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Research Article

Academic self-efficacy, online self-efficacy, and fixed and faded scaffolding in computer-based learning environments

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ABSTRACT

This research aimed to determine the effects of motivational scaffolding and adaptive scaffolding on academic and online self-efficacy in learners interacting with a multimedia learning environment within the field of technology. The study involved 146 students from four tenth-grade classes at a public institution in the municipality of Soacha (Cundinamarca-Colombia). The research followed a quasi-experimental design with two independent variables: (1) motivational scaffolding (static and faded by the student) and (2) adaptive scaffolding (fixed and differentiated), it also included two dependent variables; academic and online self-efficacy. A factorial MANCOVA statistical analysis showed a significant interaction of adaptive scaffolding and motivational scaffolding on self-efficacy for online learning. There was also evidence that differential adaptive scaffolding had a substantial effect on academic and online self-efficacy. These findings suggest that the use of motivational and differential pedagogical and/or didactic strategies in virtual learning environments, which integrate scaffolding faded by the student, enhances learners' personal judgments about their abilities to learn content within the field of technology.

Keywords: self-efficacy, motivational scaffolding, adaptive scaffolding, in computer-based learning environments

INTRODUCTION

Undoubtedly, computer-based learning environments have been increasingly recognized for their positive impact on education over the past few decades. These environments have the potential to facilitate and enhance teaching and learning processes across various educational levels and fields of knowledge (Azevedo et al., 2022; Lajoie & Azevedo, 2015; Tempelaar et al., 2012; Valencia-Vallejo et al., 2018).

Indeed, learning environments often feature non-linear navigation and incorporate a variety of multimedia resources, such as videos, interactive activities, concept maps, and both graphical and textual information. Additionally, these environments may include simulations to reinforce concepts, learning management systems for creating, managing and delivering diverse educational content, databases and online resources for exploring specific topics. (Alomyan, 2004; Chen & Macredie, 2002; Mui, 2016). These platforms are accessible from anywhere in the world, 24/7, effectively overcoming the time and space constraints associated with traditional learning processes.

Some researchers argue that the use of computational learning environments enhances the development of self-regulatory learning skills and learner performances (Azevedo et al., 2022; Greene et al., 2011; Lajoie & Azevedo, 2015; Zhang & Quintana, 2012). These environments are also reported to have positive effects on motivation towards learning (Belland et al., 2013; Elford et al., 2022; Ollonen & Kangas, 2024; Sun et al., 2023; Valencia-Vallejo et al., 2018). Similarly, studies indicate that these environments facilitate social interactions through collaborative work (Kaliisa et al., 2022; Van Hoe et al., 2024; Yildiz Durak, 2024) and can be tailored to accommodate individual differences, thereby enhancing interaction efficiency (Alomyan, 2004; Chuang et al., 2021; Wang et al., 2018).

This study addresses a critical aspect in the design of computer-based learning environments: the integration of motivational and adaptive scaffolding that not only maintains students' interest and engagement but also accommodates their individual needs. This research is crucial because it offers an innovative approach to personalizing educational support, thereby improving students' academic and online self-efficacy. By tailoring scaffolding to students' cognitive styles and allowing them to decide when and how to remove scaffolding as they become more proficient, more autonomous and resilient learning is fostered.

From a practical perspective, the findings of this study have the potential to significantly influence the design of virtual learning platforms. By implementing scaffolding strategies that dynamically adjust to learners' needs and allow for self-regulation, educators and educational software designers can create more effective and personalized learning environments. This would not only improve student motivation and self-efficacy, but also lead to higher educational achievement, particularly in technical areas such as electronics, where this study is focused.

Despite the potential benefits of computer-based learning in education, research indicates that these environments do not equitably benefit all students (Beserra et al., 2014; López-Vargas et al., 2012, 2017); as not all learners achieve the desired learning outcomes when interacting with such educational platforms. Some studies suggest that the effectiveness and efficiency of these environments may be linked to the motivation they provide, which tends to support students' efforts in achieving their learning objectives (Belland et al., 2013; Elford et al., 2022; Ollonen & Kangas, 2024). In this context, researchers have proposed using motivational scaffolding to enhance student engagement, dedication, and perseverance when learning different content in these environments (Belland et al., 2013; Duffy & Azevedo, 2015; López-Vargas et al., 2022; Valencia-Vallejo et al., 2018).

To address this issue and enhance motivation towards learning, some researchers have designed scaffolds aimed at boosting students' academic self-efficacy. These scaffolds are intended to improve students' perceptions of their capabilities when undertaking learning tasks in these environments (López-Vargas et al., 2020, 2022). Generally, scaffolding is effective in encouraging learners to set achievable goals, providing positive feedback on their achievements, motivating them to try, and reinforcing their belief in their ability to achieve the desired performance. It is important to note that most of these motivational scaffolds are fixed, meaning they are consistently present within the learning environment (Greene et al., 2011; Kim & Hannafin, 2011).

In this line of work, it is suggested that scaffolding should be designed to gradually fade as student competence increases and should also account for individual differences among students (Ayedoun et al., 2020; Jackson et al., 1998; Pea, 2004). However, studies indicate that automatically faded scaffold and addressing individual student characteristics is a complex process to implement in learning environments. This complexity arises because the system or scenario often cannot accurately assess a student's current knowledge level or provide adaptive support tailored to their specific learning needs (Ayedoun et al., 2020; Cagiltay, 2006; Jackson et al., 1998; Pea, 2004).

To address this issue, the use of flexible scaffolds is proposed, allowing students to decide which parts of the scaffold to remove based on their own knowledge (Jackson et al., 1998). Additionally, it is suggested that considering the student's cognitive style can provide differential support (López-Vargas & Triana-Vera, 2013; López-Vargas et al., 2022; Valencia-Vallejo et al., 2018).

A consensus has not yet been reached in the academic community regarding the efficient and effective use of scaffolds, as these do not fully address the diverse learning needs and characteristics of students. Therefore, further research is necessary to understand and explain potential methods for adapting and fading scaffolds in response to learners' needs and characteristics (Cagiltay, 2006; Kim et al., 2018; Pea, 2004).

This study explored the concept of academic and online self-efficacy in the context of designing and implementing motivational scaffolding within a multimedia environment in the area of technology. Research on academic self-efficacy indicates that students' beliefs about their expected outcomes when undertaking a learning task significantly impact their achievement (Bandura, 1997; Pintrich & Zusho, 2002; Zimmerman, 2000). Indeed, the perceived judgments one has about their own abilities to successfully complete a learning task directly influence their effort, persistence, and adaptation of cognitive processes. In this regard, academic self-efficacy is recognized as a strong predictor of learning achievement and academic success (Bouffard-Bouchard, 1990; Gerhardt & Brown, 2006; Moos & Azevedo, 2009; Pajares, 1996; Schunk, 1990; Usher & Pajares, 2008).

Similarly, online self-efficacy plays an important role; this is because it is not only important, personal judgments to understand the mastery of knowledge contained in the virtual environment, but also, the proper management of time and the efficient and effective use of technological resources when learning with computational environments (Stephen & Rockinson-Szapkiw, 2021; Yavuzalp & Bahcivan, 2020; Zimmerman, 2017). A positive perception to learn with support from these learning environments allows the student to safely navigate the scenario and take advantage of the potential of the resources arranged there. In this order of ideas, students need to feel confident and competent to interact with computational scenarios as an online self-efficacy deficit can negatively affect confidence and, consequently, hinder the desired learning achievement (Artino & McCoach, 2008; Azizi et al., 2022; Zimmerman & Kulikowich, 2016).

Considering the approaches and evidence presented in the previous studies, the present research aimed to address the following questions:

1. Are there significant differences in academic and online self-efficacy among high school students who learn content in electronics through a multimedia environment that incorporates a fixed adaptive motivational scaffolding compared to those who interact with a differential adaptive motivational activator?
2. What is the effect of using static and faded student-delivered motivational scaffolding on academic and online self-efficacy when high school students learn electronics content in a multimedia environment?
3. Is there an interaction between motivational scaffolding and adaptive activators on academic and online self-efficacy in students engaging with a multimedia environment for electronics content?

LITERATURE REVIEW

Computer Scaffolding

In the educational context, the term scaffolding refers to a pedagogical strategy designed to support students in achieving the desired levels of understanding and competence during the learning process (Wood et al., 1976). In computer-based learning environments, motivational scaffolding serves as a type of support aimed at enhancing learners' interest, effort, and perseverance required to complete a learning task (Belland et al., 2013; Elford et al., 2022; Ollonen & Kangas, 2024). Computational scaffolds are software applications that aid students in reaching their learning goals. These aids may include messages, feedback notes, step-by-step guides, simulations, and other interactive elements such as pop-up windows or characters that assist learners during their interactions with the software (Belland et al., 2013; Kim & Hannafin, 2011; Lajoie & Azevedo, 2015; Zhang & Quintana, 2012).

Pedagogical aids can be presented to students in either a fixed or dynamic form. Fixed scaffolds are aids that are consistently available and accompany the learner throughout the entire learning process (Azevedo et al., 2008). In contrast, dynamic scaffolding involves support that gradually fades and may eventually be removed, depending on the learner's level of competence (Molenaar et al., 2008, 2012; Tuckman, 2005). Fading can be managed by the system (computational environment) or by the user (Jackson et al., 1998). When the fading is managed by the student, it allows them to take responsibility for their learning process, interact more independently with the environment, and make decisions based on their acquired competence. This strategy empowers the learner to self-regulate and adapt their approach as they develop their skills.

Another important characteristic that computational scaffolds should possess is adaptability to the individual needs of the learner. Adaptability refers to the ability to adjust and personalize the support provided according to each learner's specific requirements (Ayedoun et al., 2020; Basu et al., 2017; Pea, 2004). In this context, some researchers consider the cognitive style of the learner when designing computational scaffolds (Alhalafawy et al., 2021; Chang & Yang, 2023; López-Vargas et al., 2022; Valencia-Vallejo et al., 2018). Cognitive style encompasses the tendencies and preferences of students in processing, organizing, and understanding information (Hederich-Martínez, 2004; Hederich-Martínez et al., 2022; Nozari & Siamian, 2015; Witkin et al., 1977).

Academic Self-Efficacy

Self-efficacy refers to the set of judgments a person has about their abilities to perform a specific task at a given level of performance (Bandura, 1997; Bradley et al., 2017; de la Fuente et al., 2021; Zimmerman, 1995). A person with high self-efficacy will feel confident and secure in their abilities when approaching tasks, thereby reducing the likelihood of negative thoughts about their performance. They will have high expectations for finding adequate solutions to difficulties, be willing to invest more effort, and exhibit greater persistence in overcoming challenges (Cerino, 2014; de la Fuente et al., 2021; Ithriah et al., 2020; Kurtovic et al., 2019; López-Vargas & Triana-Vera, 2013; López-Vargas & Valencia-Vallejo, 2012; Pajares, 1996; Ratsameemonthon et al., 2018; You, 2018).

On the contrary, individuals who doubt their abilities are likely to struggle with persistence and effort, often giving up easily when faced with obstacles during the learning process. They tend to avoid tasks they perceive as difficult, set easy-to-achieve goals, and have difficulty managing thoughts related to potential failures. As a result, they may underestimate their own academic performance (Bandura, 1994, 1999; de la Fuente et al., 2021; López-Vargas et al., 2022; Peechapol et al., 2018; Zimmerman, 1995).

In this area of research, multiple studies have linked the perception of academic self-efficacy with learning achievement, identifying it as one of the best predictors of success (Dixon et al., 2020; Gunawan & Shieh, 2023; Pajares, 1996; Ratsameemonthon et al., 2018). Consequently, it is important to propose pedagogical and didactic strategies that enhance students' academic self-efficacy. Such strategies are likely to increase students' motivation to learn and their commitment to task development and learning goals. By boosting confidence in their academic abilities, these strategies prepare students to confront and overcome academic challenges, equipping them with the cognitive tools needed to persist in achieving their objectives and maintain a positive attitude towards learning (López-Vargas et al., 2020; López-Vargas et al., 2022; You, 2018).

Self-Efficacy for Online Learning

This type of self-efficacy refers to individuals' beliefs in their own abilities to successfully complete learning tasks within computational learning environments (Aldhahi et al., 2021; Ithriah et al., 2020; López-Vargas et al., 2022; Masry-Herzallah & Watted, 2024; Stephen & Rockinson-Szapkiw, 2021; Zimmerman, 2017). Zimmerman and Kulikowich (2016) argue that self-efficacy for online learning encompasses more than just the use of technology. According to Zimmerman and Kulikowich (2016), this form of self-efficacy also involves self-regulation, as well as the learner's communication and time management skills when interacting with such environments.

In conclusion, the literature review highlights the transformative potential of information technologies in education, particularly through the use of motivational and adaptive scaffolding in computer-based learning environments. The research reviewed suggests that these approaches not only enhance academic and online self-efficacy but also foster learner autonomy and self-regulation. However, the diversity in responses to different types of scaffolding points to the need for more personalized pedagogical designs that are tailored to individual student characteristics. Thus, future studies should focus on refining these technologies to maximize their effectiveness, promoting more equitable and personalized learning experiences.

In the present research, a motivational scaffolding was designed and integrated into a multimedia environment focused on technology to enhance students' self-efficacy. This scaffolding feature two key elements:

(1) motivational scaffolding (static and faded by the student themselves) and

(2) adaptive motivational scaffolding (fixed and differential).

METHOD OF THE STUDY

Research Design

The study utilized a quasi-experimental design involving pre-formed groups of students from a public education institution in Cundinamarca, Colombia. The research included two independent variables:

(1) environment with motivational scaffolding (static and faded by the user) and

(2) adaptive motivational scaffolding (fixed and differential).

The dependent variables were academic self-efficacy and online self-efficacy, with the latter assessed across three dimensions: learning, time management, and technology use. Pretest scores for academic self-efficacy and online self-efficacy served as covariates. Data analysis was conducted using a 2 × 2 factorial MANCOVA procedure.

Participants

A total of 146 students (64 males and 82 females) from four tenth-grade classes at an educational institution in Soacha, Cundinamarca, Colombia, participated in the study. The participants' ages ranged from 14 to 18 years (mean [M] = 15.6; standard deviation [SD] = 1.02).

Materials

Computational environment

The multimedia learning environment used in the study is called "Arduprogram." It focuses on basic notions of Arduino programming, including eight learning units were designed:

1. what is Arduino?,
2. Arduino hardware,
3. programming environments,
4. programming digital outputs,
5. programming analog outputs,
6. understanding and programming loops,
7. programming digital inputs, and
8. programming analog inputs.

The environment has the following versions:

Adaptive motivational scaffold: This component aims to support the learner's motivation by sending messages to encourage effort and persistence. The motivational messages have two versions: differential and fixed.

Differential motivational scaffold: These messages are tailored to the student's cognitive style based on the field dependence-independence (FDI) dimension. In this dimension two poles are recognized, field independence and field dependence. Students with a tendency towards field independence have a logical approach, are more autonomous, accept ideas only after analyzing them and prefer individual work. (Hederich-Martínez, 2004; Nozari & Siamian, 2015). For this population, differential scaffolding activate messages that reaffirm their autonomy and the idea that their effort and persistence generate satisfactory results.

The latter, i.e., students with a tendency to field dependence have a global and holistic perception, prefer linear education programs, are oriented by external factors, accept ideas as they are presented, and prefer teamwork (Chen & Macredie, 2002; Hederich-Martinez, 2004). For this class of learners, motivational messages have a high affective charge that emphasizes the capabilities they possess, in addition to those that can be acquired through effort and persistence in the development of the task.

In the fixed motivational scaffold, the student's cognitive style was not considered in the DIC dimension. In this sense, the messages give positive feedback and encourage them in a general way to develop each of the learning tasks presented by the multimedia environment.

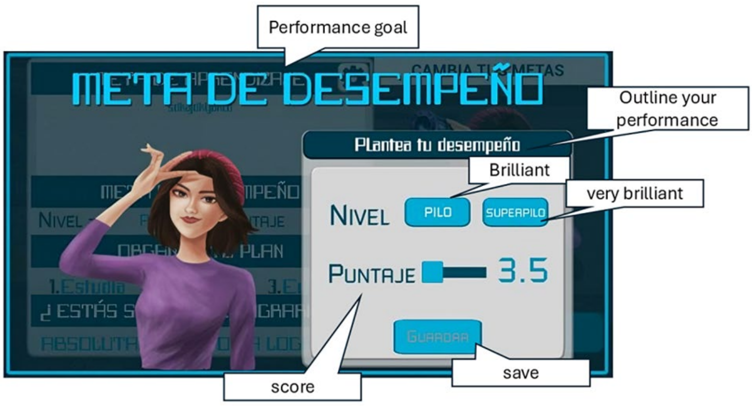


Figure 1. Learning goal, self-imposed by the learner (Source: Authors)

Figure 2. Organize your study plan: The sequence of activities allows you to navigate the environment autonomously (Source: Authors)

To determine the cognitive style of the students, they took a test prior to interacting with the computer environment. Once the tendency of their style was identified, they were assigned to the corresponding software version.

Environment with motivational scaffolding: In this version of the software, self-efficacy serves as the primary motivational indicator. The scaffolding is implemented through modular components, allowing students to deactivate modules they perceive as no longer necessary in the fading-out version. This scaffolding supports learners before, during, and after each learning unit and is delivered through pop-up notifications. The modules are described, as follows.

Learning goal setting module: In each learning unit, students are required to autonomously set their learning goals. These goals are categorized into various levels of difficulty to accommodate individual differences. The software presents exercises ranging from low to high complexity, enabling learners to begin with simpler tasks and progressively tackle more challenging goals throughout the learning process (see **Figure 1**).

Organize your plan module: This module enables students to plan and organize their approach to the learning unit. By organizing the sequence of activities, it serves as the foundation for displaying the navigation tree within the interface (see **Figure 2**).

Self-efficacy judgment module: This module aims to encourage learners to reflect on their decisions made in the previous modules regarding goal setting and activity planning. It prompts them to compare these decisions with their beliefs about their own capabilities and to reinforce their commitment to achieving their goals. In this module, learners select the option that best reflects their feelings about their goals in response to the question, "How do you feel about your goals?" (see **Figure 3**).

Choice synthesis module: To conclude this phase of preparation, the "Arduprogram" software provides a summary of the choices made thus far. It offers the learner the option to review, adjust, change, or validate these choices (see **Figure 4**).

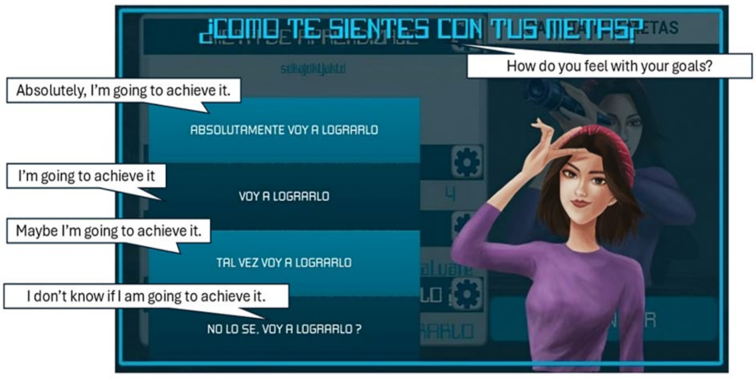


Figure 3. Self-efficacy judgment to achieve the self-imposed goal (Source: Authors)

Figure 4. Synthesis of choices to address each learning unit (Source: Authors)

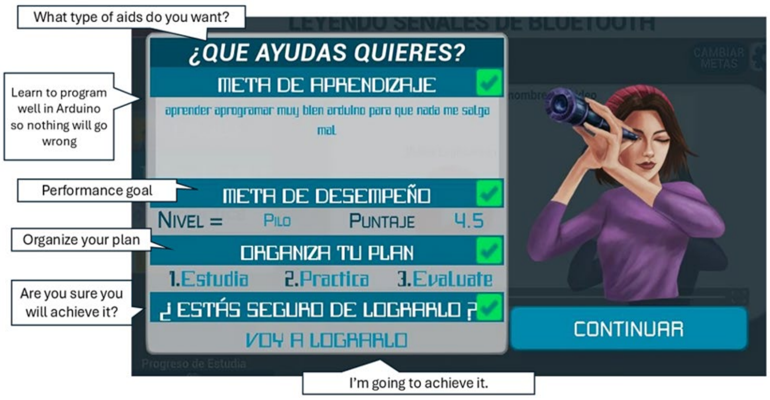


Figure 5. Interface for self-efficacy modules (Source: Authors)

Scaffolding design through modules empowers learners to decide which modules to delete based on their developed skills. This decision-making process is facilitated through a checklist (see **Figure 5**).

Instruments

The self-efficacy scales were translated from English to Spanish following the guidelines of Streiner et al. (2015). Three native speakers of Spanish, with pedagogical training in English, performed the translation of the items. The results of these translations were compared and analyzed by two bilingual specialists in Spanish and English, with the aim of evaluating the fidelity of the Spanish version with respect to the original. Subsequently, the research team reviewed, commented and adjusted this version to ensure conceptual equivalence between the two versions.

Academic self-efficacy subscale of the MSLQ

The motivated strategies for learning questionnaire (MSLQ) developed by Pintrich et al. (1991) was used to measure students' academic self-efficacy. The subscale is part of a larger questionnaire consisting of 81 items, with only those items related to self-efficacy beliefs being utilized for this study. Responses are given on a 7-point Likert scale, where 1 denotes "strongly disagree" and 7 denotes "strongly agree." For this study, the instrument yielded Cronbach's alpha of 0.87.

OLSES test

The online learning self-efficacy scale (OLSES) by Zimmerman and Kulikowich (2016) was employed to measure self-efficacy for learning in online environments. This self-report questionnaire consists of 22 items divided into three categories:

(1) learning in online environments (8 items, Cronbach's alpha = 0.77),

(2) time management (5 items, Cronbach's alpha = 0.77), and

(3) use of technology (9 items, Cronbach's alpha = 0.79).

Responses are rated on a 7-point Likert scale, where 1 indicates "never" and 7 indicates "always."

Data Analysis

Data analysis was conducted using the statistical package for the social sciences version 25. To ensure the quality of the results, the dataset was organized and validated. Univariate and multivariate outliers were removed based on Mahalanobis distance. The statistical assumptions of normality were also validated, with skewness and kurtosis values both less than the absolute value of 1.09. These values indicate an acceptable univariate normal distribution. Homogeneity of variance-covariance matrices was assessed using Box's test, which showed a significance level of 26% ($p > 0.05$). Additionally, the homogeneity of regression slopes between the independent variables and the covariates was verified, with all p-values greater than 0.13 (Mertler et al., 2021; Pituch & Stevens, 2015).

Procedure

To conduct the study, the directors of the departmental educational institution in Cundinamarca, Colombia, were contacted and granted permission for the participation of the tenth-grade students. The research proposal was subsequently presented to the students, teachers in the technology area, and the students' parents, from whom informed consent was obtained.

Following the collection of consent forms, a group-administered test was conducted to determine the cognitive style of the students. Subsequently, the MSLQ academic self-efficacy pretest and the OLSES online self-efficacy test were administered on separate days, using a Google Drive form for data collection.

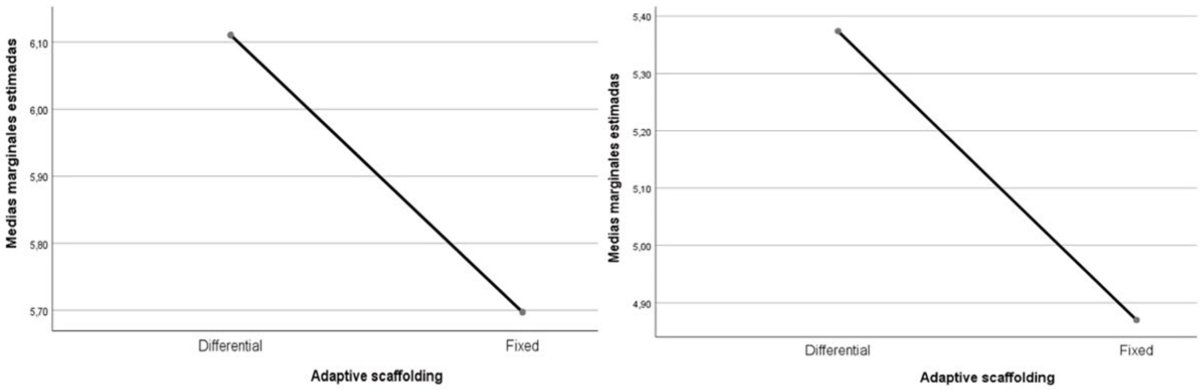
The four tenth-grade classes were then randomly assigned to different conditions within the multimedia environment featuring motivational scaffolding. The first group worked with the environment that included fixed motivational scaffolding and fixed scaffold. The second group used the environment with faded scaffolding and fixed scaffolding. The third group interacted with an environment featuring differential scaffolding and fixed scaffolding, while the fourth group engaged with the version containing both differential adaptive scaffolding and faded motivational scaffolding.

All students received an induction on the installation and operation of the multimedia environment. They then interacted with the environment over a period of five months during their technology course sessions. One week after the experience concluded, the students were administered the academic self-efficacy subscale of the MSLQ and the OLSES online self-efficacy scale, again managed through a Google Drive form.

The experimental process was approved by the Ethics Committee of the Universidad Pedagógica Nacional (Bogotá, Colombia).

Table 1. Descriptive data for the dependent variables academic self-efficacy (AS), self-efficacy for learning in online environments SLOE (L: Learning, TM: Time management, and TU: Technology use)

Adaptive scaffolding	Motivational scaffolding	N	SLOE							
			AS		L		TM		TU	
			M	SD	M	SD	M	SD	M	SD
Differential	Static	48	6.05	0.57	5.37	0.91	5.45	0.89	5.48	0.88
	Faded	30	6.19	0.59	5.55	0.88	5.41	1.11	5.44	0.90
	Total	78	6.10	0.59	5.44	0.90	5.43	0.97	5.46	0.88
Fixed	Static	36	5.72	0.55	4.75	0.96	5.15	0.98	5.27	1.02
	Faded	32	5.63	0.62	4.81	0.67	5.08	0.97	5.37	0.87
	Total	68	5.68	0.58	4.78	0.83	5.12	0.97	5.31	0.95
Total	Static	84	5.90	0.59	5.10	0.98	5.32	0.94	5.39	0.94
	Faded	62	5.90	0.66	5.17	0.86	5.24	1.05	5.40	0.88
	Total	146	5.90	0.62	5.13	0.92	5.29	0.98	5.39	0.91



(a) Estimated marginal means of academic self-efficacy (b) Estimated marginal means of online self-efficacy in learning category

Figure 6. Effect of adaptive scaffold on academic self-efficacy and online self-efficacy on the learning subscale (Source: Authors)

RESULTS

Academic Self-Efficacy

The average of the academic self-efficacy subscale was 5.90, and the standard deviation was 0.62. Out of a maximum score of 7 points, the minimum value obtained was 4 and the maximum was 7. In the present study, the subscale presented a reliability of 0.87.

Self-Efficacy for Online Learning

The mean score for the self-efficacy for online learning subscale was 5.13, with a standard deviation of 0.92. The scores ranged from a minimum of 3.1 to a maximum of 6.8, out of a possible 7 points.

For the time management subscale, the mean score was 5.28, with a standard deviation of 0.98. Scores ranged from a minimum of 2.6 to a maximum of 7.

The technology use subscale had a mean score of 5.39, with a standard deviation of 0.91. The scores varied from a minimum of 2.14 to a maximum of 6.86 out of a possible 7 points.

Table 1 presents the descriptive statistics for the study variables.

From the MANCOVA factorial analysis, firstly, it is concluded in relation to the independent variable (adaptive activator), that academic self-efficacy presented significant differences [$F (1, 138) = 18.5$; $p < 0.01$, $\eta^2 = 0.118$] (part a in **Figure 6**). These differences were in favor of students who were provided with differential messages according to their cognitive style. Regarding self-efficacy for online learning, significant differences were only observed in the learning subscale [$F (1, 138) = 11.98$; $p < 0.01$; $\eta^2 = 0.082$] (part b in **Figure 6**). These differences also favored students who received motivational messages in line with their cognitive style. The results show that there are no significant differences in the time management subscale ($F [1, 138] = 0.004$; $p = 0.952$; $\eta^2 = 0.02$) and, neither in the use of technology [$F (1, 138) = 0.02$; $p = 0.087$; $\eta^2 = 0.01$].

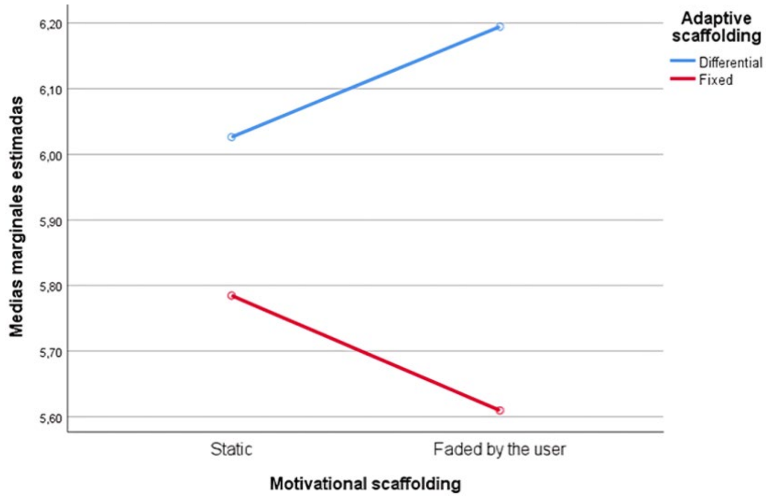


Figure 7. Estimated marginal means of academic self-efficacy by type of scaffolding and motivational (Source: Authors)

Regarding the second independent variable (motivational scaffolding), the results showed no significant difference in any of the dependent variables. The following results were obtained: academic self-efficacy [F (1, 138) = 0.02; p = 0.89, η^2 = 0]; online self-efficacy subscale learning [F (1, 138) = 0.02; p = 0.89; η^2 = 0.01]; time management subscale [F (1, 138) = 3.17; p = 0.08; η^2 = 0.02] and technology use [F (1, 138) = 0.98; p = 0.32; η^2 = 0.01]. Finally, the interaction analysis between the independent variables on the dependent variables showed only significant differences in academic self-efficacy [F (1, 138) = 4.11; p = 0.048; η^2 = 0.03].

A post-hoc analysis allowed us to determine that there was a significant difference only in students who worked with fading scaffolding (p < 0.001) and that, within this group, students who received differential motivational messages, that is, according to their stylistic characteristics, significantly improved their academic self-efficacy (M = 6.19; SD = 0.59), compared to peers who received fixed motivational messages (M = 5.63; SD = 0.62) (**Figure 7**). For the other dependent variables, no significant differences were found. The results showed the following values: learning [F (1, 138) = 1.28; p = 0.26; η^2 = 0.01]; time management [F (1, 138) = 0.42; p = 0.52; η^2 = 0.003] and technology use [F (1, 138) = 0.14; p = 0.70; η^2 = 0.001].

DISCUSSION AND CONCLUSIONS

In response to the research questions that guided this investigation, the following discussion is presented. Regarding the first research question, the results demonstrated that differential motivational scaffolds–specifically, the presentation of motivational messages tailored to the students' cognitive styles within the DIC dimension–positively influenced both academic self-efficacy and the self-efficacy for online learning subscale. This suggests that aligning motivational scaffolds with students' cognitive styles enhances their perception of self-efficacy. These findings support prior research indicating that motivational scaffolds can bolster students' self-efficacy when engaging with computational environments (López-Vargas & Valencia-Vallejo, 2012; López-Vargas et al., 2020; Valencia-Vallejo et al., 2018, 2019).

This study is among the first to generate adaptive scaffolds that account for students' cognitive styles. Such scaffolding serves as a pedagogical tool that motivates students to achieve learning goals while respecting individual differences. Successful experiences within each learning unit build learners' confidence in their abilities, reinforcing their belief in their capability to accomplish learning tasks. It is also likely that motivational scaffolds, tailored to cognitive styles, foster academic resilience by motivating students to confront challenges and setbacks in a positive manner. This encouragement may lead to increased effort, a positive attitude during learning, and a stronger sense of security in their abilities.

Given these results, it is important to acknowledge that this study is one of the few to specifically address cognitive styles in the DIC dimension for designing differential motivational scaffolding. The research provides empirical evidence and guidelines for understanding the adaptability of computational scaffolds based on cognitive styles. However, further research is needed to explore this area in greater depth.

Overall, these findings align with multiple studies suggesting that incorporating motivational scaffolding enhances online self-efficacy and learning achievement (López-Vargas et al., 2022; Stephen & Rockinson-Szapkiw, 2021). Additionally, adaptability appears to be a crucial factor in improving academic performance in virtual learning environments (Alhalafawy et al., 2021; Ayedoun et al., 2020; Basu et al., 2017; Chen et al., 2023; Noroozi et al., 2018; Park & Yun, 2018; Tawfik et al., 2018). The current study further illustrates that the use of motivational scaffolds can promote active student participation in their learning process.

No significant differences were found in the self-efficacy subscales for time management and technology use. This result may be attributed to the learning environment itself, which may have lacked pedagogical support specifically designed to promote these aspects. Additionally, students' interaction with the multimedia environment may have respected their learning rhythms, and it is possible that the students already possessed digital competencies, given their familiarity with computers, cell phones, and the Internet. This could explain the absence of statistically significant differences related to the interaction with the multimedia environment.

Regarding the second research question, the study did not reveal significant differences in any of the dependent variables concerning the second research question. This outcome could be explained by the possibility that the group of students with the option to fade the motivational scaffolding at their own discretion chose not to do so. It was evident that students preferred to continue using the scaffolding in its entirety, with none of the modules fading out. This suggests that students may have felt more secure using the complete scaffold. Similar findings were reported by Narciss et al. (2007) in research involving university students who did not utilize tools for self-regulated learning in a web-based environment as expected.

It is possible that students in this study lacked the stimulus to reduce or eliminate parts of the scaffold during their learning process. The absence of direct persuasion within the scaffolding design may have contributed to this behavior. Future research should consider incorporating direct interventions within scaffolds to motivate students to gradually eliminate the provided tools (Kester & Paas, 2005).

The literature on scaffolding presents mixed findings: some studies suggest that fixed scaffolding leads to better cognitive outcomes and problem-solving abilities compared to faded scaffolding (Belland et al., 2015; Karabay & Meşe, 2024; Tawfik et al., 2018), while others indicate that fading scaffolds can achieve the desired learning outcomes (Gidalevich & Kramarski, 2019; Molenaar et al., 2012; Spector et al., 2014) and promote motivation toward learning (Shin et al., 2024).

The findings of this study are consistent with those of other studies that found no significant differences in performance between fixed and faded scaffolds (McNeill et al., 2006; Wu & Pedersen, 2011). It is noteworthy that the focus of this investigation was on motivational aspects, such as academic and online self-efficacy. The contradictory results concerning the effectiveness of fixed versus faded scaffolds in terms of performance or motivational variables suggest that more research is needed to explore the role of learners' stylistic characteristics in the design and implementation of scaffolds in computational learning environments.

Regarding the third research question, there was an interaction between the independent variables, resulting in significant differences in academic self-efficacy. The group that interacted with fading scaffolding combined with differential motivational scaffolds had a significantly higher mean compared to the group that used the same type of scaffolding but with fixed motivational scaffolds.

This result indicates that differential motivational scaffolds, tailored to students' cognitive styles within the DIC dimension, had a favorable effect by motivating students to exert more effort and persist in achieving their learning tasks. When students have the autonomy to fade the scaffolding, they may feel more confident in their abilities to learn, particularly in the context of technology. The opportunity to control scaffolding, coupled with motivational triggers aligned with cognitive styles, likely enhances students' autonomy and self-efficacy. This suggests that adaptable scaffolding, aligned with learner-centered pedagogy, supports the development of academic self-efficacy and autonomous learning.

The findings of this study highlight the significant potential of computational learning environments to enhance learning by adapting to individual characteristics, learning rhythms, and, importantly, allowing students to control the fading of scaffolds. This adaptability empowers students to take a more active role in their learning process and positions them as central agents in achieving desired learning outcomes.

Projections

For future research, it is crucial to examine the impact of scaffolding on learning achievement more comprehensively. Additionally, exploring the role of cognitive style, specifically within the DIC dimension, is recommended. In the current study, cognitive style was only considered for designing adaptive scaffolding but was not treated as an independent variable, leaving room for further investigation into its direct effects.

The quasi-experimental design of this study, where pre-existing groups were used instead of randomly assigned ones, limits the generalizability of the findings. To strengthen the validity of future studies, increasing the sample size and employing random group assignments are advisable.

Furthermore, the reliance on self-reported measures for academic and online self-efficacy presents a limitation. Incorporating additional, more objective indicators to assess student behavior and performance in these areas would provide a fuller understanding of the impact of scaffolding.

Considering the practical application of the developed software, it is essential to ensure compatibility with mobile devices and low-end computer equipment, commonly found in public schools. Additionally, the software should be optimized to function effectively without requiring high bandwidth for cloud-based database communication. This would make the tool more accessible and practical in diverse educational settings, particularly in resource-constrained environments.

Limitations of the Study

In addition to the previously mentioned limitations, this study presents others that should be considered. Although cognitive style was included in the FDI dimension for differential scaffolding design, there are other dimensions of cognitive styles that could be explored for a more comprehensive analysis and a more detailed differential impact.

Regarding the duration of the study, the research was conducted over five months. A longer period could provide a broader perspective on the long-term effects of scaffolding on self-efficacy and learning.

The specific context may also influence the results. The research was conducted in a public institution in a municipality in Colombia, which could limit the generalizability of the findings to other educational settings or to populations with different socioeconomic and cultural characteristics.

In terms of assessment, the main focus was on academic and online self-efficacy, without directly measuring academic achievement or performance on specific learning tasks, which restricts a comprehensive understanding of the impact of scaffolding on effective learning.

Finally, interaction with advanced technology was limited. Given that the multimedia environment employed may not have integrated state-of-the-art technologies, results may vary if more advanced learning platforms are used.

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Declaration of interest: The authors declare no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

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