The seductive details in online mathematics learning

Los detalles seductores en el aprendizaje en línea de matemáticas

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ABSTRACT

The new technologies and multimedia formats have given rise to highly attractive synchronous virtual environments for learning mathematics. However, the cognitive theory of multimedia learning suggests that it is preferable to eliminate seductive information from a multimedia presentation. Nevertheless, it is still unclear whether this effect manifests in ecological situations such as synchronous video conferences. In order to address this gap, two experiments were conducted to examine the effect of instructional, decorative, and seductive images on mathematics learning through synchronous video conferences, for both beginner and advanced students. The first experiment (n = 156) revealed that both materials with instructional graphics and materials without graphics are more efficient (i.e., they generate higher performance with equal mental effort) than materials with seductive graphics. In the second experiment, the moderating role of prior knowledge was analyzed (n = 163), including advanced students in the study. The results suggested that novice students performed better with materials containing instructional and decorative graphics compared to those presenting seductive graphics. However, this disadvantage of learning with seductive graphics disappeared in advanced students. It is concluded that the effectiveness of online mathematics learning depends on the type of graphics used and the level of prior knowledge. These results are discussed from the perspective of cognitive load and multimedia learning, and practical guidelines are provided for teaching and researching online mathematics learning.

Keywords: didactic use of computer; multimedia system; mastery learning; cognitive ability; learning process.

RESUMEN

Las nuevas tecnologías y los formatos multimedia han dado lugar a ambientes virtuales sincrónicos de aprendizaje de matemáticas muy atractivos. No obstante, la teoría cognitiva del aprendizaje multimedia sugiere que es preferible eliminar la información seductora de una presentación multimedia. Sin embargo, aún no está claro si este efecto se manifiesta en situaciones ecológicas como las videoconferencias sincrónicas. Con el fin de abordar esta brecha, se llevaron a cabo dos experimentos para examinar el efecto de las imágenes instructivas, decorativas y seductoras en el aprendizaje de matemáticas mediante videoconferencias sincrónicas, tanto para estudiantes principiantes como avanzados. El primer experimento (n = 156) reveló que tanto los materiales con gráficos instructivos como los materiales sin gráficos son más eficientes (i.e., generan mayor desempeño con igual esfuerzo mental) que los materiales con gráficos seductores. En el segundo experimento, se analizó el papel moderador del conocimiento previo (n = 163), incluyendo estudiantes avanzados en el estudio. Los resultados sugirieron que los estudiantes principiantes obtuvieron un mejor desempeño con materiales que contenían gráficos instructivos y decorativos en comparación con aquellos que presentaban gráficos seductores. Sin embargo, esta desventaja de aprender con gráficos seductores desapareció en los estudiantes avanzados. Se concluye que la efectividad del aprendizaje en línea de matemáticas depende del tipo de gráfico utilizado y del nivel de conocimiento previo. Estos resultados se discuten desde la perspectiva de la carga cognitiva y del aprendizaje multimedia, y se proporcionan orientaciones prácticas para la enseñanza e investigación del aprendizaje en línea de las matemáticas.

Palabras clave: aprendizaje asistido por ordenador; sistema multimedia; aprendizaje del dominio; capacidad cognitiva; proceso de aprendizaje.

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INTRODUCTION

A widespread assumption is that digital technologies contribute to innovation and improvement in education and learning (Haleem et al., 2022; Miralles Martínez et al., 2019). These technologies encompass devices, multimedia materials (e.g., graphics and texts), and communication channels, integrated within the term online learning, to foster the acquisition of knowledge (Clark & Mayer, 2024). To ensure that the enthusiasm for technologies leads to greater learning gains, the design and use of digital environments should consider the characteristics of the human cognitive architecture (Sweller, 2024). The most relevant aspects of this architecture are working memory, long-term memory, and the processes that occur between them (Forsberg et al., 2021).

The multimedia principle is a derived finding from this architecture that considers the processing of new information in working memory (Mayer, 2012). It suggests that acquiring new information in long-term memory is enhanced when extraneous text and graphic information (i.e., seductive details) are removed from a computer-based multimedia lesson (Fiorella & Mayer, 2021; Moreno & Mayer, 2000). Apparently, seductive details demand attentional resources or cognitive load, reducing the processing of the information that needs to be learned (Bender et al., 2021). This effect is commonly observed in students who have no prior knowledge of the material (Sanchez & Wiley, 2006). However, it is still unclear how seductive details interact with prior knowledge (Mayer & Jackson, 2005; Wang & Adesope, 2016), or if these effects occur in ecologically valid conditions of online learning. Consequently, this study introduces the literature on seductive graphics and prior knowledge, and the results of two studies involving learning materials in the field of mathematics.

Online learning and multimedia learning

Online learning involves delivering educational information through digital platforms aimed at facilitating the acquisition of knowledge and skills (Clark & Mayer, 2024). While online learning has been theorized and researched from multiple and varied theoretical approaches (e.g., Downes, 2022) in this work, it is assumed that the effectiveness of online learning depends on how the design and use of technology and instruction align with the goals of acquiring domain-specific knowledge and the characteristics of the student (Castro-Alonso et al., 2021; Chen et al., 2017). In this context, cognitive theory of multimedia learning is a solid instructional perspective that has been widely used for designing and researching digital environments.

This theory suggests that people learn better when learning materials include both text and graphics, rather than just using materials with text alone (Mayer, 2012, 2020). The three main assumptions are that people have two separated channels for visual/spatial material and auditory/verbal material (Sadoski & Paivio, 2013) that has a limited processing capacity (Sweller, 2024), and should actively process relevant information to construct a coherent mental representation (Fiorella, 2023). From this perspective, online learning can be more effective when it guides students in selecting relevant information from a multimedia lesson, encourages the creation and organization of a mental representation in working memory, and promotes its integration into long-term memory. Relevant information (i.e., text and graphics) imposes an intrinsic load on working memory, while task-unrelated information (e.g., seductive images) imposes an extraneous load. Since extraneous load hinders learning, it should be minimized as much as possible (Mayer, 2019).

Seductive graphics

Not all information included in multimedia lessons is equally effective. According to the coherence principle, people comprehend and learn more when graphics, words, sounds, and symbols that are unrelated to the information being learned are excluded (Garner et al., 1989; Lehmann & Seufert, 2017; Mayer et al., 2008). Regarding graphics, Sung and Mayer (2012) have defined three types. *Instructional graphics* are external representations that facilitate understanding of the information, increase cognitive interest, and are directly related to the learning goal (i.e., they impose intrinsic cognitive load) (Harp & Mayer, 1997). For example, a lesson on calculating the volume of cylinders presents an image of a cylinder along with words pointing out the base and height.

On the other hand, *seductive graphics* are information elements unrelated to the learning goal and impose extraneous cognitive load. They are highly captivating, energizing, and evoke emotions, but they can consume working memory resources to the point of reducing attention to the relevant information, causing extraneous cognitive load (Sundararajan & Adesope, 2020). For example, a lesson about cylinders includes an image from the popular news showing a vendor throwing a cooking gas cylinder from a truck at a robber. *Decorative graphics* are also information elements unrelated to the learning goal and also impose extraneous cognitive load, but they are intended to be cognitively neutral, increase situational interest, make the presentation visually appealing, and create a pleasant tone (Schneider, Dyrna, et al., 2018). For example, a lesson on cylinders includes an image of natural landscapes such as a beach or a forest.

Most studies indicate that students who learn with seductive and decorative graphics score lower on performance tests compared to students who learn without these graphics (Mayer, 2019; Noetel et al., 2021; Rey, 2012; Sanchez & Wiley, 2006; Sundararajan & Adesope, 2020). The theoretical explanation is that seductive details induce extraneous processing in working memory (i.e., they distract, interrupt, or divert attention), leaving few resources available to construct a mental representation of the material and integrate it with knowledge retrieved from long-term memory (Bender et al., 2021; Mayer, 2020).

The use of seductive details seems to be justified from an emotive-motivational perspective (Kintsch, 1980; Renninger & Hidi, 2016). These perspectives advocate for the inclusion of phrases, graphics, and even unrelated sounds that, although unrelated to the learning goal, increase interest in the learning materials. However, the existent research suggests that seductive details may be beneficial under specific conditions, such as high pressure (Fries et al., 2019) or emotional arousal (Schneider, Wirzberger, & Rey, 2018).

Regarding the field of mathematics, to the best of our knowledge, there are very few studies on seductive and decorative details, and none conducted under the ecological conditions of online learning. For example, Fries et al. (2019) examined seductive details in a video on matrix properties under high and low-pressure conditions with 259 students. In the low-pressure condition, seductive details resulted in lower performance on the final test compared to those who learned without seductive details. However, no performance differences were found under high-pressure conditions. Furthermore, a recent meta-analysis (Sundararajan & Adesope, 2020) reported a surprisingly positive effect (g = 0.42) of seductive details in math and statistics materials. This analysis only involved 288 students from two experiments. The findings regarding decorative graphics also appear to be inconclusive (Lindner, 2020; Magner et al., 2014; Mikheeva et al., 2021). Apparently, decorative graphics seem to have the advantage of reducing math anxiety or generating situational interest that could promote learning (Park et al., 2005).

Prior knowledge

Novice and advanced students exhibit different performance on a task due to the type of knowledge they possess (Kalyuga, 2021; Richter et al., 2021; Zambrano R. et al., 2019). It seems to be more effective for novices to receive high support and guidance with appropriate integration of text and graphics (Hoogerheide et al., 2019). However, the effectiveness of these materials is reversed when students have relevant knowledge of the material in long-term memory (i.e., advanced students) (Jiang et al., 2023). Advanced students perform better than novices, probably because they retrieve a large amount of relevant information from long-term memory without being limited by working memory constraints (Kalyuga, 2021). However, the performance of these students may be compromised when they receive materials that incorporate a high level of support and guidance that they do not need. This result is referred to as the expertise reversal effect (Jiang et al., 2023; Kalyuga et al., 2003). Therefore, multimedia design for advanced students should avoid redundant images and words (i.e., already known information) and progressively increase the level of material complexity (Kalyuga, 2021).

The greater cognitive capacity of advanced students may reduce the extraneous cognitive load associated with seductive and decorative details (Korbach et al., 2016; Mikheeva et al., 2021; Sanchez & Wiley, 2006; Sundararajan & Adesope, 2020). However, there is very little empirical research on this relationship. For example, Magner et al. (2014) studied the effect of decorative details on performance in tests of near and far transfer in basic geometry (e.g., parallel lines, complementary angles, sum of angles, vertical angles). It was found that novices learned more with materials without decorative details than with them in the near transfer tests. However, advanced students learned more with the decorative details than without them in the same tests. In the delayed transfer tests, the advanced students performed better than the novices, and no interaction effects were found.

Wang and Adesope (2016) compared three types of materials (i.e., without seductive details, seductive details at the beginning, or seductive details at the end of the lesson) in geography materials (i.e., earth formation). It was found that novices without seductive details had higher performance than those who learned with the other materials. However, advanced students learned more without seductive details and with seductive details at the end than with seductive details at the beginning of the lesson. Fries et al. (2019) also examined the effect of prior knowledge, but in interaction with learning pressure. When students are novices, the inclusion or omission of seductive details did not affect learning under low pressure. However, in the high-pressure condition, novices learned more with seductive details than without them. These factors did not produce different results in advanced students. The results seem to support partially the hypothesis that learning with decorative and seductive images imposes extraneous processing on working memory only in novice students

(Korbach et al., 2016). However, it is unknown whether these results are consistent in the domain of mathematics and under the ecological conditions of online synchronous education.

The present study

The present study aimed to examine the coherence principle in online mathematics learning. In online synchronous sessions, many factors come into play that are not present in laboratory studies or controlled classroom conditions. Therefore, the research question was whether a multimedia lesson delivered through synchronous classes with instructional graphics improves mathematics learning outcomes compared to lessons with seductive graphics or without graphics. A second question was whether prior knowledge (i.e., novice and advanced students) moderates the learning outcomes.

EXPERIMENT 1

The purpose of Experiment 1 was to test the following hypotheses: learning with instructional graphics fosters a higher performance, lower mental effort, and higher efficiency (h1) than learning with seductive graphics. Additionally, learning without illustrations fosters a higher performance, lower mental effort, and higher efficiency (h2) than learning with seductive graphics.

Method

Participants

An a priori power analysis with a power .8 and a medium effect size .06 (Field, 2024) revealed that 156 participants would be sufficient to reliably test our hypotheses. The study involved 156 Ecuadorian students enrolled in a public school in Rumiñahui, as part of their mathematics curriculum. However, two students were unable to complete the study. Eighty males and 74 females participated, with an average age of 14.18 (SD = .80). The participants had not received prior instruction on the topic under study (i.e., geometric shapes), as confirmed by the pre-test during which they were unable to solve any tasks and selected the option "I don't know". Academic compensation was provided to students for their participation in the study during their mathematics class. Moreover, the educational institution authorities and parents were duly informed about the study and provided necessary authorization.

Design and procedure

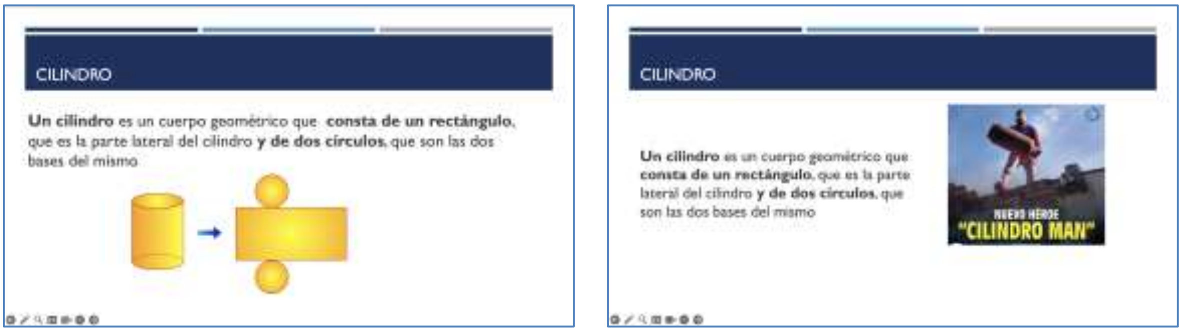
The study design featured three graphic conditions: instructional graphics, seductive graphics, and no graphics, and were conducted in a 45-min session. The students were randomly assigned to the conditions and the session was implemented by one of the authors. Firstly, each student was asked to complete a 10-min prior knowledge test. Secondly, the groups were created according to the condition, and each group used the Microsoft Teams platform. Thirdly, each student, under their respective conditions, received a 20-min multimedia lesson on calculating the volume of geometric shapes, with only the graphical representation differing. Finally, students were asked to complete a 10-min questionnaire to assess the acquired knowledge.

Materials

The entire experiment was conducted on Microsoft Teams. Electronic quizzes were used for the tests, and the presentations were made in PowerPoint. The learning material was mathematics-related, specifically about the volume of solid objects, and consisted of 13 timed slides under the control of the instructor. The material had approximately 1000 characters and was structured with text accompanied by instructional graphics, seductive graphics, or no graphics (Figure 1). All pictures were removed in the no graphic condition.

Figure 1

Sample of materials with instructional (a) and seductive graphic (b)



a b

Measures

Performance. Performance was measured before and after the multimedia presentation with the same knowledge test. It consisted of 6 multiple-choice questions covering the learning material. Each question had four options, and each option was scored between 1 and 4 points based on the level of complexity of the response. For example, the question 'What is the volume of a prism with a height of 5 cm and a base area of 10 cm?' was worth 1 point for correctly multiplying to obtain the volume. The question that asked to find the volume of a hexagonal prism with a base edge of 6 m, an apothem of 5.2 m, and a height of 27 m, was worth 2 points because it required two steps: calculating the base area and performing the multiplication. A 4-point question was 'Find the diameter of the circular base of a cylindrical water tank measuring 3 m in height and 1 m in diameter'. 'If you wanted to fill it halfway, how many liters of water would it hold?' In this case, four steps were required: calculating the base area, calculating the volume of the body, converting the measurement, and dividing the value in half.

Mental effort. Cognitive load was measured using the mental effort scale after each learning task using a 9-point subjective mental effort scale (Van Gog & Paas, 2008). The scale varied from 1 (very, very low mental effort) to 9 (very, very high mental effort).

Cognitive efficiency. Efficiency (E) refers to the quality of learning because of combining performance and mental effort (Van Gog & Paas, 2008). High efficiency refers to achieving a high performance while expending relatively low mental effort. Conversely, low efficiency implies achieving relatively low performance outcomes despite investing considerable mental effort. Efficiency was determined by standardizing the task performance and mental effort scores of each participant. Specifically, *z*-scores were computed for both effort (R) and performance (P) for each participant, and the formula $E = [(P - R)/2^{1/2}]$ was used.

Results

The data were analyzed using a one-way analysis of variance (ANOVA). The independent variable was the type of graph (instructive graph, seductive graph, and no graph), and the dependent variables were performance, mental effort, and efficiency in the retention tests (Table 1). A significance level of .05 was used for the analysis, along with ηp^2 as a measure of effect size, with values of .01, .06, and .14 corresponding to small, medium, and large effects, respectively (Field, 2024).

Table 1
Descriptive statistics

Learning condition	*M*	*SD*
Performance		
Instructive graphics	6.14	2.34
Seductive graphics	1.94	1.41
No graphics	4.49	2.18
Mental effort		
Instructive graphics	20.51	5.03
Seductive graphics	22.08	4.95
No graphics	20.06	5.36
Efficiency		
Instructive graphics	.57	.99
Seductive graphics	-.77	.80
No graphics	.19	1.02

Regarding performance, the ANOVA revealed a statistically significant difference, *MSE* = 4.09, $F(2, 151) = 55.12$, $p < .001$, $\eta p^2 = .42$. Post hoc Bonferroni tests showed that the material with instructive images resulted in higher performance compared to seductive images ($p < .001$) and no images ($p < .001$). Additionally, the material without images resulted in higher performance than the material with seductive images ($p < .001$).

Concerning mental effort, the ANOVA did not show significant differences among the three learning conditions, *MSE* = 26.23, $F(2, 151) = 2.19$, $p < .001$, $\eta p^2 = .03$, suggesting that the groups invested an equal level of cognitive load. Finally, regarding cognitive efficiency, the ANOVA revealed a statistically significant difference, *MSE* = .89, $F(2, 151) = 26.97$, $p < .001$, $\eta p^2 = .26$. Post hoc Bonferroni tests suggested that the material with instructive images was more efficient than the material with seductive images ($p < .001$), and equally efficient as the material without images ($p = .13$). It was also found that the material without images was more efficient than the material with seductive details ($p < .001$).

Discussion

This experiment aimed to test whether students who learn with instructional graphics achieve better performance, experience less mental effort, and consequently are more cognitively efficient than those who study with seductive graphics (h1). This hypothesis was partially supported, as our data only supported the hypotheses of performance and efficiency. Overall, our results are consistent with previous findings on the advantage of learning with instructional graphics (Moreno & Mayer, 2000). It appears that instructional graphics imposed intrinsic load that induced the creation of a more coherent mental representation of material, which resulted in better retention of information in long-term memory.

The result regarding mental effort suggests that the material that included instructional graphics imposed a similar mental load as the material with seductive graphics. This does not imply that both types of graphics induced similar processing in working memory. It is likely that decorative graphics increased cognitive interest, which led to an increase in cognitive processes associated with understanding the material (Bender et al., 2021). On the other hand, seductive graphics may have consumed high attentional resources with the disadvantage of interrupting or diverting attention from the construction and acquisition of a coherent mental model (Park et al., 2011). The result of efficiency revealed that the combination of performance and mental effort is better for instructional graphics. In other words, although both types of materials impose a similar cognitive load, learning with instructional graphics is more cognitively efficient in terms of academic achievement.

Our second hypothesis was that students who learn without graphics would have higher levels of performance, lower mental effort, and higher efficiency (h2) than those who learn with seductive graphics. Our results partially support this expectation, as evidence was found only for performance and efficiency. We expected that the removal of seductive graphics would reduce extraneous mental processing (i.e., extraneous cognitive load), resulting in lower demands on working memory resources (i.e., lower mental effort scores). However, our results suggest that the removal of interesting graphics, while significantly improving performance, does not imply a reduction in information processing load. An alternative explanation could be that mental load was a mediating factor (Park et al., 2011). That is, the essential information of the material imposed a high intrinsic cognitive load associated with the elaboration of a mental model of the material, while the seductive details imposed high mental resources, perhaps due to insufficient time to comprehend the material.

EXPERIMENT 2

The purpose of this experiment was to test hypotheses regarding prior knowledge. When students are novices, instructional graphics promote better learning outcomes than seductive graphics (h1); similarly, decorative graphics foster superior learning outcomes than seductive graphics (h2). However, when students are advanced, instructional, and decorative graphics produce similar learning outcomes as instructional graphics (h3).

Method

Participants

An a priori power analysis with a power .8 and a medium effect size .06 was performed (Field, 2024) which indicated that 158 participants would be sufficient to reliably test our hypotheses. Participants were 163 Ecuadorian students from public education, 75 males and 88 females, with a mean age of 12.99 years (SD = .97). The activities were conducted as part of the mathematics subject. The institution authorities and parents were provided with information about the study and gave their authorization for participation. Additionally, all participants received 10 points in their subject as compensation for their effort.

Two groups from the upper basic education level were recruited. One had not received instruction on vectors because this topic was excluded during the COVID pandemic period (i.e., novice students), and the other had already received instruction on vectors as part of the preparation for secondary education (i.e., advanced learners). The ANOVA revealed that novice students (n = 79, M = 2.30, SD = .70) had lower prior knowledge than advanced students before the experiment (n = 84, M = 4.38, SD = .70, MSE = .37, $F(1, 157)$ = 452.13, p < .001, ηp^2 = .74). No difference was found between students who learned with instructional graphics (n = 58, M = 3.8, SD = 1.17), decorative graphics (n = 52, M = 3.33, SD = 1.22), and seductive graphics (n = 53, M = 3.01, SD = 1.20, MSE = .37, $F(1, 157)$ = 2.97, p = .054, ηp^2 = .03). These results suggested that prior knowledge was the differentiating factor among the participants.

Design and procedure

A 2 (prior knowledge: novices vs. advanced) x 3 (type of graphics: instructional, decorative, and seductive) factorial design was used. The dependent variable was performance in a specific domain: vectors. Participants were randomly assigned to all study conditions.

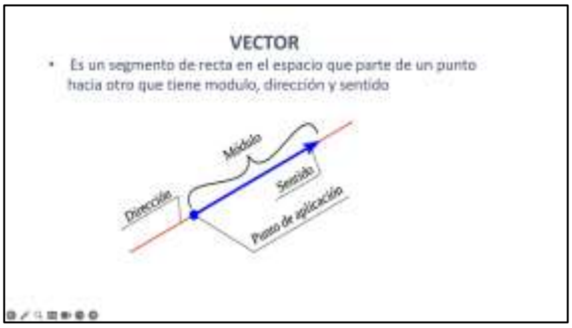
The procedure was administered by one of the authors and two teacher assistants. The advanced group underwent a retrieval practice session on vectors one day before the experiment, overseen by an instructor who ensured evocation of the topic through questioning and testing. On the day of the experiment, all students were instructed to access the Zoom video conferencing platform and adhere to the teachers' directives throughout the class. Subsequently, participants individually completed a 7-minute pretest assessing prior knowledge, comprising five multiple-choice items. Following the pretest, participants were allocated to their respective study conditions using Zoom breakout rooms. Assigned teachers for each group delivered a multimedia lesson based on the study condition and directed participants to review it, lasting approximately 45 minutes. Finally, participants underwent a 7-minute posttest featuring five multiple-choice items. Upon completing all tests, students were thanked for their participation.

Materials

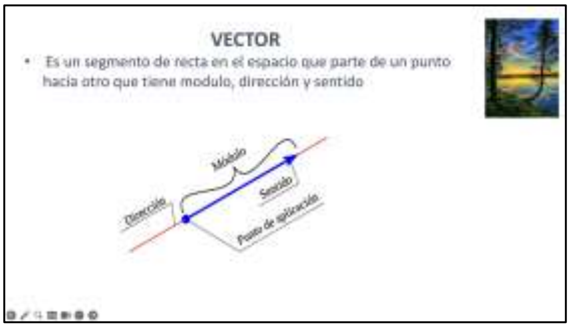
The entire experiment was conducted on the Zoom platform. Electronic questionnaires were used for the tests, and the presentations were created in PowerPoint. The learning material was about mathematics and consisted of 12 slides with identical text describing the fundamental concepts of vectors: definition of a vector, characteristics, magnitudes, elements, and an exercise. In the instructional graphics version (Figure 2), 11 images were added in a section of the lesson that described the characteristics and components of vectors. In the seductive graphics version, 13 animated GIF images unrelated to the lesson's goal were added. And in the decorative graphics version, landscape images that did not correspond to the lesson's goal but were not visually appealing were added.

Figure 2

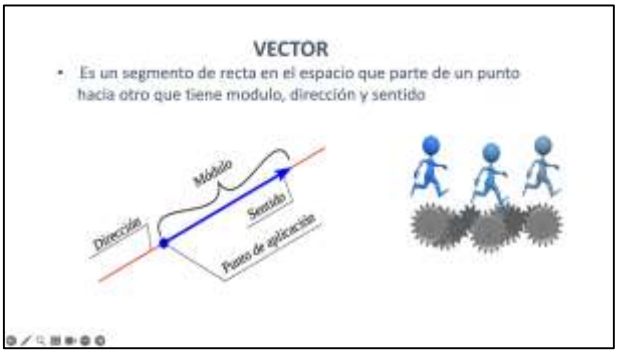
Sample of materials with instructional (a), decorative (b) and seductive graphics (c)



a



b



c

Performance measurement

Performance measurements were conducted before (i.e., pretest) and after (posttest) the learning phase. Prior knowledge of the learning materials was measured using a five-question multiple-choice questionnaire. Each question was scored with 1 point. The knowledge acquired in the learning phase was measured using another questionnaire with five multiple-choice questions, each worth one point. The questionnaires were electronic, delivered to each student via a virtual platform, and students were instructed to keep their cameras on. Additionally, a digital timer was used to control the response time for each questionnaire.

Results

The data were analyzed using an analysis of variance (ANOVA): 2 (prior knowledge: novices vs. advanced) x 3 (types of graphics: instructional, decorative, and seductive). The dependent variable was performance in the retention tests (Table 2). A significance level of .05 was used for the analysis, along with ηp^2 as a measure of effect size, with values of .01, .06, and .14 corresponding to small, medium, and large effects, respectively (Field, 2024).

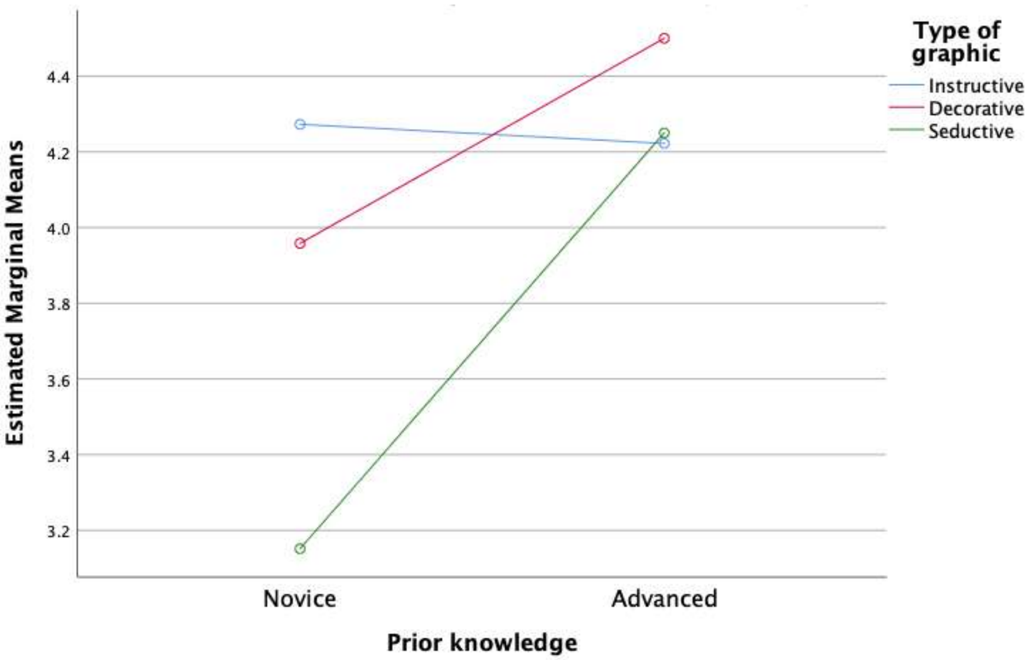
Table 2
Descriptive results

Learning condition	*M*	*SD*
Novice		
Instructive graphic	4.27	.77
Decorative graphic	3.96	1.04
Seductive graphic	3.15	1.15
Advanced		
Instructive graphic	4.22	.80
Decorative graphic	4.50	.75
Seductive graphic	4.25	.85

The ANOVA revealed a significant main effect for prior knowledge condition, suggesting that advanced students (M = 4.32, SD = .79) performed better than novice students, M = 3.71, SD = 1.12, MSE = .83, $F(1, 157) = 13.16$, $p < .001$, $\eta p^2 = .08$. The ANOVA also showed that the main effect of graph types was significant, indicating a difference between those who learned with instructional graphs (M = 4.25, SD = .12), decorative graphs (M = 4.23, SD = .13), and seductive graphs (M = 3.70, SD = .13, MSE = .83, $F(2, 157) = 5.91$, $p = .003$, $\eta p^2 = .07$). A post hoc Bonferroni analysis revealed that instructional graphs ($p = .008$) and decorative graphs ($p = .012$) were superior to seductive graphs.

The ANOVA also revealed a significant interaction between the main effects, MSE = .83, $F(1, 157) = 5.181$, $p < .007$, $\eta p^2 = .06$ (Figure 3). The post hoc Bonferroni analysis showed that when students have lower prior knowledge, learning with instructional graphs ($p < .001$) and learning with decorative graphs ($p < .004$) results in better performance than learning with seductive details. There was no difference between instructional and decorative graphs ($p = .73$; $\eta p^2 = .13$). When students are advanced, there was no difference between learning with instructional graphs and seductive details ($p = 1.00$), between instructional and decorative graphs ($p = 1.00$), or between instructional and seductive graphs ($p = .69$; $\eta p^2 = .01$).

Figure 3
Interaction between prior knowledge and graph type



Discussion

The second experiment aimed to examine the effect of decorative details and the mediating role of prior knowledge. The first hypothesis was that for novices, instructional graphs would result in better performance than seductive graphs. Our data provide evidence for this expectation, which is consistent with the first experiment. Instructional graphs guided the selection of relevant information and induced the formation of a more coherent mental representation of the study material, resulting in greater knowledge acquisition. Instructional graphics appear to have enhanced both the comprehension and acquisition of material information in long-term memory (Mayer, 2020).

Our results also support the second hypothesis that decorative graphs lead to better learning outcomes than seductive graphs. Decorative details, although not designed to contribute to the learning goal, may have increased situational interest in the material (Magner et al., 2014), which may have induced extraneous load during processing material information. It appears that decorative graphs created a more productive emotional condition than the emotional condition associated with seductive details (Mayer & Estrella, 2014; Plass & Kalyuga, 2019).

The third hypothesis was that instructional and decorative graphs would produce similar learning outcomes to seductive graphs when students are advanced. Our results support this prediction. Advanced students, as suggested by the main effect of prior knowledge level, learned more than novices, perhaps due to their prior cognitive advantage. It seems that this advantage reduced the negative impact of seductive details (Fries et al., 2019). This finding is consistent with previous studies suggesting that high prior knowledge is a factor that reduces the effects of cognitive load and multimedia learning (Fiorella & Mayer, 2021; Mayer, 2020; Mayer & Fiorella, 2022; Wang & Adesope, 2016).

This result is explainable by the cognitive load theory (Sweller, 2024). While working memory is highly limited when students process new information, there are no cognitive limits when processing already known and organized information in long-term memory. Once the information has been acquired (i.e., this is the purpose of teaching), students expand their cognitive capacities with which they can better leverage the information they encounter in the external environment (e.g., study materials) to generate appropriate actions for that environment. In other words, advanced students utilized their extended cognitive capacity and prior cognitive structures to avoid seductive information elements and identify the most relevant information elements of the study material for more effective acquisition (Sanchez & Wiley, 2006).

GENERAL DISCUSSION

Online education is made possible by the development of technologies and information presentation formats. The easy access and management of current digital tools allow for the creation of highly engaging environments that can be incorporated into online courses (Miralles Martínez et al., 2019). However, the limited cognitive capacities of the students are not different from what they were before the advent of current technological developments (Nairne, 2022). Therefore, it is crucial that educational environment designs, to be effective in terms of academic achievement, consider how multimedia elements affect the processing of the information that needs to be learned. The present study aimed to explore the principle of coherence in online mathematics learning.

The first study explored whether a multimedia lesson with instructional graphs improves online mathematics learning outcomes compared to lessons with seductive graphs or no graphs in a synchronous videoconference session. These results are in line with previous studies on the effect of instructional and seductive details (Garner et al., 1989; Rey, 2014; Sundararajan & Adesope, 2020). Materials with instructional graphs and without graphs were more effective because they appeared to influence the creation of a more coherent mental representation of the mathematics content in online learning conditions. The results of the mental effort measurement suggest that even materials without graphs impose a cognitive load equivalent to instructional and seductive graphs. However, the equal mental effort resulted in lower efficiency in materials with seductive details.

The second study examined whether prior knowledge (i.e., novice and advanced students) moderates learning outcomes. The analyses showed that the effect of seductive and decorative details are relevant for novice students, which is consistent with previous studies (Rey, 2012; Sundararajan & Adesope, 2020; Wang & Adesope, 2016). It seems, the inclusion of instructional and decorative graphs contributes to the elaboration of a better mental representation of the mathematics material compared to material with seductive graphs. The instructional graphics were designed and utilized to complement verbal and numerical information, thereby imposing intrinsic cognitive load during the processing of the material. It is probably that this load improved comprehension and fostered a better acquisition in long-term memory.

The positive effect of decorative graphs could be interpreted from the cognitive-emotional theory of multimedia learning that highlights the emotional aspects of cognitive processing (Mayer & Estrella, 2014; Plass & Kalyuga, 2019). Decorative graphics may have increased the student's motivation and interest to understand the essential material and, thus, foster deeper learning processes leading to better learning outcomes (Magner et al., 2014; Mikheeva et al., 2021). The results for advanced students were also consistent with previous literature (Bender et al., 2021; Fries et al., 2019). It seems that advanced students leverage their prior schemas and extended cognitive capacity to avoid seductive elements and focus on the relevant elements of the material (Sanchez & Wiley, 2006).

Similar to the first experiment, the results of the second study were obtained through digital presentations of mathematics using synchronous streaming programs commonly used in current online education. Additionally, it is common for students in online classes to have varied levels of prior knowledge about the learning material. Therefore, these results could be generalized to online learning conditions that require mathematical processing for both novice and advanced students.

In conclusion, the negative effect of seductive details inhibits mathematics learning in multimedia classes via video conferencing. Multimedia online or synchronous lessons that include instructional graphics enhance student performance compared to classes with seductive graphics. Likewise, decorative graphics foster more learning compared to seductive graphics, perhaps because they increase motivation and interest. However, the superiority of these graphics was only observed among novice students. When students already have prior knowledge of the material, seductive graphics are not relevant as they appear to be ignored by advanced students. (Sanchez & Wiley, 2006).

One limitation of our studies was that independent cognitive load measurements (i.e., intrinsic or associated with essential material, and extraneous or associated with seductive/decorative material) were not included. Although the experiments were conceived from the perspective of cognitive load and the first study included a measurement of mental effort, there are currently other methods to estimate the cognitive load associated with learning material (Skulmowski, 2023). An additional limitation is that our study did not consider specific sources of extraneous load, such as students' cameras, static profile images, ambient sounds, among others, which are common in videoconference platforms such as Microsoft Teams or Zoom.

Future studies should replicate these experiments by including, for example, measurements of eye movements while students work online on computers (Bender et al., 2021; Stark et al., 2018). Another limitation was the lack of transfer of learning assessments. While it is unclear whether the results of transfer of learning assessments are a good indicator of acquired knowledge because schemas do not easily generalize to different conditions even within the same domain (Tricot & Sweller, 2014), future studies could include measurements of the application of mathematical concepts in similar conditions, either immediately or days after multimedia teaching (i.e., long-term knowledge).

These studies have clear implications for educational practice. The design of multimedia materials and online environments should consider the capabilities and limitations of both novice and advanced students. This implies incorporating prior knowledge tests and adapting multimedia materials accordingly. Current platforms often include quiz modules that can be configured to guide students in selecting materials based on their performance scores. For instance, it could be established that if a student does not attain a certain level in a math topic, materials featuring instructional graphics should be recommended.

Another educational implication is to use seductive details cautiously, particularly for advanced students. This work and previous literature consistently indicate that advanced students appear to be less affected by seductive graphs. It may be beneficial to provide math materials with some seductive graphs, or alternatively, to offer more complex materials (i.e., new information) with minimal decorative details. Given the potential challenges in achieving high performance standards in mathematics, leveraging the higher cognitive capacity of advanced students may be advantageous in advancing through the educational program with materials designed to evoke positive emotions. (Plass & Kalyuga, 2019).

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