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DEVELOPING SPATIAL COMPETENCES IN GEOLOGY USING STEREOGRAPHIC PROJECTION

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Resumo - *Estudantes de graduação em Geologia devem desenvolver habilidades e atitudes acadêmicas que lhes permitam resolver diferentes tipos de problemas geológicos encontrados em situações reais. A resolução de muitos problemas envolve a análise geométrica, em diferentes escalas, das estruturas de corpos rochosos, para caracterizar deslocamentos e deformações. Técnicas de projeção estereográfica permitem que um geocientista represente, manipule e associe dados estruturais tridimensionais em uma superfície bidimensional. O pensamento espacial é importante e indispensável na carreira do geólogo; portanto, é necessário criar oportunidades para que os estudantes de Geologia adquiram as habilidades necessárias. Esta pesquisa desenvolveu oficinas de projeção estereográfica para alunos de graduação e pós-graduação, no Instituto de Geociências da Universidade Estadual de Campinas, a fim de facilitar o desenvolvimento de uma visão 3D e melhorar o aprendizado de tópicos de Geologia Estrutural. Nas oficinas, as técnicas de resolução estereográfica manual (2D) e digital (2D-3D) foram combinadas para facilitar a compreensão dos princípios fundamentais de cada método de projeção e sua associação com livros de referência em Geologia Estrutural. A combinação de técnicas 2D-3D também facilita o desenvolvimento da cognição espacial.*
Palavras-Chave: *Geologia Estrutural, Aprendizado profundo, Metacognição, Educação universitária.*

Abstract - *Undergraduate students of Geology must develop scholarship skills and attitudes that allow them to solve different types of geological problems encountered in real situations. The resolution of many problems involves geometric analysis, at different scales, of the structures of rock bodies, to characterize displacements and deformations. Stereographic projection techniques enable a geoscientist to represent, manipulate and associate three-dimensional structural data on a two-dimensional surface. Spatial thinking is important and indispensable in the geologist's career; therefore, it is necessary to create opportunities for Geology students to acquire the required skills. This research developed workshops on stereographic projection techniques for undergraduate and graduate students, at the Geosciences Institute of the State University of Campinas, in order to facilitate the development of a 3D view and improve learning of Structural Geology topics. The manual (2D) and digital (2D-3D) stereographic resolution techniques were combined in the workshops, facilitating the understanding of the fundamental principles of each projection method, and their association with reference books on Structural Geology. The combination of 2D-3D techniques also facilitates the development of spatial cognition.*
Keywords: *Structural Geology, Deep learning, Metacognition, University education.*

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1. INTRODUCTION

Structural Geology is a highly visual discipline that aims to observe and understand the processes and geometries resulting from rock deformation, often involving "mentally projecting, rotating, and generally manipulating spatial data" (Titus and Horseman 2009, p.246). Three-dimensional spatial visualization is, therefore, an essential skill for geoscientists. From continental to submicroscopic scales, studying Structural Geology allows a geologist to characterize and reconstitute the changes that occur or continue to occur on the Earth's surface (Davis et al. 2011). Knowledge of the geological context is essential for the reduction of safety risks in diverse situations; it can be determined by analyzing the characteristics and structure of rock bodies, which must be interpreted based on scientific reasoning and geological knowledge (Hasui et al. 2019).

When studying this subject, students are expected to develop competencies that enable them to reconstitute, relate and interpret the patterns and regimes of rock deformation, and reconstitute the geological history of a study area. Stereographic Projection is frequently applied in research on various Geology branches, because it makes it possible to represent, manipulate and associate three-dimensional structural data on a two-dimensional surface. In the case of Structural Geology, the geoscientist needs to master specific concepts and develop spatial visualization skills.

For someone who is starting in geology or structural geology, it is highly recommended to use paper and pencil over software. This will help you learn the fundamentals of stereographic projection. Typically, university geology and engineering students are expected create stereonets by hand (Senanayake 2013, p.8).

In agreement with this proposition, the authors developed a series of practical activities to evaluate the complementarity of both manual and software resources. This hands-on research has offered workshops of Stereographic Projection in Geology for undergraduate and graduate students of the Institute of Geosciences of State University of Campinas, aiming students to develop theoretical and practical expertise with the stereographic projection methodology, as long as to associate theoretical principles and concepts with manual and practical activities. The main results and achievements from the workshops are presented and discussed.

2. STEREOGRAPHIC PROJECTION IN GEOLOGY

Apolônio de Perga [262-190 BC], mathematician and astronomer from Alexandria, was a pioneer in studying the principles of stereographic projection (Fonseca-Filho 2007). The geometric study by Apolônio, known as the Apolônio's problem, was revised and refined by various scholars over two centuries. This technique allows the mapping of a spherical surface on a two-dimensional plane, that is, "the sphere is projected on a plane, so that the points on the sphere correspond to unique points on the plane" (Santos 2023). In the case of Geology, the data of real geological structures can be drawn and manipulated in a sphere projected on a plane, preserving the angular relationships of the structures.

Stereographic projection is essential for a range of activities that depend on the visualization of geological structures (Blenkinsop, 1999). It is commonly applied in Engineering Geology, Petroleum Geology, Mining, Environmental Geology, among others. The tool facilitates the recognition and interpretation of rock orientation patterns, thus dividing the geological structures in two groups: linear and planar. These are represented graphically without preserving spatial relationships (Lisle and Leyshon 2004, Miguel 2018, Miguel et al. 2018).

For linear structures, one parameter, the angle of inclination of the structure, can be classified as: bearing, plunge or rake (Miguel 2018). The direction indicates the clockwise orientation of a linear structure in relation to the north; for example, an azimuth of 225º represents a southwest direction. The plunge shows the angle of inclination of the line in relation to the

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horizontal. The rake represents the inclination in the dip plane between the linear structure and the direction of the plane (horizontal plane).
Structures classified as planar have two parameters: strike and dip. The strike is the angle formed by a horizontal line of the plane as related to true north direction; The second is an angle measured perpendicularly to the direction.

2.1. Construction of the stereographic net

By bringing the image of the Earth closer to that of a sphere and adding details of longitude and latitude lines, we get the idea of what a stereogram is, in which the perimeter that limits the circle is called the "primitive", the longitude lines are called "maximum circles", and the latitude lines are the "minimum circles" (Phillips, 1971, Lisle and Leishon 2004, Carneiro, 1996, Miguel 2018).

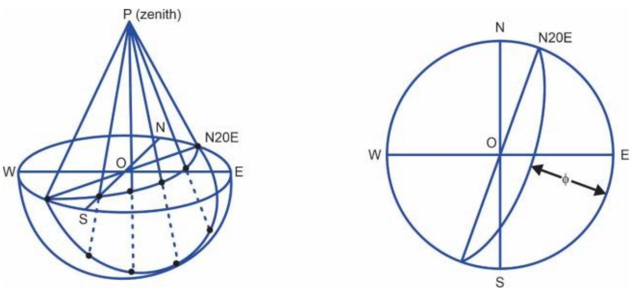

Figure 1 - The observer, at a given distance (P), looks at the projection of a plane, which is represented by its various points (1, 2, 3, etc.) on the equatorial plane. Note that the result is the drawing of an arc composed of the corresponding 1', 2', 3' etc. (Carneiro, 1996, p. 5).

To work with data of geological structures, the upper hemisphere of the reference sphere is eliminated (Fig. 1). If an observer is positioned at a point "P", at a vertical distance from the center of the sphere "O", the semicircle formed by the junction of several points and the sphere, will be seen by the observer as if it were an arc. Each point of the semicircle (1,2,3 etc.) is projected onto the equatorial plane according to the corresponding points 1', 2', 3' etc.; the arc is said to represent the stereographic projection of the plane, which represents a planar geological structure. (Fig. 1) (Miguel et al. 2018).

2.2. Spatial thinking and ability

Spatial thinking and spatial ability are not synonymous. The former refers to the skills that enable reasoning, defining, and giving meaning to spatial information; the latter refers to a set of skills that allow the performance of various mental operations, which assist in solving spatial problems. In short, they are complementary (National Research Council 2006, Oliva 2018).
Spatial thinking involves a set of cognitive operations, composed by the union of three elements: spatial conceptualization, spatial representation, and spatial reasoning. Conceptualizing space includes the ability to relate units of measurement, to know coordinate systems, to know ways to calculate distances, and to understand the different dimensions of space. Representing space involves knowledge of the relationships between views, the effect of projections, and graphic design principles. Spatial reasoning has to do with the ability to think on solutions and make decisions about different spatial information. The combination of these attributes allows an individual to structure and find answers to spatial problems (National Research Council 2006).
Spatial ability is the set of characteristics that a person holds for solving visual-spatial problems. Linn and Petersen (1985) listed these abilities, which include: representing, transforming, generalizing and remembering symbolic, non-linguistic information. The authors also classified spatial abilities into spatial perception, mental rotation and spatial visualization. Spatial perception is the ability to determine exteroceptive (outside the body) and interoceptive (representations of one's own body, such as positioning and orientation) spatial relationships. Mental rotation is the ability to mentally rotate images in different dimensions (2D, 3D). Spatial visualization skills may require the use of spatial perception and rotation, as they involve multi-step tasks and the possibility of different problem-solving strategies. Black (2005) has registered that mental rotation is a type of spatial ability associated to

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misconceptions and conceptual difficulties in Earth Sciences. The author argues that "many educators have assumed that nothing can be done to improve spatial ability" (Black 2005, p.412), but he identifies opportunities to develop strategies focusing on spatial aspects of concepts.

The development of spatial skills, which ultimately provides competence in spatial thinking, is desirable and necessary for Geology students and professionals, but many students have difficulty for learning content of this nature (Miguel 2023). Research conducted in the field of Neuroscience has shown that the human brain has two visual areas, which are functionally segregated: the first, called the ventral pathway, is responsible for identifying objects; the second, called the dorsal pathway, is responsible for storing and locating trajectories. Therefore, individuals with a high capacity for processing spatial information make greater use of the dorsal pathways, while people with a greater capacity for processing object information make greater use of the ventral pathways; thus, it is understood that spatial visualizers and object visualizers process spatial tasks by means of different neural activities; however, it is important to make it clear that spatial thinking can be trained and learned by object visualizers (Kozhevnikov et al. 2007, Motes et al. 2008, Miguel 2023).

3. COMPETENCE AND SKILL

> *Competence is the ability to act effectively in a certain type of situation, supported by knowledge, but not limited to it. To face a situation in the best possible way, several complementary cognitive resources must be put into action and in synergy; the knowledge is among them (Perrenoud, 1999, p.4).*

Perrenoud's understanding of competence exposed above is close to a didactic approach; the author attributes several concepts to competences, but the emphasis lies on the mobilization of cognitive resources (Ricardo 2010). For Perrenoud (1999) competences are important goals for training, and can respond to a social demand, aimed at adapting to the job market and its changes, they can also provide the means to learn about reality, and not be defenseless in social relationships.

The National Common Curricular Base (NCCB), a normative document that defines the learning rights of all students in Brazilian schools, is guided by the development of competences, and defines this term as "the mobilization of knowledge, skills, attitudes and values to resolve complex demands of daily life, the full exercise of citizenship, and work" (NCCB 2018).

When dealing with the two terms: competence and ability, it can be assumed that they are inseparable values. A competent person is one who, faced with a problem situation, is able to solve it, using skills related to that particular task as a resource; therefore, there is a complementary relationship between the two terms. Bordoni (2015) defined competence as the ability to perform mental operations that select and associate the skills, knowledge and attitudes appropriate to a task. Therefore, competence is "knowledge in action", and skill is "know-how". According to the researcher, there are several ways to facilitate the development of skills, and she says that: group activities, project development, interdisciplinary work, and the use of contextualization are some examples of strategies. Dias (2010) argues that the various concepts presented to define competences could compose a division of the term into three components: knowing, knowing-how, knowing-being; but she warns that this simplification should not be accepted, because:

> *(...) knowledge is part of competence but cannot be confused with it; competences are described as actions, but it is not the fact of describing actions that explains or enables action, or success; competences are directly related to the context (Dias 2010, p.74).*

Zabala and Arnau (2014) argue that competency-based learning arises from the need to change the traditional teaching method, characterized by memorization of facts, which ends up hindering the acquisition of knowledge that can

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be applied in real life. This teaching methodology favors superficial study practices on the part of students and results in poor and short-term learning, making it impossible to develop competence (Miguel 2023). Regarding study shortcuts, within the theme of competence and skill development, Moretto (2017) presents the following example and questions:

> *(...) a teacher programs the process of solving first-degree equations for a class. He explains how to do it, presents two examples, and asks students to solve twenty problems from a list. At the end, he prepares a test with five problems from the list. He observes that most students achieved a score higher than 7.0 out of a maximum of 10 points. Can he say that the students developed competence for solving first-degree equations? Or is he just assessing whether they have developed the ability to solve problems? (Moretto 2017).*

If the concept of skill refers to "knowing how to do things", it can be said that the objective was achieved, but competence has to do with "knowing what you are doing"; in short, it is possible to develop skills, but not develop competencies (Moretto 2017).

3.1. Teaching competence

To facilitate the development of skills and abilities, teachers can encourage students to take an active and leading role, however, the vision of teaching is often centered on the transmission of knowledge, and teachers feel comfortable with this form of teaching, considered traditional (Perrenoud, 1999). This methodology tends to classify students as good or bad, according to the grades achieved in summative assessments. This teaching model encourages passive behavior and superficial study practices on the part of students (Miguel 2023), making it difficult to develop skills, even though it often allows for the acquisition of skills.

A competence to teach does not come from initial or continuing education; it is built throughout practice (Perrenoud et al. 2002) and through constant critical analysis of the teaching-learning method used. The role of the educator is to prepare the best conditions for the development of competences; therefore, information must be transmitted within a context and with language appropriate to the public, always respecting cultural and emotional values (Bordoni 2015). Perrenoud et al. (2002) presents a list of the main attitudes that teachers can take in the construction of knowledge and competences, which are: (1) organizing a constructivist pedagogy; (2) ensuring the meaning of knowledge; (3) creating learning situations; (4) managing heterogeneity; (5) regulating training processes and paths. The author also adds two ideas and justifies them: reflective practice and critical implication; the first because we have a society in transformation; the second because society needs teachers who are involved in the political debate on education, at all levels.

Whenever possible, the educational material offered should take advantage of available technologies, prioritizing proactive interactivity. It is important that the materials are stimulating from a cognitive point of view, allowing the student to perform diverse tasks. Personalizing the content can be a differential that will provide a personal relationship with the student, with the aim of motivating him/her to learn independently (Costa et al. 2011).

4. WORKSHOP ON STEREOGRAPHIC PROJECTION IN GEOLOGY

The activities involved training in solving three-dimensional problems in two-dimensional support, using stereographic networks in paper diagrams (2D) and in software (2D and 3D). The target audience was composed by Geology undergraduate and graduate students of the Institute of Geosciences at the State University of Campinas. The objective of the workshop was to observe the development of skills (mainly spatial visualization) and the development of problem-solving competencies in Structural Geology.

Each workshop activity began with a brief theoretical presentation of the related content, followed by an exercise related to the subject,

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and a discussion to clarify doubts; then, the activity was applied. The pace of the workshop was up to the participants; the activities only continued after any doubts had been resolved. Participants were also encouraged to carry out the activities in groups and to take a critical stance on the way the content was presented. The order in which the activities were carried out included practicing on a sheet of paper and then solving the same exercise in stereographic projection software. This order was intended, first, to work on cognition and psychomotor skills, since on a sheet of paper there are a series of manual operations to be performed, which are carried out according to the geometric transformation requested in each situation (exercise). It was also an opportunity to practice fine motor skills, using tissue paper, a 3mm mechanical pencil, etc. Solving the same exercise in an application aimed to work on the mental transfer of two-dimensional data from the sheet of paper to a three-dimensional representation in software (mental rotation skill), in addition to encouraging a critical analysis of the two results (spatial reasoning). The workshop content involved the concepts of Stereographic Projection, construction and elements of a stereogram (or stereographic network); usual notations in Structural Geology, Stereographic Projection techniques, in addition to the application of a little-used network called Tangent Diagram (Carneiro et al. 2018), with the perspective of offering space for reflection on its advantages and limitations, compared to the best-known stereographic networks (Schmidt and Wulff) (Tab. 1) (Miguel et al. 2018).

Table 1 - Schedule of the Stereographic Projection workshop, offered half-day, for three consecutive days (Miguel 2018; Miguel *et al.* 2018)

FIRST DAY	
THEORETICAL PART	PRACTICAL PART
Attitude of a geological surface	Notation conversion: quadrant and azimuthal
Stereographic projection: definition, principles and techniques	What does the reading of a Brunton compass and a Clar compass indicates
Elements of a diagram	Data conversion between Brunton and Clar compasses
Types of diagrams: Schmidt and Wulff	Projection techniques: planes, lines, intersection of planes/lines, angle between planes/lines, apparent dip
Projection techniques: planes and lines, intersection of planes/lines, angle between planes/lines, apparent dip	
SECOND DAY	
THEORETICAL PART	PRACTICAL PART
Rotation: What is it? What is it for?	Rotation operations: vertical, horizontal and oblique axis
Rotation operations: vertical, horizontal and oblique	
THIRD DAY	
THEORETICAL PART	PRACTICAL PART
Tangent Diagram	Tangent diagram: intersection and apparent plunge
Rosette Diagram	Tangent diagram: cylindrical and conical folds
Statistical analysis of stereographic data	Rosette diagram (software only)

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4.1. Selection of stereographic projection exercises aimed at developing skills and abilities

The choice of exercises was based on the central question: *What skills should students develop in this subject?* Skills are the central element of planning; before the activity, they act as a learning objective, and at the end of the process, they constitute the learning outcome (Fig. 2). During the formulation, it is essential that skills are clearly established and described in assessable terms, so that the action that the student is intended to perform is indicated, and that they are related to specific activities and content (Brusi et al. 2011).
Learning activities are programmed actions or tasks that students perform to develop content and acquire the knowledge and skills necessary to acquire skills (Fig. 2). Brusi et al. (2011) argue that the organization of content is the teacher's responsibility, but students can be allowed to participate in the formulation of objectives. For the authors, the choice of activities is based on multiple criteria, such as: educational objectives, problems raised, degree of autonomy granted to students, learning style, teaching method, location where the activity is carried out, and time available. In the case of the Stereographic Projection in Geology workshop, the aim was to select exercises that were not simple applications of techniques, in order to avoid purely mechanical and memorized solutions, since this teaching method results in the acquisition of skills that, in most cases, are remembered for a short time, and when the individual goes months or years without practicing the techniques, they notice that they have forgotten them. Therefore, the workshop was divided into: 1) theoretical presentation and discussion of the subject, 2) exercises with cases related to the debated theme, 3a) solving the exercise on a sheet of paper, 3b) solving the same exercise in software (Fig. 2). In stage three, in addition to reinforcing the subject by solving each activity twice, it was also an opportunity to practice spatial thinking (Fig. 3), since the computer program shows a three-dimensional result of planar and linear structures. Each selected exercise required the retrieval of theoretical information on Structural Geology topics, the development of skills in solving projection techniques (mainly manual), and the ability to visualize geological structures and their interaction in two-dimensional and three-dimensional space (Fig. 2).

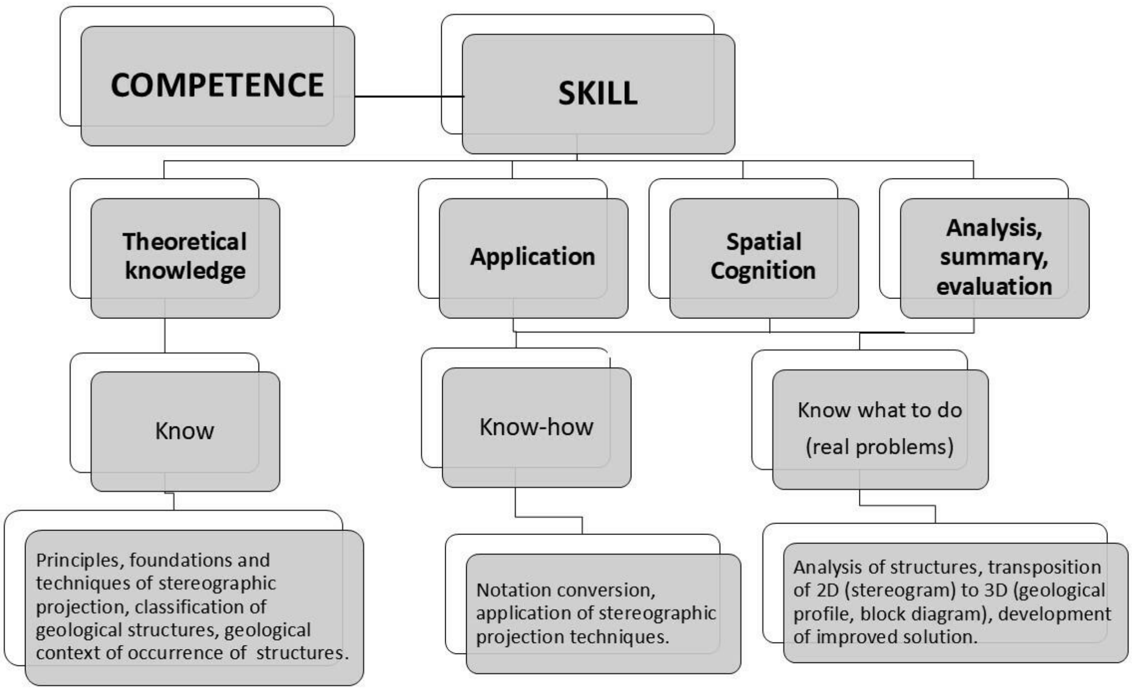

Figure 2 - Skills required for the Stereographic Projection in the Geology workshop. Note that the competency is composed of the set of required skills.

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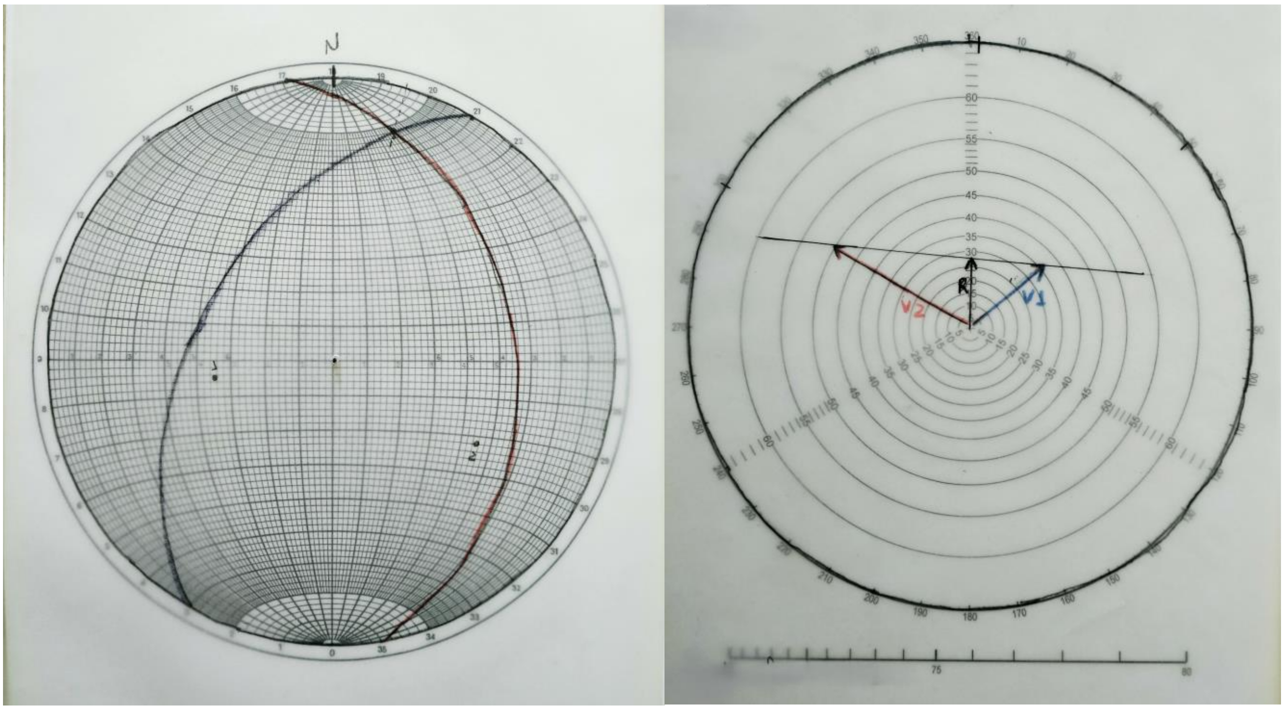

Figure 3 - Exercise of intersection of two planes. In this activity, students should find the attitude of the two sides of a fold, N50W 35NE and N30E 50NW. The Image shows the different ways of resolution the workshop exercise, manual and in software's of stereographic projection.

5. EVALUATION OF THE RESULTS OF STEREOGRAPHIC PROJECTION WORKSHOPS

Two face-to-face workshops of the stereographic projection were offered in the Geoscience Institute of the State University of Campinas (Unicamp), authorized and certified by the Ethics Committee for Research with human beings (resolution 510/2016) under number 64493017.1.0000.5404. The first workshop was aimed at undergraduate Geology students who, at the time, were taking the Geological Design course, whose programmatic content includes theory and practice of stereographic projection. The second workshop has been offered to any undergraduate and postgraduate student at the Geoscience Institute of Unicamp. The difficulties encountered in both workshops were similar, thus they will be dealt with together.

The first difficult observed in undergraduate students was the conceptualization and construction of the stereographic network, mainly the association of the network with descriptive geometry and trigonometry content. Moreover, in the initial stage a trouble was observed to classify the geological structures as lines and planes, probably because of the lesser skill in spatial thinking, that is, imagining geological structures in 3D. To project the dip angle of lines and planes was a recurring difficulty.

The stereographic projection techniques studied (see table 1) in the workshops represented real situations and avoided the mechanical use of the stereogram. The participants were motivated to explain the steps required to project the structures used in each technique, and the reason it was done in that way. Most errors have been related to conceptual issues or inattention to the data contained in the exercises.

Workshops participants had more difficulty in the exercises related to the rotation technique, about an axis vertical, horizontal and oblique; in this specific case, the use of 3D stereographic projection software was essential to training spatial thinking. Even after the resolution in 3D, participants still had difficulty understanding the rotation techniques, then the movement of the structures was showed step by step, in 2D and 3D, simultaneously.

In the end of the workshop, it was clear that questioning participants about: what, how, and

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why they did the exercise in that way was essential to avoid a simple memorization of the techniques. The application of the techniques in 2D software contributed to the comparative and critical analysis of the manual results, and the 3D software was important to develop the spatial cognition.

6. DISCUSSION

The results of this study confirm that the teaching-learning process should aim to train people capable of analyzing and solving problems, creating ideas and developing them. The data obtained reveals that a balance between informative and formative teaching is essential for the development of skills and competences. The information provided by tutors gives students access to a set of knowledge, study methods and ways to solve everyday problems in the chosen profession (Núñez & Silver 2000). On the other hand, allowing students to take an active and leading role in their learning enables them to live an individual experience of evaluation, regulation and organization of their own cognitive process (Ribeiro 2003). Sorby (2007) described a similar positive impact on developing 3D spatial skills from activities connecting multimedia software with a workbook in an instructional setting.

Beber et al. (2014) warn that the act of learning causes changes in behavior; the subject who understands the way in which one learns expands his or her capacity to construct knowledge. The authors also state that the intervention of the teacher, in some contexts, can contribute to the achievement of metacognition. The teacher can help with the reflection on possibilities and obstacles in the search for knowledge, thus providing interaction, support and motivation.

8. LIMITATIONS

The described workshops focused on a practical complementarity of manual (hands-on) and software (digital) resources of Stereographic Projection in Geology. The number of enrolled students was quite limited, in spite of the fact that the workshops were conceived to engage more students. They have developed theoretical and practical expertise using the offered resources focusing the stereographic projection methodology. The workshop was not repeated due to the Covid-19 pandemics restrictions. This means that the results are restrict, due to the small number of participants.

7. FINAL REMARKS

The described Stereographic Projection workshop favored an active and collaborative learning process. The activities carried out in small groups showed potential to improve communication between students, provided the exchange of ideas and a joint construction of knowledge. The tutor maintained the role of mediator, and not just transmitter of information. The resolution of the workshop exercises, divided into two stages: paper and software, has contributed to a better understanding of: (a) the arrangement and interaction of geological objects in three-dimensional space, (b) the understanding of a few applications of stereographic projection techniques. The computer programs facilitated reasoning and decoding of the tutor's explanations. The relaxed environment of the computer lab, the possibility of carrying out activities in small groups, and the lack of obligation to do exercises to obtain a grade, allowed learners to focus on what to do with the content, and not on worrying about memorizing the techniques.

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