



Geometry in Motion: A Craft Perspective for Design and Teaching: A Case Study - The Hinge

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Abstract. The understanding of geometry in motion is fundamental for analyzing the behavior of geometric shapes as they move or rotate in three-dimensional space. This study explores the implementation of a craft-based methodology for teaching descriptive geometry and kinematics to design students at the Metropolitan Autonomous University, Cuajimalpa. Through the design, drafting, fabrication, and evaluation of functional hinges, students applied geometric and kinematic concepts in a tangible and meaningful way, integrating theory with practice. The study aligns with experiential and project-based learning models, demonstrating improvements in students' conceptual understanding, technical skills development, and problem-solving abilities. Unlike conventional digital or theoretical approaches, this strategy provides an innovative and accessible hands-on experience that fosters deeper learning. The methodology was applied to a broader sample of 95 students across three academic terms, reinforcing the consistency and effectiveness of the approach. Future research should focus on refining assessment methods to better capture students' practical learning outcomes. Instead of relying solely on quantitative data (e.g., pre- and post-assessments), a more comprehensive evaluation should integrate project performance analysis, process observation, and self-assessment. Additionally, ensuring a structured sequence in descriptive geometry courses and standardizing teaching methodologies will be essential for improving students' understanding of kinematics and mechanical design. This study lays the foundation for exploring innovative educational strategies that strengthen the connection between geometry and its practical applications in design education.

Keywords: Descriptive Geometry, Kinematics, Artisanal Learning, Design Education, Hinge Mechanisms.

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1 INTRODUCTION

The understanding of geometry in motion is essential for analyzing the behavior of geometric forms as they move or rotate in three-dimensional space. This analysis is based on the position of

points relative to the X, Y, and Z coordinate axes, establishing a direct connection with kinematics. Its application is fundamental in the design and analysis of mechanisms, providing key tools for understanding and representing motion in physical and mechanical systems.

Kinematics, as a branch of mechanics, studies the motion of bodies without considering the forces that generate it. Its relationship with geometry in motion lies in the shared fundamental principles, such as position, trajectory, and rotation. However, in traditional education, there is often a gap between theory and practical application, making it difficult for students to fully grasp these concepts in design and manufacturing contexts.

Geometry in motion and kinematics have applications in various disciplines, including mechanical design, robotics, architecture, and education, enabling the development of functional and aesthetic solutions in articulated systems and mechanisms.

This study analyzes the effectiveness of an artisanal methodology for teaching geometry in motion and kinematics to design students at the Metropolitan Autonomous University, Cuajimalpa. Unlike traditional methods that rely heavily on digital tools or theoretical instruction, this strategy emphasizes tangible, experiential learning through the design and physical construction of functional hinges. This innovative approach aims to bridge theory and practice in a meaningful and accessible way.

1.1 Framework of the Training Strategy

The training strategy implemented in this study is based on a structured pedagogical framework composed of the following elements:

- Learning objectives: Develop technical and spatial reasoning skills; understand geometric and kinematic principles through application.
- Methodology: Combination of theoretical sessions (geometry and kinematics) and practical workshops focused on hinge design and construction using basic materials.
- Resources and tools: Foam, wooden sticks, 3D-printed models, and basic lab tools (drills, cutters).
- Pedagogical model: Experiential learning (Kolb), constructionism (Papert), project-based learning (Markham), and learning by doing (Dewey).
- Assessment: Observation of performance, model functionality, technical drawing quality, and student self-reflection.

2 THEORETICAL FRAMEWORK

2.1 Principles of Descriptive Geometry

The fundamental principles of descriptive geometry include the analysis of position, translation, and rotation of geometric bodies in three-dimensional space:

- Position of a point in space: Determined the X, Y, and Z coordinate axes, both in orthogonal and isometric projection.
- Translation of lines and planes: Allows for the analysis of displacements without altering their orientation, facilitating the representation of movements in three-dimensional space.
- Rotation of geometric elements: Studied through orthogonal and isometric projections, visualizing the changes in orientation.

Another key concept in descriptive geometry is "true shape and magnitude" of lines and surfaces. This principle allows for the determination of the actual dimensions of geometric elements when

they are not aligned with at least two of the axes in orthographic representation. To achieve this, methods such as rotation and plane changes are employed, essential tools in this field.

Without this concept, it would be impossible to accurately calculate the centroid of geometric bodies, whether straight or inclined, which would directly affect the design and functionality of electromechanical mechanisms. Consequently, true shape and magnitude is not only a theoretical principle but also a practical tool indispensable in engineering, architecture, and design.

The centroid is a key element in the analysis of balance and articulations in mechanical systems. From a technical perspective, it is defined as the weighted average of the coordinates of the points composing a figure, representing the geometric and physical balance point of the body. Its determination is essential for the construction of functional structures.

2.2 Principles of Kinematics

Kinematics is the branch of mechanics that studies the motion of bodies without considering the forces that generate it. Its essential principles include rest, trajectory, and motion, taking into account parameters such as velocity, time, and acceleration.

The five main types of motion in kinematics are:

- Uniform Rectilinear Motion (URM): Displacement at a constant speed in a straight line.
- Uniformly Accelerated Rectilinear Motion (UARM): Motion in a straight line with constant acceleration.
- Simple Harmonic Motion (SHM): Oscillatory motion characteristic of vibratory systems.
- Circular Motion: Movement around a fixed axis, present in gears and mechanical joints.
- Parabolic Motion: Curved trajectory generated by the combination of uniform horizontal motion and accelerated vertical motion.

These principles are fundamental in the design of functional mechanisms, as they allow for understanding and predicting the behavior of articulated elements, gears, and electromechanical systems.

2.3 Historical and Scientific Relevance

Kinematic structures represent the underlying framework of a moving entity, whether a biological organism or a mechanical system. These structures are reconstructed from sequences of 3D shapes obtained from multiple views, allowing for a precise analysis of kinematics and degrees of freedom.

Throughout history, kinematics has been applied to the study and development of articulated mechanisms, from the earliest machines to the most recent advancements in robotics, biomechanics, and kinematic structures.

The following are recent studies that have significantly contributed to the understanding and design of kinematic structures in various scientific and technological contexts:

- Kinematic Analysis of a Bionic Robot with an Elephant Trunk (Huang et al., 2022) [10].

This study analyzes the kinematics of a bionic robot inspired by an elephant's trunk, characterized by its flexible structure and redundant kinematics. It focuses on:

- Modeling the flexible actuator rod.
- Kinematics of a parallel module.
- Global kinematics of the biomimetic robot.

- Effect of Detachable Deformable Units on the Mobility of Modular Origami Structures (Xiao et al., 2021) [11].

This study investigates structural mobility in prismatic origami. Key findings include:

- Use of angular kinematics as an analytical tool.
- Relationship between closed-loop topology and structural rigidity.
- Design Optimization for Weight Reduction of a Two-Cylinder Reciprocating Compressor Crankshaft (Arshad et al., 2021) [2].

A lighter crankshaft was developed without compromising its mechanical properties. The analysis included:

- Kinematic, static, and fatigue studies.
- Topological and dynamic modal evaluation.
- Application of Support Vector Machines in the Design of Theo Jansen's Linkages (Hwang et al., 2019) [5].

Machine learning techniques, specifically Support Vector Machines (SVM), were used to optimize the design of Theo Jansen's articulated mechanisms. The study developed:

- Two databases compiling the orbital properties and dimensions of the mechanisms.
- A trajectory classification system to enhance functionality.
- Development of a Programming and Simulation System for Four-Axis Robots (Slavkovic et al., 2022) [7].

A virtual model in MATLAB/Simulink is presented for the offline programming and simulation of industrial robots with hybrid kinematics.

2.4 Related Work in Teaching Methodologies

Recent studies have explored innovative strategies for teaching geometry and kinematics, particularly in design and engineering education. Kolb (1984) proposed the experiential learning cycle as a foundational model, highlighting the importance of learning through concrete experiences and reflection.

Papert (1980) emphasized constructionism, where tangible creation helps internalize abstract concepts. Dewey (1938) advocated for learning by doing, supporting hands-on approaches in education. More recent works have explored the use of digital prototyping, virtual reality, and modular systems like LEGO Technic to teach kinematic principles (Xu et al., 2020; Isogawa, 2016).

Additionally, scholars such as Nigel Cross have emphasized design as a way of thinking, highlighting the need for iterative problem-solving and reflection in practice (Cross, 2006) [4]. Donald A. Schön introduced the concept of the "reflective practitioner," which underscores the importance of reflection-in-action as a critical aspect of professional design education (Schön, 1983) [8]. These perspectives reinforce the value of engaging students in hands-on, reflective design processes like those described in this study.

3 RELATIONSHIP BETWEEN DESCRIPTIVE GEOMETRY AND KINEMATICS

The intersection between geometry and kinematics is evident in the analysis of mechanical, robotic, and natural systems. For example, joints, which are essential in robotics and mechanical design, illustrate how movements can be generated and controlled in different contexts. From hinges to gears and transmission systems, geometry in motion provides tools to optimize the design of functional mechanisms.

The teaching of geometry and kinematics has been enriched using new technologies and practical methodologies:

1. Vpl and rapid prototyping. Carota and Tomalini (2023) [3] highlight how tools like Rhino and Grasshopper enable the understanding of complex geometric shapes by combining theory and practice.

2. Visualization and embodiment. Anderson and Wall (2015) [1] demonstrate how technologies like Kinect and 3d visualizations promote the understanding of kinematic concepts through physical interaction.

3. Robotic kinematics with virtual reality. Xu et al. (2020) [9] propose a system that combines simulation and remote control to teach robotic kinematics, fostering a flexible and safe learning environment.

Additionally, accessible tools like LEGO Technic demonstrate how creativity and experimentation can be enhanced through user-friendly technologies, as exemplified by Isogawa (2016) [6] in his book *The LEGO Power Functions Idea Book*.

However, despite these technological advances, it is crucial to recognize that artisanal technology has been a constant throughout history, from prehistoric times to the present day. Today, it remains an invaluable resource in university education. Disciplines such as ceramics, carpentry, and jewelry-making show how hands-on, artisanal teaching remains fundamental in understanding design and creation principles through geometry and kinematics.

In our case, we have implemented an artisanal methodology at the Teaching Support Laboratory (LAD) at the Metropolitan Autonomous University, Cuajimalpa, to help fourth-term design students understand geometry in motion through the construction of hinges. Initially, students faced challenges in theoretically understanding how a hinge works and is constructed. However, when they brought this experience into the workshop and worked with materials such as foam board and wooden sticks, they were able to internalize these concepts. Using tools like drills and foam cutters, they built functional mechanisms, which allowed them to tangibly understand the relationship between geometry and kinematics.

The artisanal work at the LAD is designed to promote practical and experimental learning, prioritizing the construction of geometric models and functional mechanisms. Through the use of materials such as foam board, wooden sticks, and basic assembly components, students apply fundamental geometric principles to the design and fabrication of three-dimensional prototypes. This artisanal approach not only fosters creativity but also strengthens the understanding of abstract concepts by transforming them into tangible solutions.

4 METHODOLOGY

At the beginning of the course, students learned to draw revolution bodies in both orthogonal and isometric projection, such as cylinders and cones (Figure 1), in both upright and inclined positions. Additionally, they studied intersections between cylinder-cylinder and cone-cone (Figure 2), developing essential skills for three-dimensional geometric representation.

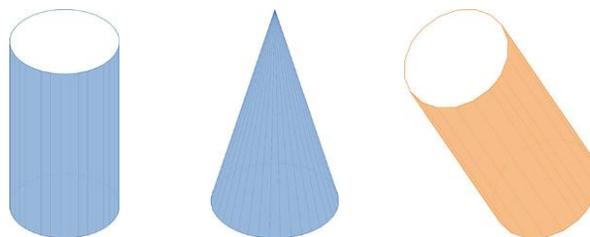


Figure 1: Cylinder and cone.

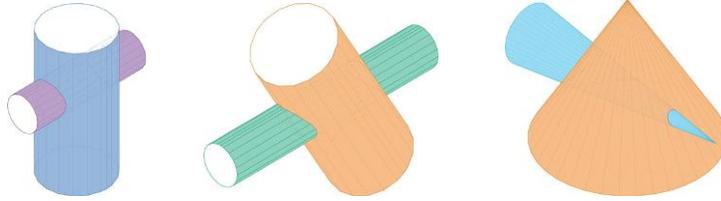


Figure 2: Intersection between cylinder-cylinder and cone-cone.

During this introductory phase, the concept of hinge was explained, along with its functioning and application in various contexts. To reinforce comprehension, a 3D-printed hinge model (Figure 3) was presented, accompanied by its construction plans (Figure 4) and with the respective explosive (Figure 5), which were developed by the instructors responsible for this study. This material allowed students to analyze the structure and design of the mechanism before proceeding with its manual construction.



Figure 3: 3D-printed hinge.

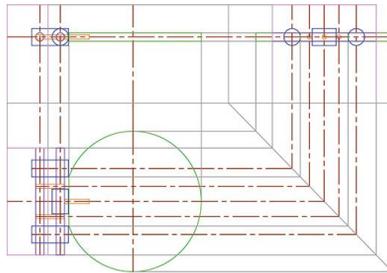


Figure 4: Construction planes of the hinge.

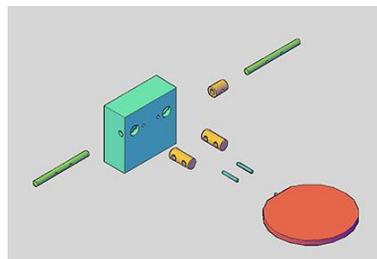


Figure 5: Explosive of the hinge.

4.1 MODEL DESIGN AND PLANNING

Students were informed about the materials available for the construction of their models, which were to be built exclusively with Styrofoam and wooden sticks. Additionally, they were required to incorporate the following mandatory geometric shapes into each model:

- Cylinder, Cone, Sphere, and Prism

All these elements were made of Styrofoam board in different sizes, while the wooden sticks varied in diameter, emphasizing the importance of geometric tolerances, particularly in cylinder intersections.

As an initial approach to the design process, students conducted a physical analysis of the 3D-printed model, complementing it with sketches in which they defined the movements the hinge needed to perform, and the elements required for its functionality. During this phase, key aspects of the support structure design were also discussed, considering forward/backward or up/down movements, depending on each student's proposal.

To validate their design, each student created a prototype using modeling clay (Figure 6), ensuring that it met the established geometric requirements. Once the prototype was approved, they acquired the necessary materials and began detailed sketches with precise measurements, defining exactly which piece would enable the hinge's movement.



Figure 6: Clay model.

4.2 Construction and Assembly in the Teaching Support Laboratory (LAD)

Once the models were defined, the students worked in the Teaching Support Laboratory (LAD). Before starting the construction, they received training on safety and the use of the available tools, which included: bench drill, saw cutter, sanding machine, and Styrofoam cutter.

These were the only tools used in the manufacturing process. After familiarizing themselves with their operation and understanding the application of geometry in the cuts, the students worked autonomously on the construction of their models. Using the materials provided, each student designed and assembled their own functional hinge, applying the principles of kinematics and motion geometry in a practical manner.

4.3 Evaluation and Analysis of the Model

In the final phase, the behavior of each hinge was evaluated to verify that it met the design and functionality requirements established at the beginning of the project. During this analysis, the key geometric relationships that enable articulated movement were identified, ensuring that the parts maintained precision in their assembly and proper mobility.

The implemented methodology allowed students not only to develop technical skills in the construction of mechanisms but also to reinforce their understanding of the relationship between geometry and motion through an experimentation-based learning process.

5 RESULTS

The exercise of constructing a hinge as a learning model for motion geometry aligns with the principles of Project-Based Learning (PBL). This approach, developed and supported by various authors, emphasizes the importance of engaging students in hands-on projects that allow them to connect theory and practice in a meaningful way.

5.1 Impact of Project-Based Learning (PBL)

This approach facilitated:

- The connection between theory and practice: Students were able to understand abstract concepts such as kinematics and geometry by applying them in a tangible context.
- The development of technical and creative skills: The use of simple materials and basic tools fostered creativity and manual dexterity.
- Collaborative learning: Students shared ideas and solutions throughout the process, enriching their educational experience.
- The challenge of designing and building a functional hinge is directly related to the ideas of various experiential learning theorists.

5.2 Applied Theoretical Models

- David Kolb and the experiential learning cycle.

The methodology used in this exercise follows the four stages proposed by Kolb: Concrete experience: Students designed and built a physical hinge model using Styrofoam and wooden sticks. Reflection: During the construction and evaluation of their models, they reflected on how geometry and tolerances affected movement. Abstract conceptualization: They related their practical findings to the theoretical concepts of geometric intersections. Active experimentation: They adjusted their models to improve functionality and completed the construction plans of the hinges in orthographic and orthogonal projections.

- Markham, Larmer, and Ravitz: Designing Effective Projects.

According to these authors, an effective project should include an essential question that motivates investigation and learning. In this case, the question posed was: *How to design a functional hinge that applies the principles of motion geometry?* Students actively participated in all stages of the project, from planning and design to construction and analysis, developing technical skills, and solving real-world problems related to mechanical design.

- Seymour Papert and constructionism

Papert emphasizes the importance of constructing tangible objects as a way to learn abstract concepts. In this exercise, students designed and built a functional hinge, allowing them to visualize the kinematics of the mechanism and gain a practical understanding of the relationship between geometric components in a moving system.

- John Dewey and experiential learning

Dewey argues that learning is more effective when students are actively engaged in experiences with practical relevance. In this case, students not only acquired theoretical knowledge about geometry and kinematics but also applied it directly by designing and constructing a functional

hinge. This process reinforced the concept of "learning by doing," allowing them to solidify their understanding through experimentation.

5.3 Results Obtained

Out of 95 students, 89 successfully completed a functional hinge. Approximately 63% of students required design iterations to achieve full functionality, illustrating the iterative nature of learning in this method. Additionally, 12 students explicitly referenced the importance of understanding geometric tolerances in their self-reflection reports.

Several students expressed that the hands-on activity helped them "finally understand how geometry applies in real design," as noted in informal classroom reflections

The study was conducted with 37 students during the 24Fall term, 44 students in the 23Fall term, and 7 students in the 21Fall term. The exercise was not implemented in the 22Fall term due to the professor's sabbatical. These students participated in the construction of the hinge at the Teaching Support Laboratory (LAD) (Figure 7).



Figure 7: Students working in the LAD.

The main findings were as follows:

1. Development of Technical and Practical Skills.

Students designed and built functional models that integrated basic geometric shapes (cone, cylinder, sphere, prism) with articulated mechanisms, meeting the defined objectives. They learned to use tools such as bench drills, sanding machines, and Styrofoam cutters, developing essential skills for artisanal construction (Figure 8).

2. Understanding and Application of Geometric and Kinematic Concepts.

Students demonstrated proficiency in representing revolution bodies and geometric intersections, applying this knowledge in the design of their hinges. Through the construction and analysis of the model, they understood the geometric relationships that enable articulated movement, enhancing their problem-solving abilities (Figure 9 (a) and (b)).

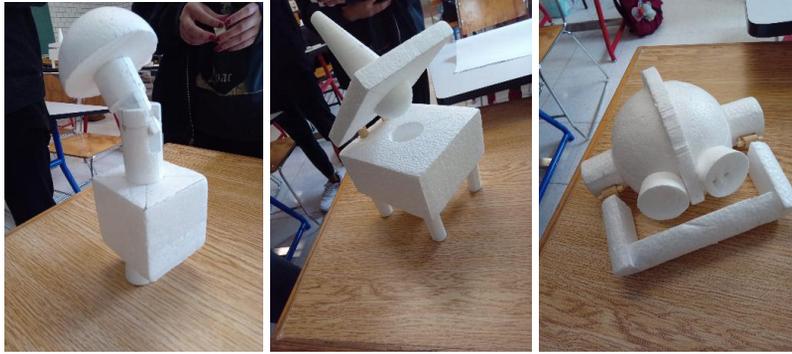


Figure 8: Students' hinge movement model.

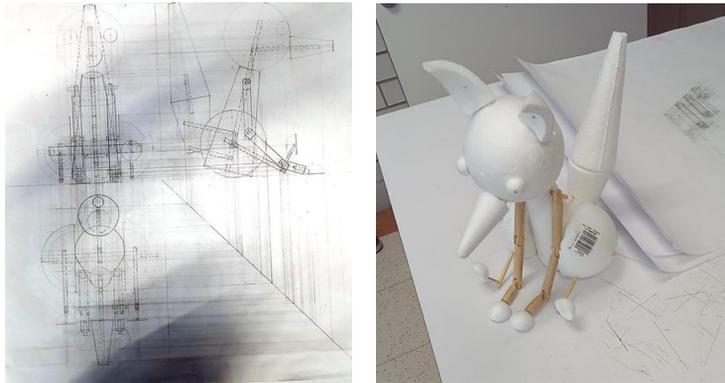


Figure 9: (a) Construction plans of the model, orthogonal projection, and (b) 3D model.

3. Innovation in the Design of Articulated Mechanisms.

Each student presented a unique model, proposing creative solutions for the movement and support of the hinge. Prototypes made from modeling clay and Styrofoam allowed students to visualize and refine their designs before the final construction, fostering an iterative project development approach.

4. Success in the Functionality of the Hinges.

The final analysis showed that the constructed hinges met the required movement criteria. Precise forward/backward and up/down movements were observed, depending on each student's design proposal. The hands-on interaction with the models allowed students to evaluate the impact of geometric tolerances and make adjustments to improve functionality (Figure 10a, b, c, and d).

5. Teamwork and Self-Management.

During the activities at LAD, students demonstrated collaboration and organizational skills, working autonomously in the construction of their models. They followed safety protocols and optimized the use of available resources, demonstrating responsibility in project development.

6. Visual and Conceptual Impact of the Models.

The final models exhibited a high level of detail and finish, resulting in hinges that were not only functional but also aesthetically appealing. Students gained a deeper understanding of the importance of geometry in design and its practical application in articulated mechanisms (Figure 11a, b, and c).

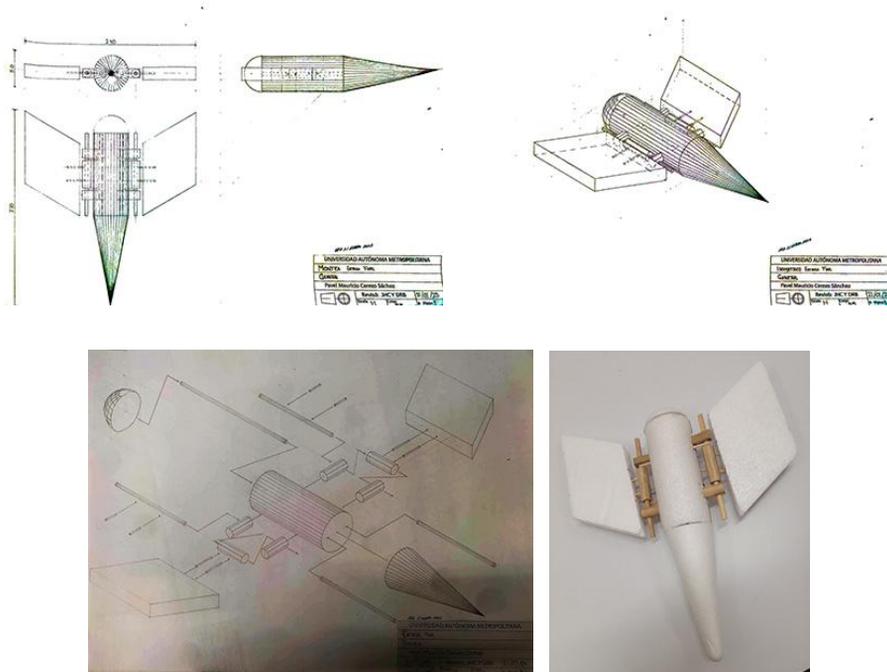


Figure 10: (a) Orthogonal projection, (b) Isometric projection, (c) Explosive, and (d) 3D model.

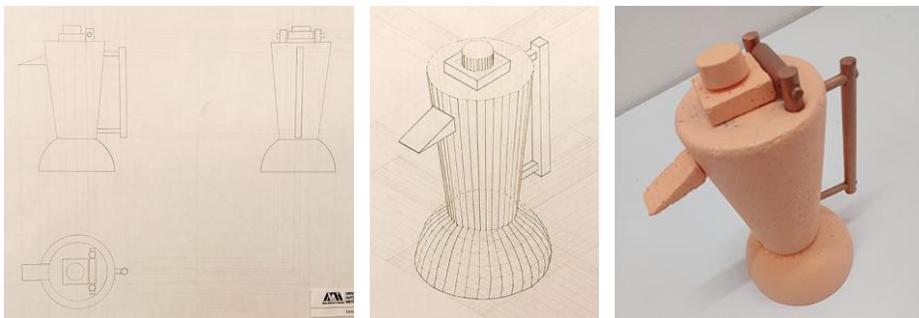


Figure 11: (a) Orthogonal projection, (b) Isometric projection, and (c) 3D model.

5.4 Synthesis of Finding

The hinge construction exercise allowed students to apply theoretical knowledge in a practical context, reinforcing their understanding of geometric and kinematic principles. Additionally, it promoted the development of technical, creative, and collaborative skills, aligning with experiential learning models (Figures 12 and 13).

These results support the effectiveness of the artisanal approach in teaching geometry in motion and suggest that its application could be extended to other areas of design and engineering.



Figure 12: Functional and aesthetically pleasing student models.

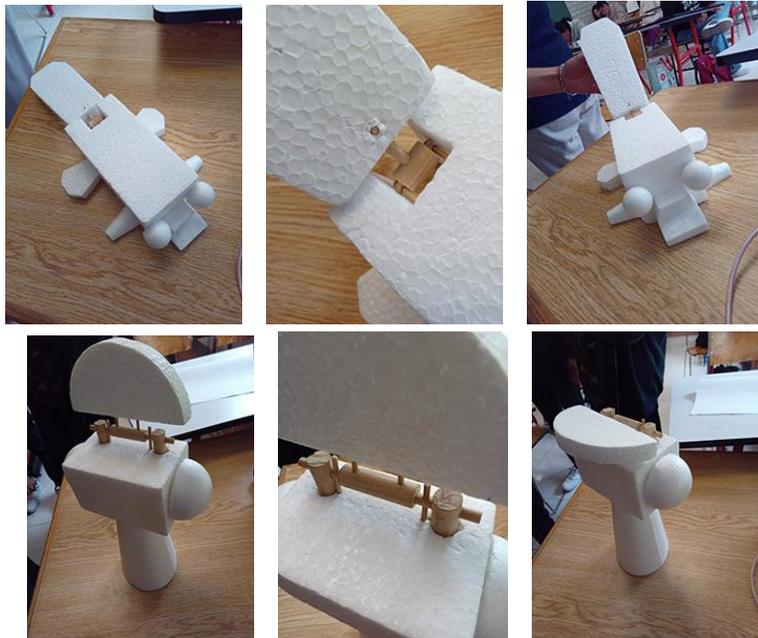


Figure 13: Hinge mechanisms demonstrated in student models.

5.5 Importance of the Learning Sequence in Descriptive Geometry

A key observation from this study is that students' difficulty in solving the hinge exercise is closely related to the learning sequence in descriptive geometry. Within the research team's work, we have developed operational programs for geometric representation, technical drawing, two-dimensional digital representation, and three-dimensional digital representation, which follow a logical progression to help students acquire fundamental concepts in descriptive geometry.

However, we have observed that students who do not take these courses (UEA - Teaching-Learning Units) in the recommended order, either because they are not sequentially structured or because they failed them, tend to experience greater difficulties when solving exercises such as the hinge construction. This indicates that descriptive geometry instruction must be approached in a structured and continuous manner to ensure solid learning.

Another identified issue is the lack of consistency in the teaching of descriptive geometry. Not all professors cover the same content or use the same methods, resulting in disparities in students' prior knowledge. Additionally, the shortage of specialized faculty in this field makes it difficult to consolidate a standardized curriculum. Descriptive geometry is a complex subject that requires specialized training and experience, which limits the number of professors willing to teach it. As a result, this affects the quality of student learning.

5.6 Theoretical Approach to Assessment

The data collection for assessing student learning was primarily qualitative. Although no surveys or interviews were conducted due to institutional limitations, data were gathered through instructor observations, rubric-based project assessments, and reflective reports written by students.

The evaluation of student learning was approached through a combination of qualitative and performance-based assessments, structured as follows:

- Performance rubrics were used to assess the functionality, creativity, and technical precision of the hinge models.
- Observational checklists documented students' ability to apply geometric and kinematic principles during the workshop.
- Technical drawing analysis ensured accurate application of descriptive geometry concepts (orthographic and isometric views).
- Student reflection reports provided insight into conceptual understanding and personal learning outcomes.

While no pre-/post-quantitative tests were conducted, this multimodal evaluation provided a comprehensive picture of learning progression, aligned with the principles of experiential and project-based learning.

6 CONCLUSIONS AND FUTURE RESEARCH

This study demonstrates that the construction of a functional hinge as a learning model is an effective strategy for teaching geometry in motion and kinematics to design students. The implemented craft-based methodology allowed students to connect theory with practice, develop technical skills, and understand geometric and kinematic principles in a tangible manner.

In contrast to the initial version of the study, which involved a limited sample, the activity has now been implemented with 95 students across three different academic terms, confirming the consistency and effectiveness of the approach. The results highlight improvements in conceptual understanding, technical skill development, and students' ability to solve design problems, supporting the broader applicability of this methodology.

The approach is aligned with experiential learning and project-based learning models, demonstrating that students can apply abstract geometric concepts to practical situations. However, several challenges remain:

1. Difficulties faced by students who do not follow the recommended sequence in descriptive geometry. Students who skipped or failed prerequisite courses struggled more with the hinge design task.

2. Lack of consistency in teaching practices. Instructors do not always cover the same content or use comparable teaching strategies, leading to disparities in student preparation. Furthermore, the complexity of teaching descriptive geometry contributes to a shortage of qualified instructors, which can affect learning outcomes.

One of the main challenges in evaluating this methodology is that traditional quantitative tools, such as knowledge tests, may not adequately capture students' practical learning. In this study, several students demonstrated a deeper understanding of theoretical concepts only after engaging in the hinge construction exercise. This suggests that the assessment of learning geometry in motion should include:

- Performance-based evaluation of the final project.
- Process observation during the design and construction stages.
- Student self-assessment and reflection.

In conclusion, this study confirms that the teaching of geometry in motion through physical model construction is an effective strategy in design education. Expanding the implementation to 95 students strengthens the method's validity and suggests its potential for broader application.

To further advance this line of research, we recommend:

- Developing more comprehensive assessment tools that combine practical performance, process evaluation, and student reflection.
- Comparing the craft-based method with digital and technology-based approaches.
- Analyzing the impact of structured learning sequences on student performance in geometry and kinematics.
- Proposing pedagogical strategies to standardize the teaching of descriptive geometry and minimize disparities in student knowledge.

This study provides a foundation for improving the teaching of geometry in motion, emphasizing the value of structured learning and continued exploration of innovative methodologies in design education.

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