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Evidence of Content Learning Through Animations Developed Based on the Cognitive Theory of Multimedia Learning

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ABSTRACT

Background: Considering cognitive limitations is essential for learning, as it provides subsidies for developing methodologies that successfully facilitate and help the learning process. **Objective:** We start our research by asking: "Does a video lesson containing an animation developed based on the cognitive theory of multimedia learning promote positive effects on student learning in terms of content retention and transfer?" seeking to answer it based on data analysis. **Design:** Four animations containing the narration of two different contents were produced, two with and two without cognitive overload. The research team employed forms with questions about the animations to analyse the retention and transfer of the critical content to be learned in the animations. **Setting and Participants:** Undergraduate students were divided into two groups to watch the animations and answer the research questions. **Data collection:** After analysing the participants' answers, we calculated the effect size (Cohen's d). **Results:** The tests of retention and transfer of content were compared with the values obtained in the calculus of the effect size between the participating groups. **Conclusions**: The animations that followed the cognitive theory positively contributed to learning, collaborating with the thesis that one should seek to understand and regard cognitive processing.

Keywords: Learning; Multimedia; Cognitive; Effect size.

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Evidências de aprendizagem de conteúdos por meio de animações desenvolvidas com base na teoria cognitiva de aprendizagem multimídia

RESUMO

Contexto: Considerar limitações cognitivas, é importante para a aprendizagem pois fornece subsídios para elaboração de metodologias que facilitem e auxiliem de maneira efetiva a aprendizagem. **Objetivo:** Partimos da pergunta: "Uma lição em vídeo contendo uma animação desenvolvida com base na Teoria Cognitiva de Aprendizagem Multimídia, promove efeitos positivos na aprendizagem do aluno quanto à retenção e transferência do conteúdo?", buscamos responder essa pergunta por meio de uma análise de dados. **Design:** Foram produzidas quatro animações contendo narração de dois conteúdos distintos, duas com sobrecarga cognitiva e duas sem a sobrecarga. Foram utilizados formulários com perguntas sobre as animações, para análise de retenção e transferência do conteúdo essencial a ser aprendido nas animações. **Ambientes e Participantes:** Estudantes de cursos de graduação foram divididos em dois grupos para assistir as animações e responder as questões de pesquisa. **Coleta de dados:** Após uma análise das respostas dos participantes foi feito o cálculo do Tamanho de Efeito (d- de Cohen). **Resultados:** Houve comparação entre os testes de retenção e transferência de conteúdo comparando os valores obtidos no cálculo do Tamanho de Efeito entre os grupos participantes. **Conclusões**: As animações que respeitaram a teoria cognitiva tiveram uma contribuição positiva para as aprendizagens colaborando com a tese de que deve-se buscar entender e respeitar o processamento cognitivo.

Palavras-chave: Aprendizagem; Multimídia; Cognitivo; Tamanho de Efeito.

INTRODUCTION

The constant development of new tools, devices, and technological resources (computers, tablets, computer graphics) and the advances in connectivity (internet, wireless network connection, mobile phones) require studies to deliver effective materials and methodologies in teaching. These studies involve educational research on teaching methodology with new technologies, instructional design, digital information and communication technologies (DICTs) in education, and learning psychology (Borba & Villlareal, 2005; Filatro, 2004, 2008; Maltempi, 2008; Mayer, 2009).

Technical development knowledge is also essential for multimedia instructional design, such as of information technology, gesture interfaces, information architecture, usability, accessibility, and interface design (Agner, 2011; Mazzoni, Torres, & Alves, 2002; Cunha, 2012).

According to Tardif, Lessard, and Lahaye (1991), during content teaching and development, teachers resort to methodologies that they knew at some point or improved, incorporating the teaching knowledge discussed in research into their practices. The main objective of the class is students' learning and that, in the end, they not only retain content but can transfer[1] the acquired knowledge to other learning situations.

Mayer (2009) affirms that although each person can capture and process information, educational resources disregarding students' cognitive limitations can cause an overload in cognitive processing. Mayer's cognitive theory of multimedia learning and the discussions in neuroscience (Bear et al., 2002) mention the limitations of the visual and auditory canal, which can execute the so-called *selective attention*.

A cognitive theory of learning presupposes the stimuli that specific student actions and interactions with educational resources will cause in their mind so that the teaching-learning process is more easily developed. Mayer (2003, 2009) developed the cognitive theory of multimedia learning through several experiments (Harp & Mayer, 1997, 1998; Mayer, Heiser, & Lonn, 2001; Moreno & Mayer, 2000; Mayer et al., 1996; Mayer & Jackson, 2005), working with the cognitive theory of the dual channel, in which the student receives information through the eyes and ears, and the two channels complement each other.

Mayer, Heiser, and Lonn (2001) conducted four experiments with university students. First, the researchers gave them a class on how lightning forms, using a graphic video animation as an educational resource. Next, those students saw an animation while hearing the simultaneous narration that explained the natural phenomenon. According to the authors, when students received texts on the screen simultaneously summarising the narrated information or the written captions of the narration, they performed worse on retention and transfer tests than students who did not receive the on-screen texts.

This "principle", based on Mayer (2009), called *redundancy*, mentions that adding texts on the screen can overload information processing in the visual

[1] According to Mayer (2009), the retention of content is related to the memorisation of the information presented, i.e., the student records that information. The transfer of content is a process in which the student can apply that content in other learning situations, or think of solutions to problems related to that content.

channel, causing students to divide their visual attention between two different sources: animation and text.

Students also performed worse in the transfer tests when the authors added interesting but irrelevant details to the narration or inserted interesting but conceptually irrelevant video clips within or before the video. This principle, called *coherence*, is consistent with the hypothesis that *immersive details* in the video and narration disturb attention, selecting relevant content, and organising information, as they awaken prior knowledge irrelevant to the lesson, disturbing and deviating attention from the core content.

From the perspective of neuroscience, according to Bear et al. (2002), Gazzaniga (2009), Jääskeläinen (2012), and Springer and Deutsch (1998), we found discussions about how much information overload is detrimental to the selection of information in cognitive channels. As a result, the mind has difficulty concentrating and selecting the information it needs. Bear et al. (2002) give the example of a person trying to read a book in the middle of an urban, bustling, noisy square. The person will certainly have information losses in reading, as their auditory canal receives irrelevant information overload.

Considering such brain activities and cognitive processing capabilities can bring relevant contributions to the development of educational resources. For example, some studies use electroencephalography for the analysis of pathological problems, development of applications and technologies for people with physical disabilities and classification of learning objects according to the level of attention (Viveiros & Camargo, 2014; Spindola, 2010; Velloso & Pereira, 2014).

Quintanilha (2017) writes about approaching strategies with Generation Z, people born in the 1990s and who entered university from 2010 onwards, reinforcing how important it is that educators renew their teaching methods. The article shows Facebook as a communication channel and Youtube® as a channel for sharing video lessons students themselves developed and concludes that students strongly adhere to the methodology that involves technological resources, which leads the researcher to reflect on the need for quality content for them.

Given the above, we begin our research by asking: “Does a video lesson using an animation developed based on the cognitive theory of multimedia learning promote positive effects on student learning in terms of retention and transfer of content?” We hypothesise that there is a gain in learning, i.e., producing multimedia instruction taking into account the student’s cognitive processing has positive effects on learning when considering the retention and transfer of content.

COGNITIVE THEORY OF MULTIMEDIA LEARNING

Based on experimental research results, Mayer (2009) discusses the cognitive relationships that occur during learning through an educational resource and subsequently infers on the improvement in cognitive processing after this resource adds the principles of his theory. These conclusions are based on retention and transfer tests that analyse the results of the experiments.

Mayer's theory originates from a study within cognitive psychology, considering Paivio's (1986) influence. Paivio (1969) shows that verbal information is processed differently from visual information and that verbal information is superior to visual information when the presented information sequence is required. Baddeley (1986) proposes working memory as a scheme in a block divided into two parts, illustrating Paivio's theory.

Mayer's studies (2009) proceed in the psychological-cognitive field based on the cognitive processing of the human mind through experimental tests that, by observing human behaviour and practical experiments, return data on the performance of an educational resource in learning.

Mayer et al. (2001) discuss the processing capacity in the visual and auditory channels, which, when receiving information, promote a selection of content. The authors conclude that when the student receives an image and a text equal to the narration in a multimedia presentation, their visual channel undergoes overload, impairing the selection of relevant content for the lesson. Therefore, when producing an animation, the importance of reducing or eliminating extraneous cognitive processing must be considered, such as removing unnecessary sounds and noise for the lesson, such as music, sound effects and other excesses, so that students can focus their cognitive channels on the relevant information.

Martins, Galego and Araújo (2017) analysed didactic videos produced in the biology course based on TCAM. In addition to comparisons on the most and least attended principles, the authors also noted that the lack of experience with the software made the production of the videos difficult.

In turn, Fernandes (2018) discussed practical means of applying TCAM principles to reduce cognitive overload in materials from the corporate environment, resulting in a material model that satisfies the principles of the theory, becoming a fundamental guide for instructional designers and content producers.

Concerned with the quality of the resource that will be made available to the teachers, Oliveira et al. (2018) evaluate and classify seventy educational software for science in elementary education, categorising them according to the learning theories redesigned in the research –although not based on TCAM– that are also concerned with the cognitive aspect involved in the software they presented. According to the authors' conclusions, they are significant improvements regarding product accessibility and compatibility.

With the support of TCAM, Santos, Silva, and Santos (2015) discuss multimedia learning in the initial education of physics teachers, analysing the multimedia materials produced in terms of the cognitive processing involved.

It is possible to find other discussions and studies involving the cognitive theory of multimedia learning as a basis for producing educational resources that respect the cognitive processing of the users and students involved (Cappelin, 2015; Koshiyama, 2016; Lopes, 2016). One can also find studies[2] involving comparisons between multimedia instruction that uses and the one that does not use TCAM principles.

According to Mayer's cognitive theory of multimedia learning (2009), a multimedia presentation can be produced using *words* (written texts, narration, etc.) and *images* (illustrations, films, animations, etc.), which may only be *words* or just *images*, or both, *words* and *images* together.

The student has two sensory receptor channels for this multimedia presentation: the eyes and the ears. Both channels can receive the *words*. In the case of written texts, they will be received by the eyes, and in the case of spoken texts (narration), by the ears. At that moment, a selection of information is converted into images and sounds and later organised in the student's mind, integrating them with their previous knowledge and creating new relationships.

The author explains the importance of using the two channels in an inter-complementary way to help during the learning process. His theory works for multimedia instruction to eliminate extraneous cognitive processing of content and evidence, manage essential cognitive processing, and promote generative cognitive processing to amplify positive knowledge retention and transfer results.

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[2] Mclaren, Mayer, and Forlizzi (2017) and Fiorella and Mayer (2016).

In neurosciences, an example of cognitive processing limitations is when one is in the middle of a large number of sounds, “and our brain must be capable of analysing the important sounds while ignoring the noise” (Bear et al., 2002, p. 371). In this way, by eliminating unnecessary noise and sounds from an educational resource that uses animations, videos and sounds, we help select the important sounds that our brain analyses. In this way, the student can concentrate more on multimedia instruction objectives, as Bear et al. (2002) discussed on the tonotopic organisation in the primary auditory cortex.

Regarding the relationship between Mayer’s cognitive theory of multimedia learning (2009) and the neurosciences, Bear et al. (2002) state that the visual and the auditory canal can perform *selective attention*. Using Mayer’s principles (2009) to reduce extraneous cognitive processing would facilitate this brain action in which the sensory channels would select the objective of the lesson.

According to Bear et al. (2002, p. 659), the brain receives all the information that reaches the sensory channels, such as the eyes and ears. However, it does not process all of them because “the brain simply cannot process all the sensory information that enters simultaneously ”. This statement is also used by Mayer (2009) when he mentions that the student’s cognitive system selects relevant information in multimedia instruction.

Mayer (2009) analyses twelve multimedia design principles for reducing extraneous processing, managing essential processing, and promoting generative processing, all based on experimental studies and grounded in a theory of how people learn from “words and images” through the dual channel.

MATERIALS AND METHODS

Initially, we selected two lessons: 1st) “How lightning is formed”; and 2nd) “How a manual bicycle tire pump works”.

Based on these animations, we began producing an adapted multimedia instruction using current resources.

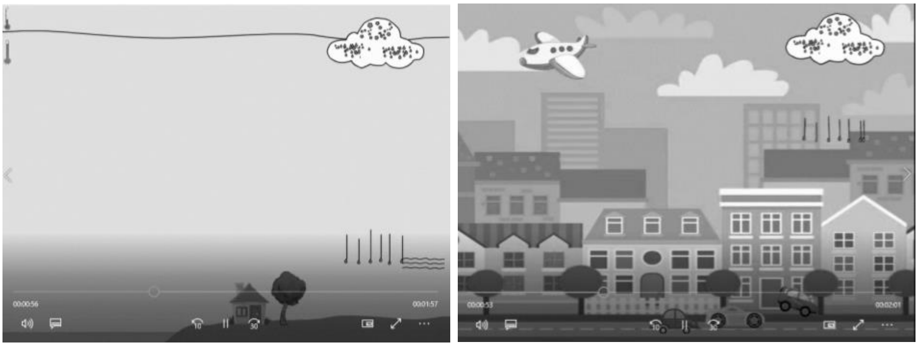
We created two animations on the formation of lightning. One of the animations followed the cognitive theory of multimedia learning principles, being clean and objective, according to Mayer’s (2009) principle of coherence and redundancy. We did not add excessive graphic elements or sounds to avoid cognitive overload (Figure 1a).

The events in this animation used the student's two cognitive channels, eyes and ears, in a complementary way, per the multimedia principle. The events happen according to a narration in a synchronised way (principle of temporal contiguity). There is no caption on the screen. Instead, the narration is done with a friendly human voice (voice and personalisation principle) and the keywords spoken in the narration are highlighted on the screen (signalling principle). This animation (Figure 1a) can also be called "clean lightning animation" to understand the survey better.

We produced a second animation with a narration of how lightning happens. However, this second animation sought to contradict the principles of the cognitive theory of multimedia learning by looking for elements that would cause students' cognitive overload.

Figure 1

Animation about how lightning forms, produced for the experiment: a) "clean lightning animation": following the principles of the cognitive theory of multimedia learning; b) "dirty lightning animation" with cognitive overloads that do not follow the principles of the cognitive theory of multimedia learning. (Based on Mayer, 2009)



a) b)

Figure 1b shows a frame of this second animation with cognitive overload. Excessive graphic elements and movements were added to the animation to divert the student's attention. We also added city traffic noise, the movement of cars and planes, and narration with a machine voice out of sync with the events of the animation. During the animation, students hear a crash with a passing car. Some elements were removed, such as the freezing point line in the sky and the temperature markers. Even with the same narration and with the main elements of “clean animation”, this overloaded animation seeks to show that such excesses harm attention. This animation (Figure 1b) can be called “dirty lightning animation”.

In the same way as the lightning lesson, we created two animations to address the operation of a pump to inflate a bicycle tire, one of them per the cognitive theory of multimedia learning (Figure 2a), which can be called a “clean tyre pump animation”, and another video with an animation containing cognitive overloads (Figure 2b), which could be called “dirty tyre pump animation”.

The “clean” animation of the pump (Figure 2a) was produced in a simple, clean way, in which the student can see the mechanisms involved, the movement of the valves and the piston, and the behaviour of the air when the handle is pulled or pressed. When the narrator, in a human and friendly voice, mentions essential keywords in the lesson, they are indicated in texts on the screen, also respecting the principle of temporal and spatial contiguity.

In the production of the “dirty” animation of the pump (Figure 2b), irrelevant elements were added in the narration with an excess of information and a graphic with many visual elements so as not to help in understanding the mechanism.

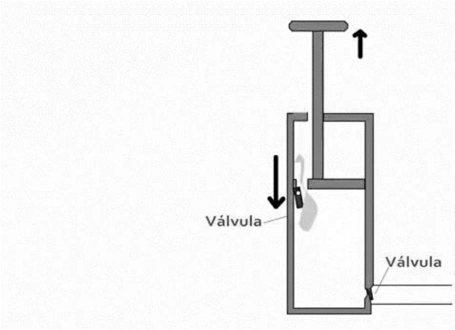
In this one, characterised as “dirty”, the student cannot visualise the pump mechanism, which is described by the narration and essential for the lesson. There is only one bicycle with an image in the background, without movement but full of details, which seeks to divert the student’s attention for a few moments. There is no synchrony between the narration and the movement of the handle on the tire pump.

Another strange processing factor added is the interesting but irrelevant subjects told by the narrator in the middle of the lesson; that is, the explanation about how the pump works is interrupted by a curiosity about the use of flat tires in certain situations, for example, by cars on dunes.

Figure 2

Animation about the operation of a bicycle tire pump: a) “clean pump animation”: following the principles of the cognitive theory of multimedia learning; b) “dirty pump animation” with cognitive overloads without

following the principles of the cognitive theory of multimedia learning.
(Based on Mayer, 2009)



a) b)

The videos were then allocated to a storage platform, becoming limited-access online material for the experiment.

After we created the videos with the animations, we prepared the materials for the pre-tests and post-tests to generate data for analysis.

The pre-test on how lightning is formed was printed on the front side of an A4 sheet. This pre-test was completely anonymous, i.e., each participant was identified only by a number in the corner of the sheet. This form contained the following information: Gender: a) Male, b) Female; Age: a) Under 18 years old, b) Between 18 and 25 years old, c) Between 26 and 35 years old, d) Between 36 and 45 years old, e) Over 45 years old. In the sequence, the students were asked to score, on a 1-5 scale –with 1 for "I know very little" and 5 for "I know a lot"– the statements: a) "I can tell the difference between a cumulonimbus and a cloud", b) "I know what a low-pressure system is", and c) "I know what an electrostatic discharge is". Finally, there is a discursive question: "Write an explanation about how lightning is formed".

This pre-test analyses students' prior knowledge and gives them an idea about the topic covered in the class and the videos.

The post-test was a double-sided sheet with the following questions from Figure 3:

Figure 3

Post-test questions on lightning formation. (Mayer, 2009, p. 38)

Retention Test *Write an explanation of how lightning forms.* **Transfer test** *What makes lightning have a low intensity?* *Suppose you see clouds in the sky but no lightning. Why not?* *What does air temperature have to do with lightning?* *What causes lightning?*

For the lesson on how the pump works to fill the tire, we applied an anonymous pre-test like the previous one, which, besides the questions about the participant's profile, asked: *Write a detailed explanation of how a bicycle tire pump works. Pretend you are writing to someone who doesn't know much about pumps*.

The post-test material for analysis of retention and transfer on the operation of the pump to inflate bicycle tires contains the questions in Figure 4.

Figure 4

Retention and transfer questions for the lesson on how to pump a bicycle tire. (Mayer, 2009, p. 48)

Retention Test *Write a detailed explanation of how a bicycle tire pump works. Pretend you are writing to someone who doesn't know much about pumps.* **Transference test** *What could be done to make a bicycle pump more reliable, i.e., to ensure it doesn't fail?* *Suppose you push down and pull a pump handle several times, but no air comes out. What could have gone wrong?* *What could be changed in the pump to make the pump more effective at inflating the tire, i.e. moving more air faster, filling the tire faster?* *Why does air get into a pump? And why does air come out of a pump?*

Ethics Committee

This research was duly approved by the Ethics Committee of the Teaching Institution (CEP of the Faculty of Medical Sciences at Unicamp) with CAAE number 66953617.6.0000.5404, opinion number 2.062.955 of May 15, 2017. We generated the informed consent term, in which the participants are informed about the research. Participation is voluntary, and signing the term is mandatory. Only participants who correctly completed and signed the term were included in the sample.

Experiment

After producing the animations, we visited the classes of 64 undergraduate students enrolled in the first and third years of pedagogy and degree in mathematics at the State University of Campinas.

Regarding the characteristics of the 64 participants, 44 are women, and 20 are men, of which 52 declared to be between 18 and 25 years old, nine participants declared to be between 26 and 35 years old, two were in the range of 36 to 45 years old. One participant was over 45 years old.

Of the total of 64 initial participants, 16 are newcomers to the mathematics degree course, 16 are attending the third year, and 32 are newcomers to pedagogy.

The 64 students were separated into groups A and B to participate in two experiments. Participation was completely anonymous.

Group A was formed by the 16 mathematics degree students and the 16 first-year pedagogy students. Group B's members were the 32 of the third-year pedagogy class. Thus, both groups had 32 students.

Experiment 1

Experiment 1 has two parts and was carried out with students from Group A. Each student in this group initially received a pre-test on how lightning is formed.

We handed the pre-test sheet, and the students had ten minutes to answer the first thing that came to mind. Time was necessary for the student to put their knowledge on the sheet after brief reasoning.

After ten minutes, we collected the pre-test. Then, the students in Group A watched the 2' 54" video (Figure 1b) with the animation with the "dirty" narration (with cognitive processing overload) about lightning, contradicting the principles of Mayer's cognitive theory of multimedia learning (2009).

Once the video was finished, the students received the post-test to assess retention and transfer after receiving the multimedia instruction.

Students had a longer time to answer the post-test – 15 minutes. After the pre-established time, the post-tests were collected and thus, this first part of Experiment 1 was closed.

The second and last part of Experiment 1, done right after the first part, was shorter and consisted of the same sequence as the previous one but with a lesson on how a pump works to inflate a bicycle tire.

The students in Group A then received the pre-test on how the pump works to inflate a bicycle tire. The student should always write the same identification number in all the tests so that later we could gather them for analysis without mixing up the answers.

Students had ten minutes to answer this pump lesson pre-test question. When the time was up, we collected the tests and screened students for the 30-second animation (Figure 2a) with "clean" narration (without cognitive overloads) about how a pump operates to inflate a bicycle tire. After watching the video, students had another 15 minutes to answer the post-test for analysis of retention and transfer.

When the time finished, the post-tests on the operation of a pump to inflate a bicycle tire were collected, and, in this way, Experiment 1 was closed.

Experiment 2

Experiment 2 involved Group B. The procedure and sequence were the same as in Experiment 1, with the same answering times for the tests. The only difference is that in Experiment 2, there was an inversion. First, the students watched the "clean" animation about lightning formation (Figure 1a), and then they watched the "dirty" animation about how a pump works to inflate a bicycle tire (Figure 1b). As already explained, the pre-tests and post-tests for each lesson were the same as in Experiment 1.

We defined the keywords for qualitative analysis of lesson retention tests. We defined the eight keywords in the two videos for the lesson on how lightning happens. Both in the "dirty" and the "clean" animation, the keywords were: 1. Hot air rises (updrafts); 2. Water condenses; 3. Water and heavy ice crystals fall; 4. Downdrafts, downdraft wind; 5. Negative charges at the base of the cloud and positive ones at the top; 6. Charges are close to the ground; 7. Negative charges descend; 8. Positive charges rise.

For the lesson on the operation of a pump to inflate a bicycle tire, we defined the ten keywords in the video lessons: 1. The handle is pulled up; 2. The piston moves up; 3. Inlet valve open; 4. Outlet valve closes; 5. Air enters the cylinder; 6. The handle is pressed; 7. The piston moves down; 8. Inlet valve closes; 9. Outlet valve opens; 10. The air comes out through the hose.

We tried to identify these keywords in the questions referring to the retention tests in the groups. In other words, the videos conveyed this information in the narration together with the animation. If relevant information from the video was retained, we would identify the keywords in the student's written answer.

Thus, we created an electronic spreadsheet to tabulate the data and facilitate the scoring of the qualitative analysis to count the number of mentioned keywords. In the worksheet, each line corresponds to the answer sheet of a participating student, and each column corresponds to the keyword of the retention test. Part of this worksheet is illustrated in Table 7.

After organising the worksheets for data tabulation, we started analysing the results.

After applying the experiments, we organised the groups' written pre and post-tests for the first analysis of the written results. First, some tests were discarded, according to some criteria: 1-Most blank answers; 2-Badly completed and illegible, or with answers like "I don't know" in most of the questions in the post-tests, demonstrating the participant's low commitment to watching the animation; 3-Incomplete participation in the experiment, i.e., the student participated in the first lesson but did not participate in the second lesson, which impairs the complete analysis; 4-Superficial participation in one of the lessons, showing a lack of interest, leaving most answer unanswered or poorly answered; 5-Student participated, but did not hand in the consent form correctly completed.

Table 7.

Part of the initial spreadsheet created for tabulating the data analysed from the post-tests of the lessons..

Exp Group A ("DIRTY" lightning video and "CLEAN" pump video) - 24 reviews	Pretest (score from 1 [knows little] to 5 [knows a lot])				Posttest - Retention (Lightning)
	Prior Knowledge Questions				
	You know the difference between a cumulonimbus and a cloud	You know what a low pressure system is	You know what electrostatic discharge is	You know how lightning is formed	Hot air rises (updrafts)
Exp Group A ("Dirty" lightning video) - 24 reviews					
PTR 32	1	3	2	2	1
PTR 33	1	1	1	2	0
PTR 35	3	3	3	4	1
PTR 36	1	1	2	0	1
PTR 37	1	1	3	3	0
PTR 38	1	2	2	0	0
PTR 39	1	3	2	1	0
PTR 40	1	2	3	3	0

Table 8 shows part of the colours and organisation of the post-test worksheet for the lesson on how to pump a bicycle tire.

Table 8

Part of the post-test analysis worksheet on the operation of a bicycle tire pump.

the handle is pulled up	the piston moves up	inlet valve open	outlet valve closes	air enters the cylinder	handle is pressed
Exp Group B ("Dirty" pump video) - 24 reviews					
1	0	1	1	0	1
0	0	0	0	0	0
0	1	1	1	1	0
0	0	0	0	0	0
1	0	0	0	0	1
0	0	0	0	0	0

After the initial exclusions in each group, considering the exclusion criteria adopted, we tried to equalise 24 students in each group, totalling 48 final participants in the sample. We sought this equalisation through the d-Cohen calculation formula, which “can be used when the study covers two samples with independent, same-size groups” (Brum & Previdelli, 2016). Also, the d-Cohen “was designed to be used when the scores of the two populations being compared are continuous and normally distributed” (Lindenau & Guimarães, 2012).

The post-test forms, handed after the students receive the multimedia instruction, analyse whether the excess of cognitive processing in a video impairs the understanding of the lesson, negatively interfering in the retention and transfer tests.

As shown in Tables 2 and 7, each keyword received a colour to facilitate the analysis of the answers.

When reading a post-test answer sheet, if the participant mentioned one of the keywords, that part of the sentence was highlighted with the corresponding colour on the worksheet, and the participant scored 1 on that keyword; if any keyword had not been mentioned, the participant received a score of 0 on the worksheet.

As explained by Mayer (2009), the student did not need to write the same keywords. So, for example, if the student wrote “the lever is pulled”, researchers may consider that they said “the handle is pulled up” and score it.

Figure 5 shows an answer from one of the participants in the post-test about the operation of a bicycle tire pump, i.e., after receiving the multimedia instruction. Note that the text was highlighted with colours for each keyword for the student to receive the score.

Answers accepted by the researcher are somewhat subjective but must be based on coherent conclusions. Two researchers reading the same answer may have different insights but may agree on what is acceptable.

Mayer (2009) specifies what is within the “acceptable”. For example, acceptable answers to the second question on the lightning lesson transfer test, about one seeing clouds in the sky but no lightning, include answers such as “the top of the cloud may not be above freezing level” or “no ice crystals formed”, remembering that the student does not need to write the answer in the way the researchers expect, i.e., literally. Common-sense answers in transfer tests are discarded, such as “using a lightning rod or not being under a tree” or, in the case of the tire pump lesson, “using an electric pump”. The students’ answers should show knowledge learned from the lesson attended; otherwise, they would not be counted as acceptable answers. In the readings and transfer tests, according to the questions and answers, the researchers decide what is acceptable or not, scoring the participant.

Figure 5

Image of a section analysed in a post-test on the operation of a bicycle tire pump.

1- Escreva uma explicação com o máximo de detalhes sobre como funciona uma bomba de pneus de bicicleta. Finja que você está escrevendo para alguém que não sabe muito sobre bombas

- Quando o bastão é empurrado para cima a válvula de entrada abre e a válvula de saída fecha, permitindo que o ar entre na ponta. Quando o bastão é pressionado para baixo, a válvula de entrada fecha e a de saída se abre para que o ar possa ir para dentro do pneu.

The typed pre and post-tests of all 48 participants in the final analysis sample –Group A and Group B– were analysed by two volunteers, guest research professors from different areas, who received an explanation about the research, materials and methods, and analysis criteria. After understanding the scoring process, the research professors received five randomly defined survey sheets. According to Mayer (2009), more than one researcher must analyse the data because it is not a question of being biased-free but reducing the probability of errors with a peer review procedure. After the other researchers verify the data, if they disagree about the assigned scores, they talk to each other to settle the matter.

In research involving content analysis, this discussion between peers or other researchers is often used to ensure the information was analysed qualitatively, also called external validation, which is important to clarify the analysis tools (Bardin, 1977).

RESULTS

After tabulating all the data and scoring the participants’ responses, we calculated the effect size variable.

The effect size or strength is used to compare two independent samples. Other types of measure are Hedges′s g and Glass′s Δ. There is a brief description of this subject in Lindenau and Guimaraes (2021):

> The most basic estimate of effect size in independent sample comparisons is the difference between means. However, comparing means without considering the variability of the data from which the means were calculated can hide important effect properties (p. 364).

Based on Cohen (1988), the effect size (d) is calculated by subtracting the mean score of the groups and dividing by the standard deviation of the groups, used for continuous distributions and normal.

$$d = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{(n_1-1)\cdot s_1^2 + (n_2-1)\cdot s_2^2}{n_1 + n_2}}} \qquad \text{(Equation 1)}$$

In Equation 1, also described by Lindenau and Guimarães (2012), we have that $\overline{x_1}$ and $\overline{x_2}$ are the means of the groups; s_1^2 and s_2^2 are the sample variances of the groups; and n_1 and n_2 are the sample sizes of the groups.

The effect size tells us about the improvement in standard deviation achieved by implementing a specific feature. The effect size score, according to Mayer (2009, p. 54), “is useful when we want to examine a set of experimental comparisons that used different materials and tests because it allows us to use a common metric”. It would be as if we were evaluating how much the standard deviation of a group improved in relation to the other group.

Thus, after calculating the effect size according to the tabulated data in the groups, I could construct the following tables summarising the data:

Table 7

Summary of the results of the multimedia instruction on “how lightning forms” tabulated in the experiments.

	Lesson on “How lightning is formed” RETENTION TEST (total of eight possible points)				
	Mean	**Variance**	**Standard deviation**	**Total of participants**	**Effect size**

Experiment 1 (with cognitive overload)	3.04	4.22	2.05	24	**0.33**
Experiment 2 (no cognitive overload)	2.46	2.09	1.45	24	
	TRANSFER TEST (total of four possible points)				
	Mean	**Variance**	**Standard deviation**	**Total of participants**	**Effect size**
Experiment 1 (with cognitive overload)	1.79	1.13	1.06	24	**0.31**
Experiment 2 (no cognitive overload)	1.50	0.70	0.83	24	

Table 8

Summary of the results of the multimedia instruction on "the operation of a bicycle tire pump" tabulated in the experiments.

	Lesson on "the operation of a bicycle tire pump" RETENTION TEST (total of ten possible points)				
	Mean	**Variance**	**Standard deviation**	**Total of participants**	**Effect size**
Experiment 1 (no cognitive overload)	5.75	3.76	1.94	24	**0.58**
Experiment 2 (with cognitive overload)	4.58	6.17	2.48	24	
	TRANSFER TEST (total of four possible points)				
	Mean	**Variance**	**Standard deviation**	**Total of participants**	**Effect size**
Experiment 1 (no cognitive overload)	1.92	0.86	0.93	24	**0.55**
Experiment 2 (with cognitive overload)	1.42	0.86	0.93	24	

In the multimedia lesson on "how lightning is formed", the retention tests scored 0.33, and the transfer tests scored 0.31. In the "operation of a pneumatic pump" experiment, the effect size results were 0.58 in the retention tests and 0.55 in the transfer tests.

According to Espírito-Santo and Daniel (2017, p. 58),

> Cohen (1988) established one of the most used classifications: "Large" from 0.50 to 1.00, "Medium" from 0.30 to 0.49, and "Small" from 0.10 to 0.29. If you prefer a more detailed classification, you can resort to Hinkle, Wiersma, and Jurss (2003): 0.90 to 1.00 "Very high"; 0.70 to 0.90 "High"; 0.50 to 0.70 "Moderate"; 0.30 to 0.50 "Low"; 0.10 to 0.30 "Very low". All guidelines apply to both positive and negative correlations.

That is, "the higher the effect size, the greater the impact that the central variable of the experiment is causing, and the more important becomes the fact that it contributes to the question under analysis" (Lindenau & Guimarães, 2012, p. 377). But would 0.8 be higher than 0.2? This issue is widely discussed in the literature, according to Lindenau and Guimarães (2012, p. 376), "since a consensus has not yet been reached regarding what can be considered a large effect size and what can be considered a small effect size".

According to Cohen (1988), we must compare our effects with those previously established within our area of investigation. "Getting an effect of 0.5 when typically observed values are 0.2 could mean an important effect. On the other hand, obtaining a value of 0.7 when normally observed values are 0.9 may mean this effect is not important" (Lindenau & Guimarães, 2012, p. 376).

Mayer (2009) mentions that when there are experimental comparisons of the same instructional method, the concentration is on the size of the medium effect. "When the medium size of the effect is large – or even medium– we have reason to believe that the instructional method is effective for educational practice" (Mayer, 2009, p. 54, our translation)

FINAL CONSIDERATIONS

We must understand how learning happens and the adverse effects that multimedia instruction with cognitive overload can cause, as discussed by Harp and Mayer (1998), who investigate how "seductive details" added in a lesson can harm students' cognition. In four experiments, the authors concluded that added information irrelevant to the objective of the lesson interferes with learning, impairs the organisation of the content, and distracts the student. We can relate this interference to the research results that reveal that the animation with the most over-processing and seductive details was the least effective.

This research also demonstrates a positive gain in cleaner and more direct multimedia instruction, without cognitive overloads, respecting the principles of the cognitive theory of multimedia learning. Mayer et al. (1996) discuss "When Less is More" about visual and verbal summaries, in which experiments showed that evidence of the main ideas of the lesson in a straightforward way was effective for the retention of relevant content. A clean and objective lesson provides more significant benefits for content retention and transfer, as shown in the most promising results on effect size values for the "clean" lesson.

Moreno and Mayer (2000) study the effect of coherence in multimedia learning on the argument to minimise irrelevant sounds in multimedia instruction. The experimental groups that received the multimedia lesson with sounds and background music performed worse in the tests, reinforcing the idea that an excess of unnecessary sounds can overload the auditory system, as predicted in the cognitive theory of multimedia learning. This same parameter is found in our experiment, in which we added irrelevant sounds and sound effects in the multimedia instruction with cognitive overload.

Therefore, the results reinforce the hypothesis of coherence and that the development of multimedia instruction must seek to reduce extraneous cognitive processing, i.e., the excesses, the noise, the management of the necessary processing in which multimedia instruction helps organise and select relevant content and promote generative processing, the knowledge transfer process, i.e., increasing the possibility that multimedia instruction will assist in student learning.

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AUTHORSHIP CONTRIBUTION STATEMENT

RRS conceived the research idea presented guided by SRO. RRS collected the data. RRS developed the theory and methodology, and data organisation and analysis. SRO proofread the additions and subtractions, participated in the discussion of the results, and approved the final version of the work.

DATA AVAILABILITY STATEMENT

The data that support the results of this study are only available for consultation in the Unicamp Digital Library collection via https://hdl.handle.net/20.500.12733/1639299, but cannot be reused.

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