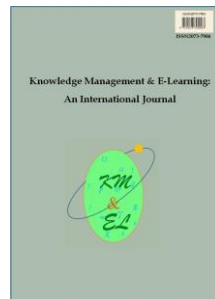

Differential effects of a fixed and a faded motivational scaffold on cognitive load and learning in multimedia environments

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Differential effects of a fixed and a faded motivational scaffold on cognitive load and learning in multimedia environments

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Abstract: The research compares the effects of two motivational scaffolding models included in a multimedia environment that addresses technological content and evaluates their influence on cognitive load and academic performance in students with different cognitive styles in the field dependence-independence (FDI) dimension. The study involved 145 tenth-grade students from a public institution in Cundinamarca, Colombia. A quasi-experimental design was used with two independent variables: type of scaffolding (fixed or faded by the student) and students' cognitive style in the FDI dimension. The dependent variables evaluated were academic performance and cognitive load in three categories: intrinsic, extrinsic and Germanic. A 2×2 MANCOVA factor analysis was performed, the results of which showed a higher intrinsic cognitive load in students with a tendency toward field dependence, compared to their peers with a tendency toward field independence. In addition, the performance of students who interacted with the multimedia environment with self-faded scaffolding was superior to those who used fixed scaffolding. The data also show that students with different cognitive styles achieved equivalent learning. Also, the type of motivational scaffolding used did not affect cognitive load.

Keywords: Scaffolding; Cognitive style; Cognitive loads; Learning achievement; Multimedia environment

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1. Introduction

Currently, computer-based learning environments (CBLEs) have gained a prominent place in educational processes, as they have become a valuable resource at different levels of schooling and in various areas of knowledge. These environments are characterized by non-linear navigation structures that integrate a variety of resources, such as videos, interactive activities, concept maps and simulations, to enrich the learning experience. In addition, some computational environments, especially those using technologies such as virtual reality (VR), offer an immersive experience that simulates a real or fictional environment and engages the user in a deeper way (Hu et al., 2020; Rahman et al., 2024; Wang & Lin, 2018).

CBLEs are available at any time and from anywhere, thus eliminating the time and space constraints inherent to traditional learning. They also allow adaptation to the needs and learning styles of users, offering different learning paths or activities based on user performance. They provide instant feedback to the user, which is critical for learning and error correction. They use intuitive interfaces that make it easy for users to navigate and use, regardless of their level of technical skill. In addition, they allow collaboration among multiple users, which facilitates teamwork and real-time communication. Technological advances in this area have allowed these environments to not only become more complex and sophisticated but also more accessible and user-friendly for learners (Fu et al., 2024; Makda, 2024; Mun & Sam, 2022; Rahman et al., 2024).

Students interacting with these learning environments must be prepared to face various challenges. Among them, the need to learn autonomously, without the direct guidance of the teacher or the support of their classmates, stands out. In this sense, they must organize themselves and follow a work plan, efficiently manage the available resources and search for other online materials to help them understand the concepts being studied. In addition, they must plan their time in order to be able to complete the tasks with quality and within the established deadlines. In other words, the learner must have skills to self-regulate their own learning process (Azevedo et al., 2022; Molenaar et al., 2012; van der Graaf et al., 2023).

Some researchers argue that CBLEs contribute to the development of self-regulation skills for learning, which improves academic performance (Azevedo et al., 2022; Azevedo & Gašević, 2019; Greene et al., 2011; van der Graaf et al., 2023). Furthermore, it has been argued that these environments generate a positive impact on motivation towards learning (Belland et al., 2013; Elford et al., 2022; Ollonen & Kangas, 2024; Sun et al., 2023;

Valencia-Vallejo et al., 2019). Studies also indicate that they favor social interactions through collaborative work (Kaliisa et al., 2022; Van Hoe et al., 2024; Yildiz Durak, 2024) and that they can adapt to individual learner differences, enabling more effective interaction with the platform (Alomyan, 2004; Chuang et al., 2021; Wang et al., 2018).

However, several studies have pointed out that computer-based learning environments do not benefit all students equally (Alomyan, 2004; Beserra et al., 2014; Chen & Macredie, 2002; Chuang et al., 2021; Rahman et al., 2024). In many cases, students fail to achieve the expected learning outcomes when interacting with these types of educational platforms. Some studies suggest that this phenomenon may be related to students' cognitive style (Angeli, 2013; Chuang et al., 2021; Gao et al., 2024; Giancola et al., 2022; Li et al., 2023; Vecchione et al., 2023), cognitive load (Çakiroğlu & Bilgi, 2022; Chen et al., 2023; Faber et al., 2024; Sweller et al., 2019) and the type of computational scaffold used (Cagiltay, 2006; Jackson et al., 1998; Karabay & Meşe, 2024; Shin et al., 2024; Vieira et al., 2021).

Regarding cognitive style, several studies suggest that this factor is related to the effective and efficient use of computational learning environments. For example, in the field dependence-independence (FDI) dimension, results indicate that, due to their cognitive characteristics, field-independent (FI) students achieve better learning performance with respect to their so-called field-dependent (FD) peers (Alomyan, 2004; Angeli, 2013; Chen & Macredie, 2002; Chuang et al., 2021).

FI learners are distinguished by their ability to orient themselves internally, which allows them to take control over their learning process by interacting with computational environments, without depending on other people. This independence allows them to explore platforms in a non-linear way, avoiding disorientation and taking more effective advantage of pedagogical strategies and available resources (Alomyan, 2004; Chen & Macredie, 2002; Chuang et al., 2021). In contrast, FD learners tend to get lost when navigating hypermedia environments. Their bias toward external stimuli leads them to focus on visually striking elements that are not always relevant to learning. In addition, they tend to require external support, preferring to learn in a group and to have control of the learning process exercised by the program or an external figure. Therefore, they prefer environments with linear navigation and clear signage, allowing them to locate themselves within the platform and receive guidance throughout their learning process (Alomyan, 2004; Chen & Macredie, 2002; Chuang et al., 2021).

In this context, cognitive style in the FDI dimension is a determining factor in the success of learning in computational environments. FD students, due to their cognitive characteristics, may find it more difficult to achieve learning objectives when interacting with these environments, which is evidence that CBLEs tend to favor FI students over FD. This fact could explain the differences in learning outcomes observed between students of different cognitive styles when using CBLEs, being an important variable to take into account when designing computational scenarios (Alomyan, 2004; Angeli, 2013; Chen & Macredie, 2002; Chuang et al., 2021; Valencia-Vallejo et al., 2019).

In relation to cognitive load, several studies have shown that the design features of computer environments can both facilitate and hinder the learning process. The mental effort a learner invests when performing a task can be negatively affected if the organization of information overloads the limited resources of working memory, preventing the proper construction of knowledge (Clark & Mayer, 2016; Faber et al., 2024; Sweller et al., 2019).

Some studies have shown that the excessive use of multiple sources of information in computational learning environments to explain the same concept can generate learning problems. This is because the student will need a greater cognitive effort to identify relevant information and discard redundant information, which affects the organization and categorization of new concepts. This, in turn, hinders the creation of new cognitive structures and may hinder, to some extent, the success of the learning process (Chen et al., 2023; Faber et al., 2024; Karabay & Meşe, 2024; Sweller et al., 2019).

In this field of study, it has been observed that when a computerized learning environment simultaneously presents different disjointed information formats, divided attention processes are generated, which hinder the structuring of knowledge. This occurs because the different materials compete for the learners' attention, which hinders to some extent the construction of knowledge (Chen et al., 2023; Clark & Mayer, 2016; Faber et al., 2024).

Therefore, the arrangement and nature of information formats in a CBLEs should reduce the learner's cognitive load and optimize the use of working memory. This would make it easier for students to focus their attention on the most relevant aspects for the formation of mental schemas, which would enhance their learning (Chen et al., 2023; Karabay & Meşe, 2024). Thus, cognitive load becomes a decisive variable in the design and implementation of computational environments and may explain, in part, the poor performance of some students when interacting with these scenarios (Çakiroğlu & Bilgi, 2022; Faber et al., 2024; Sweller et al., 2019).

Finally, the incorporation of computational scaffolds in learning environments can significantly influence the learning process, since they provide pedagogical support that facilitates the achievement of learning objectives. Several studies have shown that the use of scaffolding can improve student performance in computational environments. These didactic supports allow the student to advance in their learning process autonomously with proper guidance (Azevedo & Gašević, 2019; Belland et al., 2013; Greene et al., 2011; Zhang & Quintana, 2012).

In terms of implementation, it has been suggested that scaffolding should fade gradually as the learner becomes more proficient. However, this automatic fading poses a considerable challenge in learning environments, given that systems cannot always accurately assess a learner's knowledge level at any given time (Ayedoun et al., 2020; Cagiltay, 2006; Jackson et al., 1998; Pea, 2004). To address this challenge, flexible scaffolding has been proposed to allow the learner to decide which part of the support to withdraw based on their progress and knowledge (Jackson et al., 1998).

However, studies in this area have provided mixed results. Some suggest that fixed scaffolds produce better results (Bulu & Pedersen, 2010; Doo et al., 2020; Jaakkola & Veermans, 2018; Tawfik et al., 2018), while others find more benefit in gradual fading scaffolds (Kester & Kirschner, 2009; McNeill et al., 2006). Regarding the latter, some researchers propose that fading should be managed by the learners themselves (Cagiltay, 2006; Jackson et al., 1998).

Despite the advances in this field, there is no consensus in the academic community on the optimal use of scaffolds, as they do not always manage to adapt efficiently to the individual characteristics and needs of students. Therefore, it is essential to continue research to identify the most effective forms of fading that fit the individual needs of students (Cagiltay, 2006; Jackson et al., 1998; Pea, 2004).

This study addressed the notion of academic self-efficacy for the design of a motivational scaffolding in a multimedia environment in the area of technology. The aim of this type of scaffolding is to enhance the student's perception of his or her own abilities when facing learning tasks in these environments (Belland et al., 2013; López-Vargas et al., 2020; Valencia-Vallejo et al., 2018). In general, this type of scaffolding can help the learner to set achievable learning goals, provide positive feedback on their achievements, and foster the self-confidence and effort needed to accomplish them.

However, the use of these supports may also be related to variations in cognitive load during the learning process. This is particularly relevant in the case of students with field-dependent cognitive styles, since, being more prone to distractions, they could experience an increase in their cognitive load due to the presence of the scaffolding, which could become a possible distractor.

In view of the approaches and evidence shown in previous studies, the present research sought to answer the following questions:

RQ1: What are the effects of a fixed versus a faded-out computational scaffold on learning achievement and cognitive load in students interacting with a multimedia environment on electronics content?

RQ2: Are there significant differences in learning achievement and cognitive load in students of different cognitive styles in the FDI dimension who learn electronics content through a multimedia environment?

RQ3: Is there any interaction between fixed and fading scaffolds and student cognitive style in the FDI dimension on learning achievement and cognitive load in students interacting with a multimedia environment on electronics content?

2. Conceptual framework

2.1. Cognitive load

Cognitive load is a concept belonging to information processing theory that was developed based on the study of human cognitive architecture to improve instructional design (Chen et al., 2023; Clark & Mayer, 2016; Faber et al., 2024; Sweller et al., 2019). It is defined as the mental effort that an educational material imposes on a person's working memory in a learning process (Chen et al., 2023; Sweller et al., 2019). This concept is based on the idea that working memory is limited, something that becomes more evident when the learner is confronted with new information or complex tasks that are not yet organized in his or her long-term memory (Chen et al., 2023; Faber et al., 2024; Paas et al., 2003; Sweller et al., 2019).

In this sense, cognitive load is dynamic, as it can vary according to the degree of understanding and the level of organization of information in the individual's long-term memory. Although working memory has limitations for processing new information, these are not so strict when it comes to managing already organized data. Tasks can generate different levels of cognitive load in students, depending on their level of prior knowledge, experience with the topic, familiarity with educational resources, age, or possible disabilities (Chen et al., 2023; Sweller et al., 2019). Total cognitive load is composed of three subtypes: intrinsic, extrinsic, and Germanic, each of which affects working memory

and long-term memory differently (Aguiar & Correia, 2017; Chen et al., 2023; Faber et al., 2024; Leppink et al., 2014; Sweller et al., 2019).

Intrinsic load is related to the inherent complexity of the content. The more complex a topic is or the less experienced the learner is, the greater the intrinsic cognitive load. This complexity depends on the number of mental elements that must be managed simultaneously in working memory. Therefore, the learner's prior knowledge and the level of complexity of the subject matter are critical in determining the level of this load; the lower the knowledge of the subject matter, the higher the intrinsic cognitive load (Chen et al., 2023; Faber et al., 2024; Sweller et al., 2019).

Extrinsic cognitive load is related to the way in which information is presented to the learner. In this sense, the organization of information and the combination of graphical and textual sources can distract the learner and increase their cognitive effort (Faber et al., 2024; Leppink et al., 2014; Sweller et al., 2019). Finally, Germanic cognitive load is linked to the construction of new knowledge. This type of load arises when learners elaborate cognitive schemas that will be stored in long-term memory, in processes such as abstraction. If intrinsic and extrinsic loads are manageable, students can focus their cognitive effort on more effective learning (Chen et al., 2023; Faber et al., 2024; Leppink et al., 2014; Sweller et al., 2019).

The study of cognitive load helps to understand the functioning of the human information processing system, which guides the process of designing computational educational material to optimize the use of the limited capacity of working memory. A proper design must take into account the limitations of working memory to facilitate the transfer of knowledge to long-term memory. In this sense, computational scenarios with high cognitive load may hinder student learning to some extent (Faber et al., 2024; Sweller et al., 2019; Xue et al., 2024).

In computer environments, the structure and presentation of information can overload working memory and negatively affect the learning process. Therefore, the design of these environments should reduce the extrinsic cognitive load so that learners can focus on the Germanic cognitive load, as this is where meaningful learning occurs (Chen et al., 2023; Clark & Mayer, 2016; Faber et al., 2024; Sweller et al., 2019; Xue et al., 2024).

2.2. Cognitive style in the field dependence-independence (FDI) dimension

Cognitive style refers to the set of individual characteristics that define and distinguish each person. This concept transcends aspects related to learning and affects various areas of personality, such as perception of the environment, problem solving, interpersonal relationships and emotional aspects (Hederich-Martínez & Camargo-Urbe, 2016; Tinajero Vacas & Páramo Fernández, 2013). In general terms, cognitive styles are usually considered as a continuous system, usually bipolar, in which the characteristics of both extremes are combined to a greater or lesser extent, depending on the proximity to each pole. Thus, each person's cognitive style is situated at a point within this continuum (Giancola et al., 2022; Tinajero Vacas & Páramo Fernández, 2013; Vecchione et al., 2023).

In the educational context, probably the most studied cognitive style is the so-called field dependence-independence (FDI), proposed and developed by Witkin and colleagues (Witkin et al., 1977). In the field of information technology applied to education, research on cognitive style in the FDI dimension has consistently shown that learners classified as field independence-prone (FI) tend to perform better than their field dependence-prone (FD)

peers when interacting with computational environments. Studies indicate that FD learners prefer educational material to be organized in a sequential or linear fashion and that navigation in the digital environment is done in groups and guided by others (Alomyan, 2004; Chen & Macredie, 2002; Chuang et al., 2021).

On the contrary, FI learners prefer to have more freedom to explore the structure of the computing environment, which allows them to perform more efficiently in hypermedia environments. These students are able to establish organized navigation paths, are not easily distracted by irrelevant information, and make adequate use of most of the resources available in the digital environment. In addition, they tend to prefer individual work (Alomyan, 2004; Chen & Macredie, 2002; Chuang et al., 2021).

In this field of research, some studies have identified a relationship between student cognitive style in the FDI dimension and cognitive load during interaction with computational environments. Some findings indicate that there are no differences in cognitive load among students (Angeli et al., 2009; Angeli, 2013; Solórzano-Restrepo & López-Vargas, 2019), but another study indicates that there are differences between FI and FD students (López-Vargas et al., 2017). However, more research is needed to deepen the understanding of this phenomenon, particularly by including a computational scaffold that examines its impact on cognitive load when students interact with multimedia environments.

2.3. Computer scaffolding

The concept of scaffolding refers to the support provided to an individual to develop a skill that would otherwise be beyond his or her reach. The purpose of scaffolding is to facilitate learners' successful completion of a learning task that exceeds their current capabilities (Wood et al., 1976). In computer-based learning environments, motivational scaffolding provides a type of support that fosters the interest, effort, and perseverance necessary to complete a learning task (Belland et al., 2013; Elford et al., 2022; Ollonen & Kangas, 2024). In this sense, computational scaffolds are software tools that help students achieve learning objectives. These supports come in the form of messages, feedback, step-by-step guides, simulators, and other resources, and are usually in the form of pop-ups or characters that accompany the learner in his or her interaction with the digital environment (Belland et al., 2013; Kim & Hannafin, 2011; Lajoie & Azevedo, 2006; van der Graaf et al., 2023).

There are two main types of pedagogical supports in these scaffolds: fixed and dynamic. Fixed scaffolds are present throughout the learning process and offer constant support to the learner (Azevedo & Gašević, 2019; van der Graaf et al., 2023). On the other hand, dynamic scaffolds offer support that gradually diminishes as the learner becomes more proficient, until eventually they can be removed (Kim & Hannafin, 2011; Molenaar et al., 2012). This fading can be managed by the computer system or by the learner himself, who takes control of the process as he progresses in his learning (Jackson et al., 1998). This strategy allows the student to assume greater responsibility and make autonomous decisions in their learning process based on their learning outcomes.

In the present research, a motivational scaffolding included in the structure of a multimedia environment was designed to favor the self-efficacy of students with different cognitive styles in the FDI dimension and, in this way, to determine if there is any relationship with their cognitive load.

3. Method

3.1. Design

The study employed a quasi-experimental design with groups of students previously established in a public educational institution in Cundinamarca, Colombia. Two independent variables were included: 1) the environment with motivational scaffolding, which could be static or faded by the student, and 2) the cognitive style in the FDI dimension, distinguishing between field-dependent and field-independent students. The dependent variables were learning performance and cognitive load, the latter divided into three types: intrinsic, extrinsic and Germanic. In addition, the student's previous performance was considered as a covariate. A 2×2 factorial MANCOVA procedure was used for data analysis.

3.2. Participants

The study involved 145 students (64 males and 81 females) from four tenth-grade classes of an educational institution located in the municipality of Soacha, Cundinamarca, Colombia. The ages of the participants ranged from 14 to 18 years, with a mean of 15.6 years ($SD = 1.02$).

3.3. Materials

Computing environment: the multimedia learning environment used in the study was called “*Arduprogram*” and was focused on teaching basic notions of programming with Arduino. Eight learning units were developed, covering the following topics: 1. What is Arduino, 2. Arduino hardware, 3. Programming environment, 4. Programming digital outputs, 5. Programming analog outputs, 6. Understanding and programming loops, 7. Programming digital inputs and 8. Programming analog inputs. The environment had two versions: one with fixed scaffolding and one with scaffolding faded out by the student (Triana-Vera & López-Vargas, 2025).

Self-efficacy was used as a motivational indicator in the software. The scaffolding, on the other hand, was structured in modules presented through pop-up windows accompanied by a character. In the fading version, the student had the option of deactivating the modules he/she considered unnecessary, thus adapting the support to his/her learning process. In contrast, in the fixed scaffolding version, the modules always remained active and provided support to the student throughout the learning unit. A detailed description of each of these modules is presented below:

Goal-setting module: In each learning unit, the student must autonomously set a learning goal. These goals have different levels of difficulty to accommodate individual differences. The software offers exercises ranging from low to high complexity, so that the learner can start with simple goals and move towards more challenging objectives throughout the learning process (see Fig. 1).

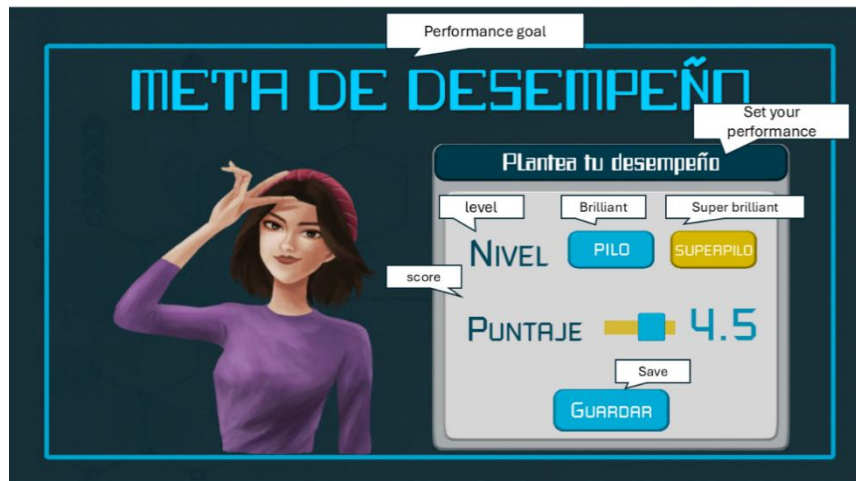


Fig. 1. Learning goal (self-imposed by the learner)

Plan organization module: this module helps the student to plan and structure the way he/she will approach the learning unit of study. This organization of the sequence of activities acts as a basis for navigation in the multimedia environment (see Fig. 2).



Fig. 2. Study plan for autonomous navigation in the environment

Self-efficacy judgment module: This module aims to motivate the student to reflect on the decisions made in the previous modules, especially in terms of goal selection and activity planning. The objective is for the learner to compare these decisions with his or her beliefs about his or her own capabilities, thus strengthening his or her commitment to achieving these goals. In this module, the learner chooses the option that best reflects his or her feelings in response to the question, “*How do you feel about your goal?*” (see Fig. 3).



Fig. 3. Self-efficacy judgment for a self-imposed goal

Choice synthesis module: To conclude this preparation phase, the multimedia software “*Arduprogram*” displays a summary of the choices made so far and offers the option to adjust, modify or validate them (see Fig. 4).



Fig. 4. Summary of choices for each learning unit

The modular design of the scaffolding allows the student to have the autonomy to decide which modules to eliminate, according to the skills he/she have developed. This is done by means of a checklist (see Fig. 5).

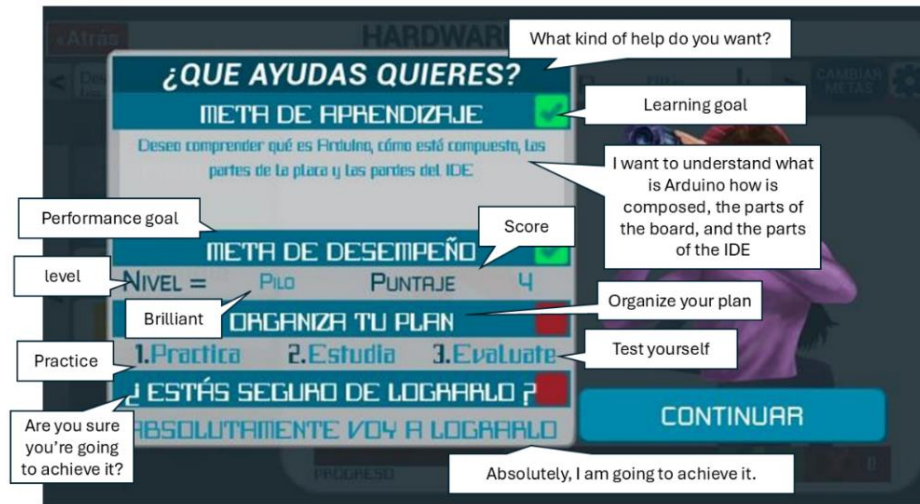


Fig. 5. Interface for self-efficacy modules

3.4. Instruments

3.4.1. Cognitive load questionnaire

The questionnaire developed by Leppink and colleagues (Leppink et al., 2014) was used, which allows assessing students' perception of cognitive load by means of 13 items. Items 1 to 4 correspond to the intrinsic cognitive load (ICL), items 5 to 8 to the extrinsic cognitive load (ECL) and items 9 to 13 to the Germanic cognitive load (GCL). This self-report instrument uses a Likert scale from 0 to 10, where 0 means "*completely disagree*" and 10 means "*completely agree*". Students completed the questionnaire eight times, once at the end of each learning unit.

In accordance with the above, the intrinsic cognitive load showed a mean of 6.00 and a standard deviation of 1.29, with values ranging from 1.79 to 8.75. The subscale presented a Cronbach's $\alpha = 0.773$. Similarly, extrinsic cognitive load had a mean of 3.58 and a standard deviation of 1.35, with a range of 0.54 to 8.63 (Cronbach's $\alpha = 0.821$). Finally, the Germanic cognitive load presented a mean of 7.62, a standard deviation of 0.99, a minimum value of 5.14 and a maximum of 9.57 (Cronbach's $\alpha = 0.793$).

3.4.2. Cognitive style test

Witkin's masked figures test (GEFT) was used to assess cognitive style in the FDI. The version developed by Sawa based on Gottschaldt's figures was applied. This test consists of five subtests, each presented on separate sheets, and each subtest includes a simple figure and a set of 10 different complex figures. The task consists of finding the simple figure within the complex figures within a given time. This instrument has been applied to Colombian students and has shown high levels of reliability, with a Cronbach's α between 0.91 and 0.97 (Hederich-Martínez et al., 2023).

The average GEFT test score was 32.65, with a standard deviation of 8.45. The test has a maximum score of 50, and student scores ranged from 5 to 49 points. According to Luk (1998), trainees who score below the mean are considered FD learners, and those who score above the mean are considered FI learners. Consequently, the groups formed were (a) a group of 73 field-dependent (FD) oriented learners; and (b) a group of 72 field-independent (FI) oriented learners (Heidari, 2022).

3.4.3. Learning achievement

Learning achievement was determined from the average of eight individual evaluations that students completed (one for each study module in the multimedia environment). Each assessment included ten problems with multiple-choice answers.

In this sense, the assessment process consisted, initially, of a structured reading of fundamental concepts about Arduino, followed by an applied practice where the learners performed activities related to the use of this technology. The applied tests contained questions on fundamental concepts, analysis, development of flowcharts, code and device connections. The grade obtained in each of the eight evaluations was assigned on a rating scale of 1 to 5, where 1 indicates a very low performance and 5 an outstanding performance.

According to the above, learning achievement yielded a mean of 3.76, with a standard deviation of 0.47. On a maximum score of 5, the scores varied between 2.29 and 4.86 among the students. In this study, the reliability of the assessments is high, with a Cronbach's α of 0.86.

3.4.4. Prior learning achievement

To measure the covariate of prior learning achievement in the area of technology, data obtained from an assessment applied by a company specialized in learning evaluation, regularly hired by the educational institution where the research was conducted, a company recognized by the Colombian Ministry of National Education, were used. This company evaluates in a standardized manner the skills of students in different areas of knowledge, in the area of technology. The results are aligned with the national census tests of educational quality. For the present study, only the results obtained by students in the area of technology were used, which are expressed on a rating scale from 1 to 5 (Cronbach's α of 0.912).

3.5. Procedure

In order to carry out the study, authorization was obtained from the school authorities, who allowed the tenth-grade students to participate in the research. Subsequently, the research proposal was presented to the students and teachers of the technology subjects. Likewise, the parents gave their informed consent so that the adolescents could participate in the activity. They were informed that the results of the study would be used for research purposes only. Once informed parental consents were collected, the GEFT masked figures test was administered to each class of students.

Then, the two versions of the multimedia environment - Arduprogram - were randomly assigned to the classes: two classes worked with the multimedia scenario with fixed scaffolding, and the other two classes worked with the multimedia environment with

scaffolding faded out by the student. Finally, students worked with the multimedia environment for one semester in the technology classes.

4. Findings

The data collected were organized using Statistical Package for the Social Sciences (SPSS) software, version 27, and both univariate and multivariate outliers were eliminated. In addition, normality assumptions were verified (skewness and kurtosis values were -2 and +2). The homogeneity of the variance-covariance matrices was tested with a Box's M p -value of 0.17. Finally, the homogeneity of the regression hyperplanes between the independent variables and the covariate was validated with p -values greater than 5 % (Mertler et al., 2021).

Pearson correlations were used to explore the relationship between the covariate, previous achievement and the dependent variables. Table 1 shows the results; there are statistically significant correlations between previous achievement and all dependent variables. These results justify the inclusion of previous achievement as a covariate in the MANCOVA analysis.

Table 1

Correlations between the covariate, previous achievement and the dependent variables

Dependent variable	r	p
Learning achievement	.339**	.000
Intrinsic cognitive load	-.257**	.002
Extrinsic cognitive load	-.241**	.004
Germanic cognitive load	-.226**	.006

Note. $N = 145$; ** Correlation is significant at the 0.01 level (bilateral)

For data analysis, the multivariate factorial covariance procedure (MANCOVA) was used with a 2 (fixed scaffolding and student-faded scaffolding) $\times$ 2 (dependency-oriented and field-independence-oriented cognitive style) design. Table 2 shows a summary of the descriptive statistics (mean M and standard deviation SD) of the dependent variables of the groups of students who interacted in the multimedia learning environment. Also, the groups of learners according to their cognitive style in the FDI dimension are indicated.

Table 2

Descriptive data for the dependent variables

Cognitive style		N	LA		ICL		ECL		GCL	
			M	SD	M	SD	M	SD	M	SD
Static	With a tendency to dependency	36	3.56	0.51	6.28	1.30	3.68	1.12	7.49	1.10
	With a tendency towards independence	48	3.85	0.50	5.49	1.47	3.28	1.35	7.58	1.10
	Total	84	3.73	0.52	5.83	1.45	3.45	1.26	7.54	1.09
Faded by the user	With a tendency to dependency	37	3.74	0.37	6.50	0.79	4.01	1.36	7.58	0.71
	With a tendency towards independence	24	4.03	0.45	5.86	1.17	3.40	1.55	7.93	0.95
	Total	61	3.85	0.43	6.25	1.00	3.77	1.46	7.72	0.82
Total	With a tendency to dependency	73	3.65	0.45	6.39	1.07	3.85	1.25	7.54	0.92
	With a tendency towards independence	72	3.91	0.49	5.62	1.38	3.32	1.41	7.70	1.06
	Total	145	3.78	0.49	6.01	1.29	3.58	1.35	7.62	0.99

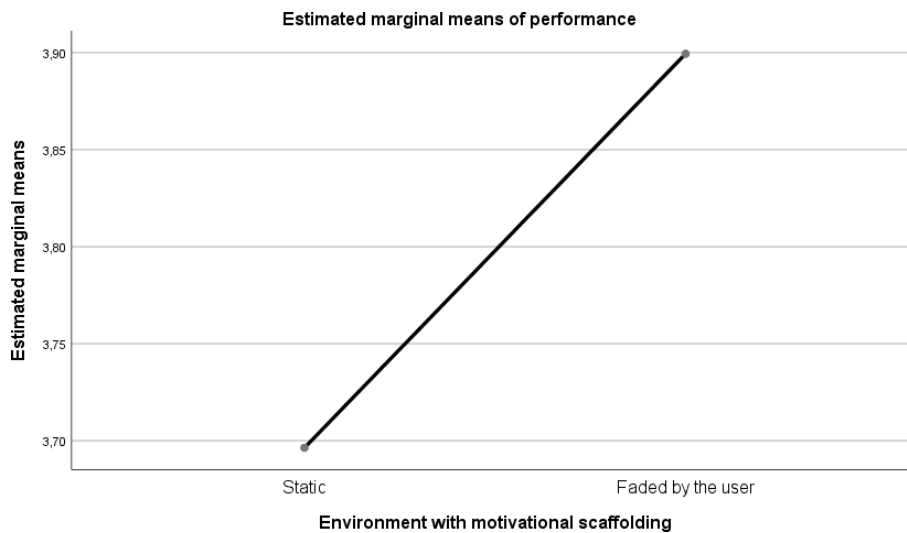
Note. LA: Learning achievement; ICL: Intrinsic cognitive load; ECL: Extrinsic cognitive load; GCL: Germanic cognitive load

Table 3 shows the results of the MANCOVA factor analysis. It can be seen that, first, in relation to the independent variable motivational scaffolding, there was only a significant difference in terms of learning achievement ($F(1, 140) = 6.84$; $p = 0.010$; $\eta^2 = 0.047$). This difference favored students who interacted with user-faded scaffolding (see Fig. 6). In terms of cognitive load, no significant differences were present.

Table 3

Multivariate tests for the 2×2 factorial MANCOVA

Effect	Dependent variable	F	p	η^2
Cognitive style	Learning achievement	2.08	.152	.015
	Intrinsic cognitive load	4.95	.028	.034
	Extrinsic cognitive load	0.71	.402	.005
	Germanic cognitive load	0.24	.629	.002
Motivational scaffolding	Learning achievement	6.84	.010	.047
	Intrinsic cognitive load	1.65	.202	.012
	Extrinsic cognitive load	0.63	.430	.004
	Germanic cognitive load	1.99	.160	.014
Cognitive style*	Learning achievement	0.10	.750	.001
	Intrinsic cognitive load	0.07	.790	.001
Motivational scaffolding	Extrinsic cognitive load	0.35	.557	.002
	Germanic cognitive load	0.74	.393	.005

**Fig. 6.** Learning achievement of students with user-fixed and user-faded scaffolding

Secondly, in relation to cognitive style in the FDI dimension, statistically significant differences were found in intrinsic load ($F(1,140) = 4.95$; $p = 0.028$; $\eta^2 = 0.034$) (see Fig. 7). In the other variables, no significant differences were observed.

Finally, in relation to the interaction between the multimedia scenario with motivational scaffolding and cognitive style in the FDI dimension, the data indicate that there are no statistically significant differences in any of the dependent variables of the study. All significances were greater than 5%.

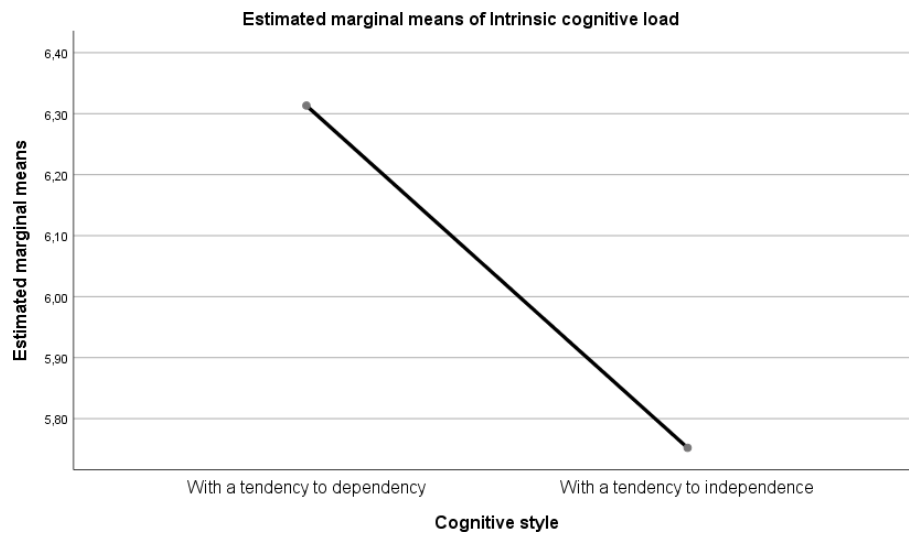


Fig. 7. Intrinsic cognitive load of students with FD and FI tendency

5. Discussion and conclusions

Regarding the first research question, the results showed that, when comparing the effect of the different types of scaffolding on the dependent variables-i.e., learning achievement and cognitive load-only statistically significant differences were found in terms of learning achievement, in favor of the trainees who used scaffolding faded by the learner him/herself. This result is particularly promising.

In this sense, one could consider that scaffolding with at-will fading allows the learner to take control of his learning process and gives him the responsibility to decide when and to what extent to fade the supports. This constitutes an interesting contribution to the development of computational scaffolding in CBLEs for several reasons. First, because this type of scaffolding acts as a temporary support, available only if the learner deems it necessary, as stated in the concept of scaffolding itself; that is, it has the ability to fade according to the differential needs of the learners (Belland et al., 2013; Cagiltay, 2006; Pea, 2004).

Secondly, personalized assistance was offered, which allowed the student to choose the supports he/she considered necessary according to his/her needs, interests and preferences, based on the results of the evaluation of his/her learning process. This strategy may have contributed to the student acting more autonomously, assuming greater commitment and responsibility, which probably increased their sense of control over the learning process. In this sense, the model that incorporates modules in the scaffolding model may provide an enabling environment that fosters greater motivation towards learning, thereby increasing their perception of personal efficacy, which encourages the student to invest more effort, to be persistent in the face of difficulties and to self-manage in a positive way.

In this line of work, these results support the findings of McNeill et al. (2006) and Kester and Kirschner (2009), whose studies indicated that the performance of students who interacted with computational scenarios with faded scaffolding was higher than that of

students who used fixed scaffolding. However, these results contradict those of Doo et al. (2020), Bulu & Pedersen (2010), Jaakkola & Veermans (2018), and Tawfik et al. (2018), who found that fixed scaffolds favor learning achievement to a greater extent compared to faded scaffolds.

Regarding the use of fixed or vanishing scaffolds, studies are inconclusive, and, on the contrary, the results of different investigations show contradictory results (Gidalevich & Kramarski, 2019). For this reason, it is important to continue to delve deeper into the effectiveness of this type of scaffolding. To the extent that computational scenarios allow adapting pedagogical and/or didactic supports according to the differential needs of students, these can be adjusted in real time on the basis of the acquired knowledge, which is a way of empowering the student in his or her learning process.

Finally, the scaffolding model does not overburden the user's cognitive resources, nor does it complicate the learning task. Both fixed and fading scaffolding for the learners will not generate significant additional cognitive load. This result suggests that the use of scaffolding in the structure of the multimedia environments did not represent an intrusive process that added extra cognitive load to the learning process.

In relation to the second research question, it was observed that cognitive style has a significant influence on intrinsic cognitive load. The results indicated that students with a tendency toward field dependence experienced higher cognitive load compared to those with a tendency toward field independence. This finding suggests that field-dependent students had to work harder to organize their previous mental structures, probably due to the complexity of the knowledge domain addressed, in this case, Arduino programming.

It is important to note that learning to program with Arduino involves the development of structured logical thinking. Students must be able to decompose complex problems into simpler, more manageable parts, as well as decompose code in a coherent way to ensure correct program operation. In addition, an understanding of sensor readout flow and actuator control is critical.

This process also requires critical and analytical skills to choose the most efficient solutions, such as which sensors to use or what type of control structure is most appropriate. Reflecting on the results obtained, identifying what worked and why, is essential to improve in future interactions. It is also essential to understand circuit diagrams and schematics to make the correct connections.

This type of learning integrates the understanding and application of parallel processes that depend on the coherence and logical sequence of previous results. The learning environment in question was designed to allow students to analyze various problems and validate solutions within a structured framework that facilitated the achievement of educational objectives. In this context, students with a tendency towards field dependency are likely to have greater difficulties, as learning tasks with Arduino require autonomy, analytical skills, and an aptitude for restructuring information, skills that are not typical of this type of learner (Mahvelati, 2020). It is also possible that field-dependent learners were not able to effectively extract prior knowledge from their long-term memory when the problem is not sufficiently clear in problem-solving with Arduino, which is likely evidence of low creativity in this type of learning task (Li et al., 2023).

Therefore, field-dependent students had to invest more of their working memory resources due to the complexity of the topic, which resulted in a significant increase in their intrinsic cognitive load. This led them to employ more cognitive effort compared to their

field-independent peers, for whom this process was more natural and fluid due to their stylistic characteristics. Along these lines, these results support the findings of López-Vargas et al. (2017), who found that the total cognitive load employed in the development of learning tasks on Aristotelian logic in a computational environment is lower in field-independent students compared to their field-dependent peers. However, these results contradict the findings of Angeli (2013), Angeli et al. (2009) and Solórzano-Restrepo & López-Vargas (2019), who found no significant differences in cognitive load among students with different cognitive styles.

These discrepancies demonstrate the need for further research on the topic, especially when using self-report instruments, since students tend to provide socially accepted and subjective responses. In addition, subject content and software type may have differential effects on the student body.

In terms of learning achievement, the results are consistent with previous studies that have shown that the use of computational scaffolding promotes more equitable learning among students with different cognitive styles in the FDI dimension (López-Vargas et al., 2017, 2020; Solórzano-Restrepo & López-Vargas, 2019; Valencia-Vallejo et al., 2019). Therefore, these results suggest that the use of scaffolding within the structure of computational scenarios favors the learning of field-dependent students, as it allows them to match their performance with that of their field-independent peers.

Finally, in relation to the third research question, the results show that there is no statistically significant interaction between the student's use of a fixed or faded motivational scaffold and cognitive style in the FDI dimension. This suggests that the variables studied operate independently and do not combine to generate significant effects on the variables under investigation.

By way of conclusion, the results provide empirical evidence indicating that the inclusion of fading scaffolds, controlled by the learner him/herself, improves learner performance compared to the use of fixed scaffolds. In this sense, empowering the learner to decide on the use of particular scaffolding components shows promising results for the design of computer support tools that can be gradually adjusted over time.

Likewise, the inclusion of a motivational scaffold in a multimedia environment does not seem to have an effect on the students' cognitive load when learning technological content. In fact, the use of scaffolding, whether fixed or faded, did not generate additional cognitive load in the learning process. Scaffolding reduced cognitive load to some extent, allowed students to engage in more complex learning processes and favored learning outcomes.

The results also suggest that the use of multimedia environments with motivational scaffolding can, to some extent, reduce individual differences in the performance of learners with different cognitive styles within the FDI dimension. In addition, it was observed that learners with a tendency toward field dependence experience greater intrinsic cognitive load in learning technological topics compared to those with a tendency toward field independence.

However, further research on this phenomenon is needed to better understand the behavior of high school students when interacting with learning environments that integrate multimedia scenarios and motivational scaffolding. This raises new questions about how to maximize learning and reduce cognitive load differentially in students at different educational levels. Scaffolding design is likely to be an effective alternative for students to

learn more effectively and use their working memory more efficiently when interacting in digital environments, especially in distance education supported by web or mobile technologies.

6. Limitations

The present study has some limitations. As this was a quasi-experimental investigation, the groups that participated were not organized randomly, but were already previously established. This lack of randomization limits the generalizability of the results. To obtain more robust conclusions, it would be necessary to work with a more representative sample and to organize the groups randomly, which would make it possible to carry out an experimental investigation and provide greater empirical evidence.

In addition, the instrument used to measure cognitive load was based on student self-reports, which could have influenced their responses, as it is likely that they responded in a socially acceptable manner, introducing possible biases in the information. Additional indicators that would provide a more objective assessment of student behavior in relation to these variables would be advisable.

Author Statement

The authors declare that there is no conflict of interest.

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