



2<sup>ND</sup> INTERNATIONAL WORKSHOP

ADDITIVE MANUFACTURING  
AND SUSTAINABILITY

BOOK OF PROCEEDINGS

**IWAM 24**



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## WELCOME

In recent years, the manufacturing processes have undergone a profound transformation, driven by the rapid evolution of additive manufacturing (AM) technologies. What began as a tool primarily for prototyping through stereolithography has now expanded into a versatile and innovative field capable of producing functional, end-use components across a wide range of industries. From fused deposition modeling (FDM) to selective laser melting (SLM) and beyond, AM has unlocked new possibilities in design, material utilization, and production efficiency. Today, additive manufacturing encompasses an extensive array of materials, including metals, polymers, paper, and even biological tissues, enabling applications that span from the mechanical industry to the biomedical sector.

One of the most compelling aspects of additive manufacturing is its potential to drive sustainability in modern production processes. Unlike traditional subtractive methods, which often generate significant material waste, AM builds components layer by layer, minimizing excess material and promoting resource efficiency. Furthermore, the ability to use eco-friendly and recyclable materials aligns with global efforts to reduce environmental impact. AM also supports the production of complex, customized parts on demand, reducing the need for large inventories and long-distance transportation, thereby lowering carbon emissions. By optimizing resource use and enabling more efficient production cycles, additive manufacturing is emerging as a cornerstone of sustainable manufacturing practices.

This proceeding book arrests the latest advancements, challenges, and opportunities in the field of additive manufacturing, with a particular focus on its transformative potential and contributions to sustainability. The works presented here reflect the interdisciplinary nature of AM, showcasing innovative techniques, materials, and applications that are shaping the future of manufacturing. From cutting-edge research to real-world case studies, this collection aims to inspire further exploration and collaboration, driving the adoption of additive manufacturing as a key enabler of sustainable industrial progress. We invite readers to probe into these pages and discover how AM is not only redefining manufacturing but also paving the way for a more sustainable and efficient future.

The IWAM 2024 Organizing Committee,

João Rocha

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## Linear transformations in an engineering course – Matrices and dynamic representations

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### ABSTRACT

Several studies point to the importance of teachers creating learning environments that involve students more in the construction and communication of knowledge. On the other hand, digital technologies can be used as didactics tools to improve learning. To promote the development of skills in the area of linear algebra, more specifically in the context of linear transformations, we chose to propose an activity involving Geogebra. This software allows symbolic representations of multiple linear transformations of the plane, either through the matrix route or through its analytical expression, while also allowing the observation of the image of particular objects through this transformation. The experiment was carried out with students of an engineering course who were attending the Linear Algebra and Analytical Geometry curricular unit. The students also answered a questionnaire to evaluate their learning and assess the relevance of Geogebra in the acquisition of concepts. Their feedback shows that this software encourages creativity and promotes experimental research, having been considered an excellent ally in understanding concepts related to linear transformations and their properties.

**Keywords:** Geogebra, linear transformations, linear algebra, higher education.

### INTRODUCTION

Linear algebra is a relevant area for the academic training of engineers (Berman & Okubo, 2015). However, according to several studies, it is a source of difficulties for many higher education students, both in terms of the prior knowledge required to follow the curricular units that focus on this area (e.g. Barros, Silva & Fernandes, 2021; Barros, Fernandes & Araújo, 2016; Uzuriaga, Arias & Manco, 2008) and in terms of the knowledge inherent to the linear algebra contents themselves (e.g. Barros, 2018; Aygor & Burhanzade, 2014; Karrer, 2006). Understanding many linear algebra concepts requires a level of abstraction that many first-year engineering undergraduate students have difficulty achieving. By enabling interactive explorations and the visualization of multiple representations, Geogebra software can contribute to a more motivating learning environment that promotes the understanding of abstract concepts and helps students overcome some of their difficulties (e.g. Cordeiro & Barros, 2023; Santos & Di Blasi, 2011; Pires & Marques, 2009; Karrer, 2006).

Considering the above assumptions, we conducted an experiment with students of a Computer Engineering degree course who were attending the Linear Algebra and Analytical Geometry course. The experiment involved solving some tasks, including constructing polygons and observing their image associated with certain linear transformations.

## RESULTS

The formal concept of linear transformation was introduced by the teacher in the classroom. Students then solved a set of tasks that aimed to promote, in an evolutionary way, the understanding of the concept and its properties.

The first task was carried out with pencil and paper. Starting from the construction of the reflection of a quadrilateral  $[ABCD]$  over x-axis, and then over y-axis, it was intended that students interpret the geometric representation to determine the algebraic expression that defines it and verify that it checks linearity properties for addition and scalar multiplication. For example, in the case of reflection through the x-axis, students identified the image point of each point  $(x, y)$  of the quadrilateral and recognized that  $T(x, y) = (x, -y)$  is the law that defines this transformation. They also verified that the cartesian coordinates of the image of each point of the quadrilateral were written as a linear combination of the coordinates of that point.

The following tasks already included using Geogebra to evaluate the image of polygons through multiple linear transformations regarding their size, shape and angles.

With dynamic constructions like the one in Figure 1, students were able to observe that the image of an object through a linear transformation  $T(x, y) = (kx, ky)$ , in  $\mathbb{R}^2$ , can present changes in size in relation to the original and maintain its main characteristics (shape and angles). At the same time, they observed that  $T(x, y) = (kx, ky)$  can be represented by the scalar matrix

$$\begin{bmatrix} k & 0 \\ 0 & k \end{bmatrix}.$$

By varying the parameter k, the algebraic, matrix and graphical representations are updated, which facilitates the understanding of linear transformations whose image  $[A'B'C'D'E']$  represents a homothety of the polygon  $[ABCDE]$ .

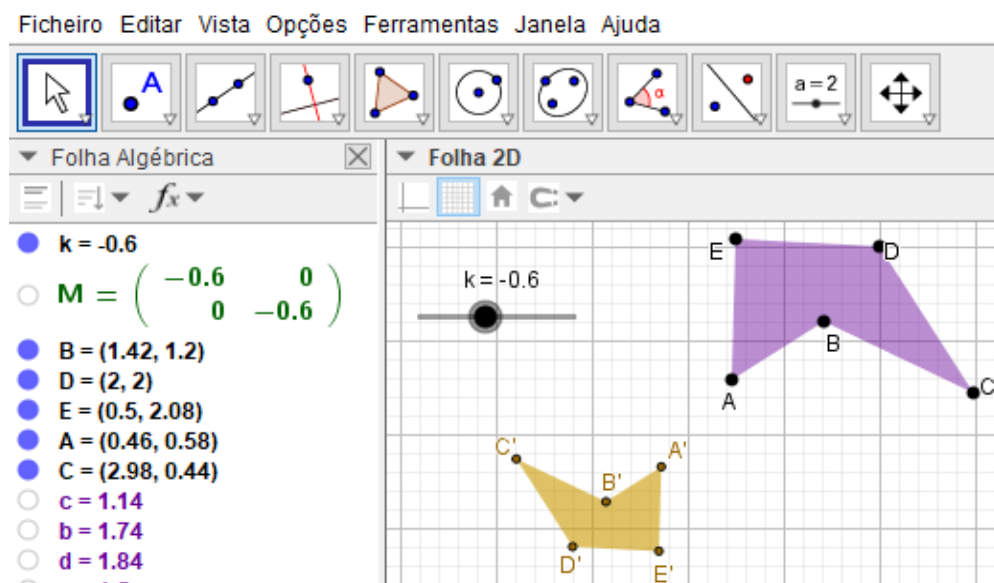


Figure 1 - Homothety.

In the last task, students were asked to apply any linear transformation to a polygon. With the help of the teacher, they built applications like the one in Figure 2, which allowed them to

understand that the square matrix of order two

$$\begin{bmatrix} a & b \\ c & d \end{bmatrix}$$

represents any linear transformation  $T(x, y) = (ax + by, cx + dy)$  of  $\mathbb{R}^2$ . By varying the values of parameters  $a, b, c, d$ , students were able to observe several linear transformations, as well as their effect when applied to a given object. The image of the polygon  $[ABCDE]$  can represent similar polygons or different deformations of this object.

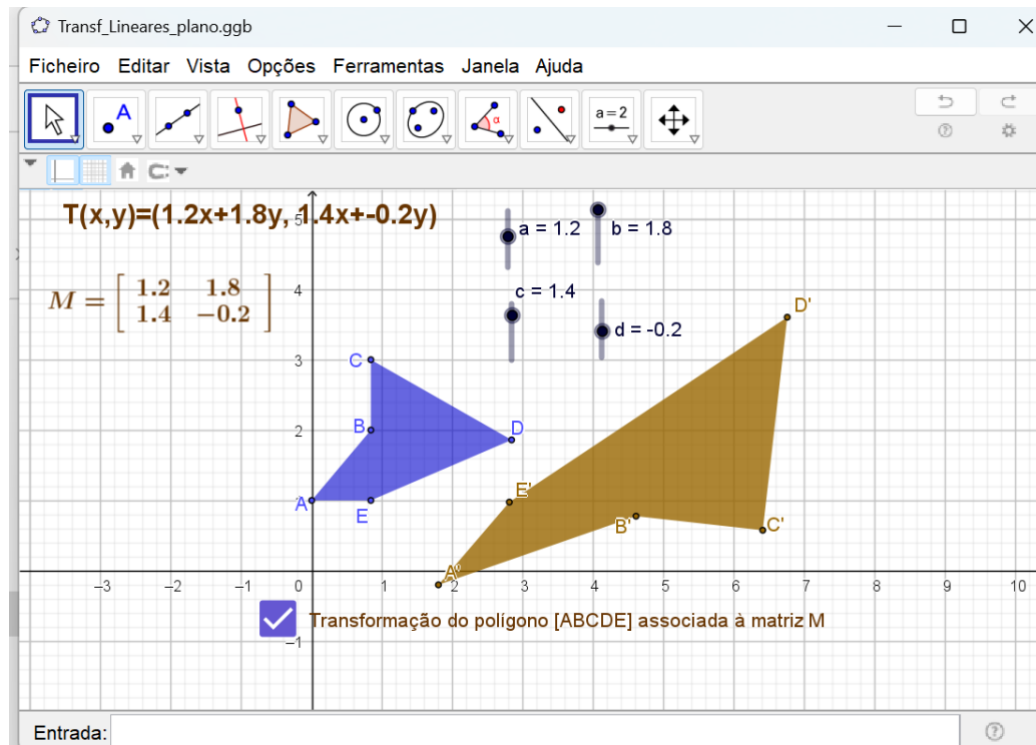


Figure 2- Deformation.

By observing algebraic and geometric representations of multiple linear transformations of the plane, students better understood the linearity properties of these functions and their relationship with the fact that the cartesian coordinates of the image of any point on the object are written as a linear combination of the coordinates of the respective point.

According to the responses to the questionnaire, given after the activity, students agree or completely agree that Geogebra allows visualizing the graphical effect of multiple linear transformations (96.1%), facilitates the identification of properties associated with them (94.1%), as well as facilitating autonomous learning (92.2%).

## CONCLUSIONS

From the results obtained, we can conclude that the Geogebra software allowed students to establish connections between what they visualized and the respective concepts, which facilitated the understanding of the equivalence between the analytical and matrix definitions of a linear transformation. The students also acquired skills in Geogebra, although it was recognized that some needed more time to familiarize themselves with the software.

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