also, its application is important in technical drawing. Visualization was defined as the ability to generate a mental image, performing various transformations on the image and retaining the settings in the representation. The visualization is evaluated by means of geometric tests and the evaluation by the Rasch model [43].

Analysis of the relevant papers found in the literature review confirms that any paper in the literature proposed a framework like the one that combines PBL with manual and origami system and CAD technical drawing.

6. Conclusions

The present gap of descriptive geometry instruction in high schools has an adverse impact on learning in undergraduate engineering schools. A major contribution of this study was to compensate for this deficit with respect to technical drawing concerns motivating students. The PBL pedagogical effect showed to the students, when drawing by CAD, the importance of having started by free hand. Learning to learn helped them in this process. Also, the literature review showed two paths, one of them goes directly to CAD, and the other starts with instruments. The present study decided to emphasize technical drawing by hand firstly, because the manual technical drawing survived in Scotland [2] and in the USA, University of Pittsburgh, where students firstly interpret and communicate with sketches and then use CAD [15]. Learning from wooden block and origami systems simulations provides the most stimulating motivation. This study has added to our knowledge of how to equip engineering students to learn to see, think, and, above all, create. It is but one step on the road to progress that should be pursued with vigor. This is a way of perceiving the object without seeing it. Change in the curriculum was imperative to improve the learning of students who had not known descriptive geometry. Moving on to draw in a mechanical engineering environment, visiting metrology laboratories and CNC machines to aid in the development of the manufacturing route. Through the perceptible representation of objects in orthographic views and isometric perspectives, students feel encouraged to design engineering products.

The limitation of the research was to have been carried out in only one university, which limits the general applicability of the proposal. However, this study can serve as a reference model not only for the case, but also for other universities, in Brazil and worldwide, interested in adopting the method approaches in their teaching and learning, according to their specific needs.

It is recommended that future research explore how the learning process could be further enhanced by adding other methods to strengthen the association of manual technical drawings with computer-generated images. Innovative software technologies expand possibilities for effective pedagogical strategies exploiting new teaching resources. It is crucial that we maximize every opportunity to restore and advance the essential contribution of technical drawing education to ensuring engineering excellence.

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References

1. G. Prieto and A. D. Velasco, Does spatial visualization ability improve after studying technical drawing? *Quality & Quantity*, **44**(5) 2010, pp. 1015–1024.
2. S. V. McLaren, Exploring perceptions and attitudes towards teaching and learning manual technical drawing in a digital age, *Int. J. Technol. Des. Educ.* **18**, 2008, pp. 167–188.
3. MEC—*Ministry of Education, National Education Statistics*, law directives and bases, Brazil, 1996.
4. C. B. Boyer and U. C. Merzbach, *A History of Mathematics*, Wiley Publishers, 2011.
5. H. E. Slaugth and N. J. Lennes, *Plane geometry with problems and applications*, Norwood Press, USA, 1910.
6. H. E. Slaugth and N. J. Lennes, *Solid geometry with problems and applications*, revise edition, Norwood Press, USA, 1919.
7. G. Monge, *Geometry descriptive*, 7 ed. Bachelier, Imprimeur-Libraire, Paris, 1847.

8. F. I. Asensi, *Geometry descriptive*, Editorial Dossat, S.A., Madrid, 1980.
9. F. E. Giesecke, A. Mithcell. H. C. Spencer, I. L. Hill, J. T. Dygdon, J. E. Novak and S. Lockhart, *Modern graphics communication*, 1st edn, Prentice Hall, 1998.
10. T. E. French and T. French, *Mechanical Drawing: Board & CAD Techniques*, McGraw-Hill, Glencoe, 2002.
11. J. M. Leake and J. L. Borgerson, *Engineering, Design, Graphics, Sketching, Modeling, and Visualization*, second edition, John Wiley & Sons, 2013.
12. D. A. Madsen and D. P. Madsen, *Engineering Drawing & Design*, 5 edn. Cencage, Oregon, 2012.
13. M. L. Martinez, A. Carretero, G. Romero and J. M. Mera, Evaluation and use of the standards in of the technical drawings in the final year Project, *WCES*-2010.
14. R. Nagy-Kondor, Spatial Ability, Descriptive Geometry and Dynamic Geometry Systems, *Annales Mathematicae et Informaticae*, **37,** 2010, pp. 199–210.
15. T. Serdar and R. H. deVries, *Enhancing Spatial Visualization Skills in Engineering Drawing Course*, In: 122nd ASEE Annual Conference, 2015, pp. 1–12.
16. M. Contero, F. Naya, P. Company and J. L. Saorin, Learning Support Tools for Developing Spatial Abilities in Engineering Design, *International Journal of Engineering Education*, **22**(3), 2006, pp. 470–477.
17. I. Cayiroglu, A new method for machining feature extracting of objects using 2D technical drawings, *Computer-Aided Design*, **41,** 2009, pp. 1008–1019.
18. A. Cincou, An Innovative and Interactive Approach to Teaching Industrial Drawing to Engineering Students. In: *Canadian Engineering Education Association*, Paper 066 2013, pp. 1–6.
19. S. Murad, I. Passero, R. Francese and G. Tortora, An empirical evaluation of technical drawing didactic in virtual worlds, *iJOE* **7**(1), 2011, pp. 23–30.
20. M. Sroka-Byzon and E. Terczynska, Perception of view—how to develop spatial imagination, *The Journal of Polish Society for Geometry and Engineering Graphics*, **25,** 2013, pp. 19–26.
21. S. Olkun, Making connections: Improving spatial abilities with engineering drawing abilities, *International Journal of Mathematics Teaching and Learning*, **10**, 2003, pp. 1–10.
22. M. Makgato and S. D. Khoza, Difficulties of Student Teachers in the Engineering Graphics and Design Course at a South African University: Snapshot on sectional drawing, *Eurasia Journal of Mathematics, Science & Technology Education*, **12**(4), 2016, pp.703–715.
23. C. Potter, W. Kaufman, J. Delacour, M. Mokone, E. Merwe and P. Fridjhon, Three dimensional spatial perception and academic performance in engineering graphics: a longitudinal investigation. *South African Journal of Psychology*, **39**(1), 2009, pp. 109–121.
24. J. Piaget, *La représentation du monde chez l'enfant*, Librairie Félix Alcan, Paris, 1926.
25. J. A. Newell, A. J. Marchese, R. P Ramachandran, B. Sukumaran and R. Harvey, Multidisciplinary Design and Communication: a Pedagogical Vision, *International Journal of Engineering Education*, **15**(5), 1999, pp. 376–382.
26. V. Hubka and W. Ernsteder, Pedagogics of Design Education, *International Journal of Engineering Education*, **19**(6), 2003, pp. 799–809.
27. B. Bender and J. Longmuss, Knowledge Management in Problem-Based Educational Engineering Design Projects, *International Journal of Engineering Education*, **19**(5), 2003, pp. 706–711.
28. J. T. Cantero, J. L. Saorin, D. Melian and C. M. Stella, 3D: Introducing Art and Creativity in Engineering Graphics Education, *International Journal of Engineering Education*, **31**(3), 2015, pp. 805–813.
29. E. S. Uria, M. G. Mujika and L. B. Apraiz, Solving the Problem of Interpreting Views: Teaching the Part Visualization Process, *International Journal of Engineering Education*, **28**(3), 2012, pp. 663–673.
30. C. E. Hmelo-Silver, Problem-based learning: What and how do students learn? *Educational Psychology Review*, **16**, 2004, pp. 235–266.
31. D. M. Cannon and L. J. Leifer, Product-Based Learning in an Overseas Study Program: The ME110K Course, *International Journal of Engineering Education*, **17**(4–5), 2001, pp. 410–415.
32. S. Bennett, P. Dawson, M, Bearman, E. Molloy and D. Boud, How technology shapes assessment design: Findings from a study of university teachers, *British Journal of Education Technology*, **48**(2), 2017, pp. 672–682.
33. M. Jorgensen, A. Havel, C. Fichten, L. King, E. Marcil, A. Lussier, J. Budd and C. Vitouchanskaia, Simply the best: Professors nominated by students for their exemplary technology practices in teaching, *Educ. Inf. Technol.*, 2018, pp. 1–18.
34. D. Field, Education and training for CAD in the autoindustry, *Computer-aided Design*, **36**, 2004, pp. 1431–1437.
35. P. J. Sillitoe, Diplomatic analysis of technical drawings: developing new theory for practical application, *Arch. Sci.*, **14,** 2014, pp. 125–168.
36. C. Burvill, B. Field, Z. Abdullah and M. Alias, Problem-Solving with Industrial Drawings: Supporting Formal Graphics Language Development for Malaysian Engineering Graduates, *International Journal of Engineering Education*, **32**(5), 2016, pp. 2172–2183.
37. J. Martin-Gutieârrez, J. L. Saorin, N. Martiân-Dorta and M. Contero, Do Video Games Improve Spatial Abilities of Engineering Students? *International Journal of Engineering Education*, **25**(6), 2009, pp. 1194–1204.
38. S. Siegel, *Nonparametric statistics for the behavior sciences*, McHraw Hill, NY, 1956.
39. T. J. Branoff and M. Dobelis, *Proceedings of the 66th Midyear Conference*, Engineering graphics literacy: Measuring students' ability to model objects from assembly drawing information, 2012.
40. R. Metraglia, G. Baronio, V. Villa and R. Adamini, Development of a self-assessment questionnaire for basic technical drawing skills: a preliminary study, *4th International Conference on New Horizons in Education*, **106**, 2013, pp. 848–859.
41. F. Provenza. *Machine designer*, 46 ed., Provenza, Sao Paulo, 1991.
42. B. Trindade, Hybrid environment for learning the fundamentals of technical drawing for engineering, *Doctoral thesis*, Federal University of Santa Catarina, 2002.
43. G. Prieto and A. D. Velasco Training Visualization Ability by Technical Drawing, *Journal for Geometry and Graphics*, **8**(1), 2004, pp. 107–115.

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