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Appropriation of Functional Analysis Tools in Learning Mechanical Design

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Abstract

Technical system design plays an important role in the training of professionals working in industrial production companies. It enables professionals to develop multitechnical systems. Functional, structural and behavioral analysis approaches form the basis for teaching and learning about the design of multitechnical systems. In addition, various tools from the industrial world are associated with each approach and used in the teaching-learning activities of the mechanical design of technical systems. However, their use in mechanical design teaching and learning activities raises numerous problems, sometimes linked to the pedagogical exploitation of these analysis tools, their use and/or their appropriation by students. From an exploratory perspective, this article attempts to identify the factors that promote the effectiveness of students' mechanical design learning process with functional analysis tools. After a description of the mechanical design learning context, students' perceptions of functional analysis tools were collected using a questionnaire. The data collected from 89 students helped address questions related to the evaluation of functional analysis tools, their appropriation by students and the identification of factors likely to promote learning effectiveness. A statistical analysis was carried out to explore the relationships between the student profile, the use of functional analysis tools, their educational use, the interaction between the student and these tools, and, finally, the effectiveness of the student's learning. The results of the analysis made it possible to highlight factors that promote the effectiveness of students' learning of mechanical design using functional analysis tools.

Keywords

Learning Effectiveness, Functional Analysis Tools, Mechanical Design

1. Introduction

Technology teachers can use a variety of methods to approach the design or anal-

ysis of technical systems. Most of these methods have their origins in functional analysis from the world of industry. Faced with the problem of matching training to jobs in the workplace, technology teachers are introducing these same functional analysis tools into the teaching-learning of mechanical design at higher technological education establishments (Gueye et al., 2020). The integration of functional analysis tools into the teaching of industrial science and technology has transformed the teaching of mechanical design. Indeed, the use of artifacts such as functional analysis tools in teaching-learning activities presupposes the consideration and modification of instrumental geneses, teaching practices and conceptualizations of these practices (Pellerin, 2015). Therefore, the mechanical design teacher must consider how to use these tools in teaching-learning situations. What are the factors that promote the effectiveness of students' mechanical design learning process when functional analysis tools are used? What difficulties do analysis tools pose for students in the mechanical design learning process? This finding justifies the study carried out as part of this research to contribute to improving the quality of mechanical design learning at higher technological education institutions. This article explores the quantitative aspects of the pedagogical uses of functional analysis tools in a didactic context at higher technological education establishments.

2. Problem

Functional analysis has become an essential part of the product design process. Indeed, the adoption of functional analysis tools in the teaching and learning of mechanical design in industrial science and technology has qualitatively improved the product design process. As a result, they are being increasingly used in product design activities. On the other hand, students are often confronted with problems linked to the pedagogical exploitation of analysis tools and their use and/or appropriation. In other words, it is essential to examine the appropriation of functional analysis tools by students in the mechanical design learning process. What factors make it easier for students to learn mechanical design using functional analysis tools? What difficulties do analysis tools pose for students in the mechanical design learning process? How can we help students use analysis tools in the learning process?

3. Mechanical Design and Functional Analysis Tools

The design of technical systems is an intellectual activity in which a number of provisions are devised to change an existing situation into a preferred one (Simon, 1991). It is the result of complex processes that consist of providing materiality to an object that does not yet exist and that exists only in the minds of those who design it (Lebahar, 2008). Contextualizing it, it consists of providing a set of proposals for describing a product (shape, size, and means of production) that globally meets a set of specifications. Mechanical design can be divided into four categories: routine design, redesign, innovative design, and creative design. All these

categories share the following three stages: problem definition to determine requirements; a conceptual definition to set up the functional structure and physical principles; and a detailed definition to offer a complete description of the design (Oosterman, 2001). Functional analysis is used systematically at every stage. Functional analysis provides both a technical and pedagogical method as part of a rational approach to building knowledge and know-how. It is an approach that uses different tools to characterize a product in the form of diagrams (Horned Beast, APTE, FAST). It consists of finding, ordering, characterizing, prioritizing and/or enhancing a product's functions. It is useful in the design or redesign phases of a product.

4. Theoretical Framework

To fully understand the phenomenon in question, to fully understand the phenomenon we are interested in, this research articulates three theoretical concepts. First, the instrumental approach developed by Rabardel (1995) is based on the importance of instrumental mediation. Next, Engeström's model of the "basic structure of an activity" takes into account the different interactions with functional analysis tools in a didactic context. Then, the use of cognitive tools (functional analysis tools) is used to develop knowledge.

4.1. Instrumental Approach

This study draws on Rabardel's (1995) instrumental approach to conceptualizing the relationship between humans and technology. The approach differentiates between an artifact and an instrument. The transition from artifact to instrument refers to a process of instrumental genesis that, according to Rabardel (1995), marks the progressive evolution of artifact use through usage. He distinguishes two processes in instrumental genesis: instrumentalization and instrumentation. Instrumentalization addresses tools and assigns functions to artifacts. Instrumentation focuses on the subject and materializes their capacity to adapt to new situations to the genesis of schemas. The instrumental approach allows for a nuanced understanding of the process of technology appropriation in context. The appropriation of a tool is defined by its concrete implementation and its long-term integration within the organization (Gueye et al., 2025). It results from a process that includes adoption and adaptation by individuals.

4.2. Cognitive Tools for Design Learning

Tools are extensions of the human being, partially differentiating us from other animal species (Jonassen, 1992). The latter are unable to conceive of the need to build them or incorporate them into their culture. In fact, over the past few centuries, human beings have evolved to use tools to survive and build new objects. Tools can be material (wheel, bow, computer, etc.) or immaterial, such as language.

In this sense, the tool is very close to the artifact, which is necessarily man-made. Indeed, some tools or artifacts have been developed or adapted to support a learning process. These are cognitive tools designed to support, guide and deepen the thought processes of their users (Jonassen, 1994). Cognitive tools activate cognitive and metacognitive learning strategies. They facilitate the process of knowledge construction by learners, as the acquisition of new knowledge has become a constructive process. From this constructivist perspective, the use of cognitive tools in design learning (functional analysis tools) will enable learners to build their understanding by facilitating the way they organize information.

4.3. Activity Theory and Design Learning Modeling with Functional Analysis Tools

Among other things, this work refers to activity theory, which focuses on human activity as a socially situated activity, such as that associated with the world of work or learning (Parks, 2000). Vygotsky (1934/1985) emphasizes the importance of tools (artifacts) and considers them as mediators between the individual and his social and cultural environment. According to Engeström (1999), Vygotsky represents the first generation of this theory.

Léontiev (1975/1984) developed the second generation by emphasizing the distinction between individual and collective action. He considered the interactions between the individual and their community.

Engeström's systemic model (Engeström, 1987) enriched the previous models by expanding them to include new poles related to social and institutional aspects, such as rules, the division of labor, and the community. The systemic model places the individual at the heart of an activity system composed of six interrelated poles (subject, tool, rules, division of labor, community, object).

This research work is based on Engeström's systemic model (**Figure 1**) for the conceptualization of the learning activity of mechanical design by means of functional analysis tools to answer questions related to improving the effectiveness of learning.

This systemic model expresses the interactions between the different poles. However, it is important to define these poles within the framework of this study. The subject is an individual or subgroup that the observer has chosen to analyze; in this specific case, it is represented by the student or group of students.

The object represents the performance objective of the activity. Here, it involves the design of a mechanical system. Tools or artifacts (functional analysis tools) are symbolic supports that serve as mediators to carry out the activity. The community represents a group of people who share a common interest and collaborate around a specific field (students, industrialists, institutes, designers). The division of labor mediates the relationship between the community and the activity/object. Rules constitute an encompassing framework of obligations, standards, regulations and procedures.

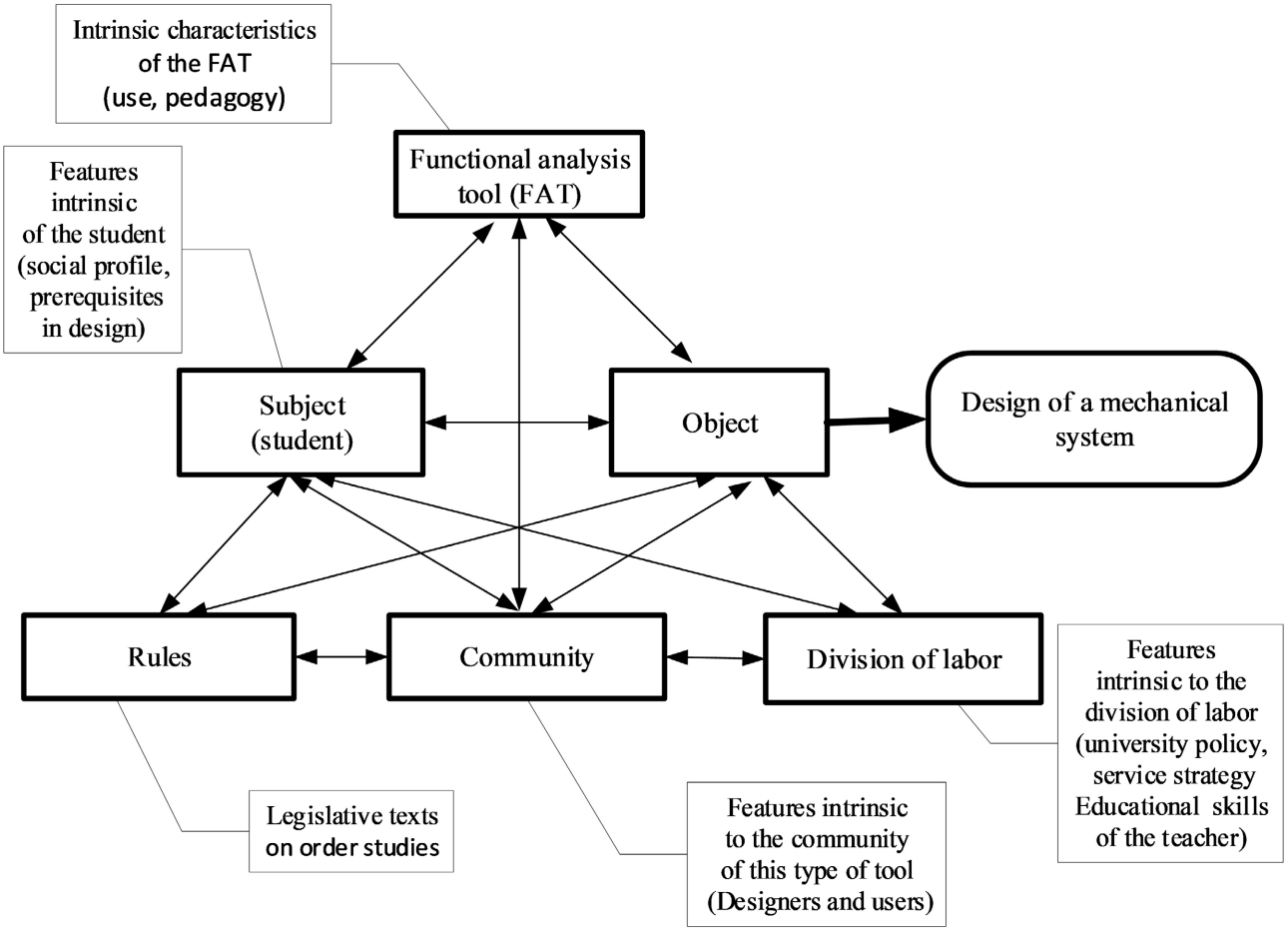

Figure 1. Application of activity theory to learning mechanical design.

4.4. Evaluation of Functional Analysis Tools

Cognitive tools, considered external objects, improve our cognitive skills (Virgo, Pillon, Navarro, Reynaud, & Osiurak, 2017; Osiurak, Navarro, Reynaud, & Thomas, 2018). They facilitate an individual's reasoning or knowledge construction (Jonassen, 1994). The use of cognitive tools is an external way to reduce internal cognitive load (Risko & Dunn, 2015). Liu et al. (2009) reported that cognitive tools can assist in problem solving. This is the case with functional analysis tools, whose main objective is to better conceptualize the problem. They belong to the most dominant and important categories of cognitive tools in the problem-solving stage.

Assessing the use of a cognitive tool raises the question of its usefulness, usability and acceptability (Tricot et al., 2003). The criteria dimensions taken into account in the evaluation of functional analysis tools are shown in **Figure 2**.

5. Research Objective

On a general level, this research contributes to improving the quality of the mechanical design learning process in higher education institutions. More specifically, it aims to identify factors likely to improve the effectiveness of the mechanical design learning process.

Figure 2. Dimensions of the evaluation of functional analysis tools.

6. Methodology

6.1. Data Presentation

The data used come from a questionnaire survey of 89 students in their 2nd year of industrial science and technology bachelor's degrees at the Higher Normal School of Technical and Vocational Education (ENSETP) in Dakar, Senegal. The sample comprised 89 students (23% girls) whose average ages ranged between 21 and 25 years. All the students had a baccalaureate. The 89 students come from four classes: Class 1 (25 students), Class 2 (20 students), Class 3 (20 students), Class 4 (24 students). The aim was to collect data to understand the factors likely to improve the effectiveness of mechanical design learning using functional analysis tools. The questionnaire was built on a Likert scale with four response modes. The pre-test stage allowed for adjustments to be made to the questionnaire where necessary (AERA et al., 2014). The student questionnaire consists of 57 items divided into four factors:

- I: Student profile (9 items);

- II: Ergonomics of functional analysis tools (33 items),
- III: Pedagogical use of functional analysis tools (8 items)
- IV: Student interaction with functional analysis tools (7 items).

6.2. Measurement of Variables

The dependent variable Y, which represents "the effectiveness of the student's learning with a functional analysis tool", was measured by the following question: Were you able to design a mechanical system using functional analysis tools? The independent variables are linked to four factors, each composed of several criteria. The first factor relates to the student's profile (Table 1), the second to the ergonomics of the functional analysis tools (Table 2), the third to the pedagogical use of the functional analysis tools (Table 3) and, finally, the fourth to the student's interaction with the functional analysis tools during learning (Table 4). The data collected was quantitative and was processed using Jamovi software. The table below presents criteria likely to influence the effectiveness of student learning with functional analysis tools. The dependent variable Y expresses the effectiveness of learning functional analysis tools in the design of a technical system.

Table 1. Criteria linked to the student profile factor.

Social profile
1. Gender
2. language
3. Age
Student training
4. Speciality (speciality)
5. Level of study(level_study)
Student prerequisites
6. Knowledge of mechanical connections (prer_mecha_connect)
7. Knowledge of mechanical power transmission modes (per_mecha_pow_transm_mod)
8. Knowledge of mechanical power transformation modes (prer_mech_pow_transf_mod)
9. Knowledge of structural design (prer_struc_design)

Table 2. Criteria linked to the ergonomics factor of functional analysis tools.

Usefulness of functional analysis tools
10. Identification of the user's need (identif_need)
11. Identification of the main function (identif_main_funct)
12. identification of constrained functions (identif_constr_funct)
13. Identification of technical functions (identif_techn_funct)
14. Identification of technological solutions (identif_techno_sol)
15. Identification of functional specifications (identif_funct_specif)

Continued

Usability of functional analysis tools
16. Clarity of the horned beast diagram (clar_horn_beast_diag)
17. Clarty of the Pieuvre diagram (clar_pieuvre_diag)
18. Clarity of functional specifications (clar_funct_specif)
19. Clarty of the FAST diagram (clar_fast_diag)
20. Coherence between main function and constrained functions (coher_main_constr_funct)
21. Coherence between technical functions and technological solutions (coher_techn_techno_funct)
22. Readability of the horned beast diagram (readab_horn_beast_diag)
23. Readability of the Pieuvre diagram (readab_pieuvre_diag)
24. Readability of functional specification (readab_funct_specif)
25. Readability of the FAST diagram (readab_fast_diag)
26. Comprehensibility of the need (compreh_need)
27. Comprehensibility of the main function (compreh_main_funct)
28. Comprehensibility of the constrained functions (compreh_ constr_funct)
29. Comprehensibility of the technical functions (compreh_ techn_funct)
30. Comprehensibility of the technological solutions (compreh_techno_sol)
Acceptability of functional analysis tools
31. Suitability of the horned beast diagram to student expectations (suitab_horn_beast_diag)
32. Suitability of the Pieuvre diagram to student expectations (suitab_pieuvre_diag)
33. Suitability of functional specifications to student expectations (suitab_funct_specif)
34. Suitability of the fast diagram to student expectations (suitab_fast diag)
35. Student investment in learning the horned beast diagram (invest_ horn_beast_diag)
36. Student investment in learning the Pieuvre diagram (invest_pieuvre_diag)
37. Student investment in learning the functional specifications (invest_funct_specif)
38. Student investment in learning the FAST diagram (investis_diag_fast)
39. Motivating students to use the horned beast diagram (motiv_horn_beast_diag)
40. Motivating students to use the pieuvre diagram (motiv_pieuvre_diag)
41. Motivating students to use the functional specifications (motiv_funct_specif)
42. Motivating students to use the fast diagram (motiv_fast_diag)

Table 3. Criteria linked to the educational exploitation of functional analysis tools.

Organization of the content of functional analysis tools
43. Structuring the contents of the horned beast diagram (struct_cont_ horn_beast_diag)
44. Structuring the contents of the pieuvre diagram (struct_cont_ pieuvre_diag)
45. Structuring the contents of the functional specifications (struct_cont_ funct_specif)
46. Structuring the contents of the fast diagram (struct_cont_ fast_diag)

Continued

Presentation of the content of functional analysis tools
47. Formulation of main functions (Formul_ main_funct)
48. Formulation of constrained functions (Formul_constr_funct)
49. Formulation of technical functions (Formul_techn_funct)
50. Formulation of technological solutions (Formul_techno_sol)

Table 4. Criteria linked to the student interaction factor with functional analysis tools.

Efficiency
51. Time to complete the design of a technical system (duration_stain)
Satisfaction
52. Easy to learn horned beast diagram (Easy_learn_horn_beast_diag)
53. Easy to learn pieuvre diagram (Easy_learn_pieuvre_diag)
54. Easy to learn fast diagram (Easy_learn_fast_diag)
55. Easy to memorize the horned beast diagram (Easy_memo_horn_beast_diag)
56. Easy to memorize the pieuvre diagram (Easy_memo_pieuvre_diag)
57. Easy to memorize the fast diagram (Easy_memo_fast_diag)

6.3. Data Analysis

To identify factors likely to improve the effectiveness of learning mechanical design, represented by the dependent variable Y, we carried out an exploratory factor analysis (EFA) of the collected data. EFA reveals hidden latent factors that can be deduced from our observed data. Above all, however, verification of the sphericity hypothesis and the adequacy of Kaiser-Meyer-Olkin (KMO) sampling are needed. An internal consistency reliability analysis was used to test the consistency of the variables selected.

7. Results

Bartlett's sphericity test verifies whether the observed correlation matrix differs significantly from an identity matrix in which all correlation coefficients are zero.

Table 5. Bartlett's test of sphericity.

χ^2	ddl	p
1709	120	<0.001

The significant Bartlett sphericity test presented in Table 5 ($p < 0.001$) confirms that the correlations between the variables are not zero, indicating that the correlation matrix is well suited to exploratory factor analysis (EFA).

In parallel, the Kaiser-Meyer-Olkin (KMO) measure is used to assess sample suitability for exploratory factor analysis (EFA). Exploratory factor analysis (EFA) is considered appropriate if KMO values are greater than 0.5. As shown in Table

6, the KMO values of the selected observed variables are greater than 0.6, suggesting good sampling adequacy.

Table 6. KMO sampling dequacy test.

	Measurement System Analysis (MSA)
General	0.772
identif_techn_funct	0.675
clar_funct_specif	0.914
coher_main_constr_funct	0.801
readab_pieuvre_diag	0.700
compreh_main_funct	0.695
compreh_ constr_funct	0.734
investis_diag_fast	0.643
struct_cont_ horn_beast_diag	0.816
struct_cont_ pieuvre_diag	0.895
Formul_ main_funct	0.861
Formul_constr_funct	0.784
Easy_learn_horn_beast_diag	0.729
Easy_learn_pieuvre_diag	0.720
Easy_memo_fast_diag	0.702
identif_main_funct	0.809
identif_funct_specif	0.628

Following the verification of the assumption of sphericity and the adequacy of Kaiser-Meyer-Olkin sampling, exploratory factor analysis (EFA) allowed us to obtain four factors, as presented in Table 7. The latter presents the factorial contributions and shows how the 16 items of learning effectiveness apply to each of the four selected factors.

The four factors revealed are composed of 16 items. The first factor related to the educational use of functional analysis tools includes items linked to the structuring of the contents of the horned-beast diagram (struct_cont_ horn_beast_diag), the pieuvre diagram (struct_cont_ pieuvre_diag), the formulation of the main functions (Formul_ main_funct) and constraints (Formul_constr_funct). However, we note a significant contribution from the item relating to the identification of the main function (identif_main_funct), a criterion of the utility factor.

The second factor relates to the usability of functional analysis tools by students. We note a strong contribution of items related to the comprehensibility of the main function (compreh_main_funct), the readability of the pieuvre diagram (readab_pieuvre_diag), the coherence between the main function and constrained functions (coher_main_constr_funct) and the clarity of the functional specifications (clar_funct_specif).

Table 7. Contributions of factors.

	Factor				
	1	2	3	4	Uniqueness
struct_cont_ horn_beast_diag	0.998				0.00998
Formul_constr_funct	0.987				9.39e−4
struct_cont_ pieuvre_diag	0.967				0.01618
Formul_ main_funct	0.660				0.41458
identif_main_funct	0.558			0.377	0.51137
compreh_ constr_funct	0.406				0.73557
compreh_main_funct		0.996			0.00232
readab_pieuvre_diag		0.963			0.05253
coher_main_constr_funct		0.517			0.73349
clar_funct_specif		0.516			0.61039
Easy_learn_pieuvre_diag			0.982		0.00373
Easy_learn_horn_beast_diag			0.966		0.02988
Easy_memo_fast_diag			0.570	0.351	0.52115
investis_diag_fast			0.398		0.82278
identif_techn_funct				0.984	0.00347
identif_funct_specif				0.301	0.84778

The third factor highlights student satisfaction. Satisfaction is significantly influenced by the perception of the ease of learning of the pieuvre diagram (Easy_learn_pieuvre_diag), the perception of the ease of learning of the horned-beast diagram (Easy_learn_horn_beast_diag), and the ease of memorization of the FAST diagram (Easy_memo_fast_diag).

Finally, the last factor relating to the usefulness of functional analysis tools brings together items linked to the identification of the main function (identif_main_funct), technical functions (identif_techn_funct) and functional specifications (identif_funct_specif).

Furthermore, Table 8 shows correlations between factors greater than 0.3, allowing the use of oblique rotation (oblimin).

Table 8. Interfactor correlations.

	1	2	3	4
1	-	0.354	0.376	0.310
2		-	0.306	0.111
3			-	0.140
4				-

We can also see from Table 9 that the proportion of the overall data variance attributable to the four factors is 66.8%. The variance of factor (1) is 24.7. That of factors (2) to (3) is approximately 16% each. For the last factor (4), the variance represents 9%.

Table 9. Statistical summaries of factors.

Factor	Sum of squares of contributions	% of variance	% cumulative
1	3.95	24.68	24.7
2	2.67	16.70	41.4
3	2.58	16.12	57.5
4	1.48	9.28	66.8

An analysis of internal consistency reliability made it possible to determine to what extent the retained items were related to each other. Furthermore, reliability provides a general index of the internal consistency of the scale as a whole (Table 10). The table shows that Cronbach's alpha for the learning effectiveness scale is 0.87. This value indicates that the homogeneity and internal consistency of the items are satisfactory for understanding the effectiveness of learning.

Table 10. Internal consistency of the measurement scale.

	Moyenne	Ecart-type	Cronbach's alpha
scale	3.17	0.435	0.870

The heatmap (Figure 3) made it possible to visualize the correlation matrix between the selected items. This highlights the strong correlations between certain items.

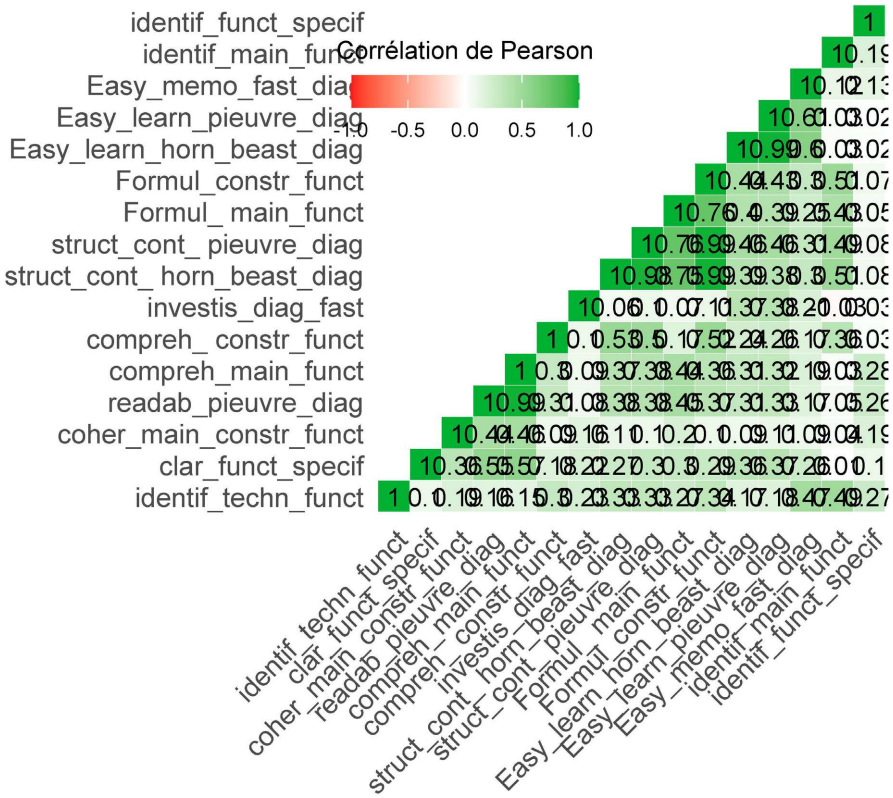

Figure 3. Correlation heatmap.

8. Conclusion

This study aimed to explore the factors that promote the effectiveness of students' learning in mechanical design through the use of functional analysis tools. In light of the literature on the effectiveness of learning and the empirical data available to us, we have developed a theoretical context allowing us to understand the framework in which students' learning of mechanical design using functional analysis tools would be considered successful, at least in part. This context is articulated around the hypothesis of student performance in interaction with functional analysis tools under the influence of four factors: the profile of the student, the ergonomics of the functional analysis tools, the educational use of the functional analysis tools and, finally, the interaction of the student with the functional analysis tools.

Overall, the effectiveness of learning depends on a set of factors, including the pedagogy of functional analysis tools, their usefulness, their usability, their acceptability and their interaction with the student.

However, it is the structuring of the contents of the diagrams (horned beast, pieuvre), the formulation of the functions (main, constraints), the identification of the functions (main, technical) and their understandability, the readability of the pieuvre diagram, the coherence between the main function and the constrained functions, the perception of the ease of learning of the diagrams (pieuvre, horned beast) and the ease of memorization of the FAST diagram, which constitute the most important factors for the explanation of the effectiveness of student learning. Indeed, the structuring of the horned beast and pieuvre diagrams must be clear for a better understanding of the need and the interactions.

The main function makes it possible to meet the main needs of the mechanical system, while the technical functions are the means implemented to achieve these functions.

Primary functions are those that define the usefulness of the mechanical system, whereas constrained functions are the requirements that the mechanical system must meet. The wording must be precise and concise for effective functional analysis.

The ease of learning of the octopus and horned-beast diagrams, as well as the ease of memorization of the FAST diagram, constitute key factors for the effectiveness of students' learning. The easy learning of these diagrams improves the understanding and memorization of concepts and therefore the learning efficiency of students.

This exploratory study in technological education draws on the practices declared by students to examine the problem of learning mechanical design. It thus enriches existing research in this area. In other words, the study explores how students perceive and use functional analysis tools while learning mechanical design, thus contributing to a better understanding of the factors that promote the perceived effectiveness of their learning.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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