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# Evaluating multimedia learning materials in primary education using eye tracking

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ABSTRACT

The development of multimedia educational materials aimed at primary school students is of great importance today. The design, mainly of images and text, can influence the efficiency of these materials in the teaching-learning process. One of the most widespread theories that deals with the correct design of multimedia materials is the Mayer's Cognitive Theory of multimedia learning. In this research work we are interested in validating some of the principles enunciated by this theory in materials aimed at primary school students (children aged seven and eleven) and in the field of geometry teaching. For this purpose, we performed four experiments using the *eye tracking* technique in the data collection process. Using *eye tracking*, we can analyze how the process of the visual observation of multimedia contents is produced. The main contribution of this study is the proposal for the use of this evaluation method, which allows us to validate empirically and objectively (physiologically) aspects such as the comprehension process of multimedia content, the attention of the students while analyzing the information provided or the cognitive load of the supplied materials. Faced with questionnaires or surveys, which have been used traditionally to analyze the efficiency of multimedia materials and have a more subjective nature, *eye tracking* provides information not consciously controlled by the students. Its use is a particularly interesting and useful source of information in the case of children, allowing us to collect information on their interests and preferences, which is more difficult to obtain using traditional techniques.



## 1. Introduction

Current technological advances have opened up a huge world of possibilities for teachers at all levels and in every field. The use of technology in the classroom can enhance student learning and make it possible for teachers to create attractive and versatile teaching electronic materials providing information in the form of text and images, moving graphic elements as well as synchronized verbal information.

Multimedia can be described as "the combination of various digital media types such as text, images, sound and video, into an integrated multisensory interactive application or presentation to convey a message or information to an audience" [1]. The use of multimedia resources and materials is becoming more common in education, offering several intervention possibilities in the teaching and learning processes of students. Technological improvement makes possible the combination of different ways of presenting verbal information (for example oral narration and on-screen text) with non-verbal presentations (graphics, videos, animations and sounds) on just one device [1,2]. When designing a multimedia presentation including contents of different natures such as texts and illustrations, it is very important to take special care that they are presented in a correct format and that the configuration allows for focusing attention to the main elements in the presentation, which will improve the general comprehension by students. When images on a screen are shown, it may be difficult for students to determine which parts have a high value of information, and in turn deserves special attention, and which ones are irrelevant, and can therefore be ignored. Thus, when creating multimedia resources and materials, it is very important to pay special attention to the design, format and configuration of the content shown.

Among the different educational levels, our focus is on the design of multimedia learning materials targeted at primary school students. At this level, one of the disciplines that involves major difficulties for students is to learn mathematical concepts [3–5]. In this sense, there have been ongoing efforts in the study of the design of effective teaching materials and resources for mathematics courses [6–10]. Teachers often use visualizations (graphs and diagrams) in order to enhance students' mathematical thinking, such that the potential of using visual repre-

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sentations are recognized as part of the mathematics learning [11–13]. For this reason, research has been recently carried out on presentation methods in mathematics teaching focused on testing different visualization methods such as pictures, two- and three-dimensional animations, in order to find the most appropriate and the most understandable ones [14–16]. In mathematics teaching, it is necessary to combine the picture method and the definition method in order to improve the existing knowledge and to enlarge it with the new facts, which is one of the points of the *cognitive theory of multimedia learning* [17]. Therefore, multimedia offers remarkable opportunities and challenges for mathematics teaching [18,19]. The approach of modern multimedia methods to learning includes a range of different possibilities applicable in mathematics lectures for different levels of education and with different levels of interactivity [12,20–22]. This technology can help students to establish solid thinking, combining various senses, which helps students to better understand the knowledge. The possibility of integrating a variety of media sources (such as words, graphs, sound and visuals) results in an improved ability to present abstract or complex concepts with increased student comprehension [23–25]. Furthermore, recent studies indicate that multimedia in mathematics teaching could create a more motivating, interesting and stimulating teaching atmosphere [26]. However, although researchers have committed substantial effort to designing innovative learning environments and examining their impact on how students learn mathematics [27], many challenges remain, such as fully understanding how students perceive and process a variety of representations embedded in these complex learning resources [28].

And, within the domain of mathematics, the geometry teaching/learning presents particular features and difficulties [29,30]. Geometry is the branch of mathematics in which the visualization is one of the most essential elements for understanding presented definitions and theorems, as well as for solving the given tasks and problems [31–33]. Results of research on geometry teaching emphasizes the importance of visualization in the intuitive understanding of geometry [34,35]. For this reason, over the last few decades, computers and multimedia tools with a high capacity of visualization have become more popular in geometry teaching and learning [20,36,37]. Thus, geometry teaching can benefit from the use of multimedia content in which text and illustrations are combined [38].

Among the main design recommendations of multimedia content (on the combined use of text and images), we find the principles of the multimedia learning proposed by Richard Mayer [17,39,40] together with some Gestalt principles [41]. The recommendations by Mayer are based on the way people assimilated the information given. Depending on the design and the format of the verbal information and images presented, content assimilation can be improved or on the contrary, an unnecessary cognitive load can be added [42]. In particular, we will analyze four of the principles of multimedia material design proposed by this author. The first one is the *Spatial Contiguity Principle,* which states that people learn better when corresponding words and pictures are presented near, rather than far from each other on the page or screen. In the same line of thinking, we found the *Proximity Principle* of Gestalt, which postulates that elements tend to be perceived as aggregated into groups if they are near each other [41]. The *Modality Principle* will also be analyzed, which states that people learn better from graphs and narrations than from animation and from on-screen text. Finally, the *Redundancy Principle* suggests that people learn better from graphs and narrations than from graphs, narrations and text on a screen.

Hence, the objective of this research is to analyze the compliance of this set of recommendations or guidelines for the design of multimedia educational materials in the field of geometry teaching and in materials aimed at primary school students. In this sense, there has been a recent growing interest in the use of neuroscience methodologies in research in the educational technology field, in general, and in mathematics learning, in particular [42,43,44,45]. One of these techniques is *eye tracking*, which has been applied to multimedia learning assessment over the last few years [46–51]. The *eye tracking* technique has been used in various fields, including advertising and evaluation of user interfaces and web pages [52,53]. However, there is a small number of studies that use this technique to evaluate content used in the earliest stages of education. The incorporation of *eye tracking* can be an ideal complement to the use of other classic techniques to collect data, such as questionnaires or interviews [54,55], which have traditionally been used to analyze the efficiency of multimedia materials. The potential of incorporating this additional source of information is in its objective nature. Faced with questionnaires or surveys, which have a more subjective nature, the *eye tracking* technique provides information not consciously controlled by the students [56]. Additionally, its use is a particularly interesting and useful source of information in the case of children, allowing us to collect information on their interests and preferences, which is more difficult to obtain using conventional techniques.

We can find previous studies that focus on investigating the effects of the aforementioned Mayer's multimedia learning principles in design, such as the *Spatial Contiguity Principle* and *Modality* one, in adults or young adult participants [2,57] and in children of similar ages to the participants of this study [58]. There are also other studies focused on the problematic process of mathematics and geometry learning [5,29,58]. Nevertheless, these works do not use an objective technique like *eye tracking* [39] as it will be done in the research described here. Nemirovsky [59] indicates that "the understanding of a mathematical concept, rather than having a definitional essence, spans diverse perceptuo-motor activities". Considering this idea, ongoing research in neuroscience, psychology and cognitive science can generate new insights into the nature of thinking in educational research and in the study of mathematics learning [60].

In this line of action, we can find some recent works that have applied *eye tracking* for assessment in science learning in the literature [48,61,62]. Related to mathematical domain, in [63] authors analyze the way students read mathematical texts (composed of formulas, graphs and plain text). However, the sample that was analyzed was of university students. Other studies at this educational level (young adults and university students) can be found in [64–69], which analyze the relationship between *eye tracking* metrics and the efficiency of the participants in equations and fractions resolution. Also, some researchers have applied *eye tracking* in the field of geometry. In [70], the authors used this technique to analyze the relationship between perceived difficulty, eye movements and cognitive load [71,72] associated with trying to comprehend specific areas (diagrams and texts) in geometry problems. In this case, the participants were high school students (of 14–15 and of 17–19 years of age). Finally, in [73], authors analyzed eye movements during geometry problem-solving activities using handwriting devices. All participants were again between the ages of 17 and 19.

There are fewer works that make use of the *eye tracking* technique to analyze the resolution of mathematics tasks by younger children. In [74], children of 11–12 years of age participated, and the *eye tracker* was used to record the geospatial visualization ability of the students and to compare the difference between the spatial abilities of both, students and experts. In [75], children of 6 to 9 years of age participated. This time, authors tested the validity of eye movement data for investigating developing number sense and estimation competence of the children. Finally, in [76], authors explored the use of *eye tracking* technology in the investigation of the way in which young children (9–10 years old) view and interpret the mathematical representations of multiplication. As we can see, there are no recent works that analyze the visual behavior of children as they try to comprehend geometric concepts.

In this research work, and with the aim of validating empirically the aforementioned multimedia design principles in Primary Education, we conducted several empirical studies using *eye tracking*. This technique lets us infer information about the attention and behavior of the visual exploration of users. By using an *eye tracker* device, we can record the so-called *fixations* (or points of gaze stabilization) that an individual generates when they look at content displayed on a screen. From such fixations we can obtain a large number of metrics associated with