Research Article

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Interactive Mind Map: A Model for Pedagogical Resource

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Abstract: This paper presents an extension of the mind map pedagogical tool, a conception in which the mind map becomes interactive and dynamic. We took advantage of all the mind map's learning potential and benefits, and we add new ones when we propose the interactive mind map tool. We develop a model in which the teacher would have an authoring tool for creating a mind map with its elements, relationships, and interactive content related to each map element. The proposed tool is rich media, as it incorporates different types of media, allowing it to reach students with different learning profiles and needs. Furthermore, the technological aspect brings the school closer to the student's reality.

Keywords: Mind Map; Interactive Applications; Technologies in Education.

1 Introduction

We live in a digitally integrated world, and we are immersed in countless technologies through which we deal with an immense amount of information. Viewing, processing, filtering, and storing all this information is a challenge, given its growing dimension. The data visualization area emerged to deal with many problems arising from the volume of data we manipulate in our daily lives, providing objective and intuitive visualization techniques.

In the educational context, data visualization can assist with techniques for a clean, friendly, and dynamic visualization of learning content. Considering that online learning environments employ very linear learning materials, usually a transcription of conventional materials for the web environment, without properly exploring the pedagogical potential of technologies.

This work proposes using data visualization techniques to create a new approach for the mind map pedagogical tool, a new conception, a technological extension in which the mind map becomes interactive and dynamic. It is a model for developing an authorial tool in which the teacher can build interactive mind maps as pedagogical resources for study contents, which apply to several areas of learning.

In this context, we take advantage of all the pedagogical potential already established by mind maps and add new features afforded by data visualization techniques, such as interactivity, visualization in blocks, and use of rich media (composite media). An adequate data visualization technique can contribute to a minimalist and fragmented layout, avoiding the user's cognitive overload, according to Sweller's theory (Sweller, 1988). It can also contribute to an interactive interface that promotes student activity and favors student engagement. According to Kalizhanova et al. (2020), when we combine technology with mind maps, we create digital maps, which we can use to promote the digital skills needed by today's society and seek an approximation with the student who experiences a technological reality.

The mind map is a pedagogical tool that can be applied for many purposes in the educational field, such as creative learning and active learning (Stankovic et al., 2011), to recall and connect previous knowledge (Farrand et al., 2002), to systematically organize information (Wu and Wu, 2020), to work on critical thinking (Rezapour-Nasrabad, 2019; Wu and Wu, 2020), in the construction of collective knowledge and collective learning (Stokhof et al., 2020), in the graphic display of information (Yang et al., 2020), and as motivation for learning (Wu and Wu, 2020), among others.

The mind map has the great advantage of making relationships between concepts more understandable and didactic through its representation. For Stankovic et al. (2011), the data visualization made possible by mind maps helps in greater integration between empirical

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and theoretical knowledge. Novak and Cañas (2006) explain that the mind map is flexible in its epistemological approach, and consequently, it also provides more flexibility in the teacher's methodology.

Therefore, considering the context presented, this work's great motivation was to use all the mind map potential to conceptualize a new dynamic and interactive learning tool that could break the learning environments' linear paradigm. Our objectives are: to present the uses and characteristics of mind maps, to conceptualize a new model of an interactive pedagogical tool based on mind maps, to demonstrate a prototype of the learning resource, and to develop a critical discussion on the benefits of mind maps and the advantages of our proposed model.

2 Theoretical Background

The concepts of mind map (Buzan, 1974) and concept map (Novak, 1977) are similar and often taken as synonyms. However, it is essential to carry out disambiguation. Due to the similarity of concepts, it is common for authors to address both theories in their publications (Davies, 2011; Eppler, 2006; Kokotovich, 2008). The next subsection will define, exemplify, and disambiguate these concepts.

2.1 Mind map versus concept map

The mind map is a concept created by Anthony Peter "Tony" Buzan in the 1960s. As explained by Eppler (2006), mind maps creatively represent sub-topics of a domain, employing icons, images, relations, following a flexible format graphic structure.

Buzan and Buzan (1994) explain that, initially, the mind map was developed with a view to facilitating the work of memory (note-taking activity). However, then they realized that creative thinking was another important application for the technique. Mind maps are powerful tools for thinking because they make it possible to sketch the main ideas and visualize quickly and clearly how they relate to each other. According to Buzan (2006), its conception is an alternative to the linear thinking of the brain as it reaches all directions and captures thoughts from different perspectives. The mind map usually structures the concepts in a network format, as seen in Figure 1 that illustrates a mind map used for teaching history.

The concept map was created by Joseph Novak in 1977 and differs in some aspects from the mind map because it is more systematic, and it is commonly associated with David Ausubel's cognitive learning theory (Ausubel, 2000). According to Ruiz-Primo and Shavelson (1996), a concept map is a structure that displays the relationships between sub-concepts related to the main concept and its manifestations (examples). Unlike mind maps, concept maps have pre-defined structures with boxes/bubbles with text and labeled connecting arrows.

The concept map is hierarchically organized with the most general and most inclusive concept located at the top, and the most specific and less general concept located at the bottom, as shown in Figure 2. On the other hand, the mind map does not have such a rigid structure, but the main topic is usually centered.

Novak and Cañas (2006) also accentuate the differences between mind map and concept map. They explain that concept map is based on an explicit cognitive psychology of learning and a constructivist epistemology. In contrast, the representation of the mind map does not necessarily have these characteristics. Concept maps are composed of relationships between concepts, established by connecting phrases, forming propositions that can be logically analyzed. Figure 2 shows an example of a concept map created with the CmapTools tool[1], developed at the Florida Institute for Human and Machine Cognition (IHMC), where Joseph Novak (creator of the concept map) develops his works to the present day.

For this work, we focus on the mind map for its graphic flexibility that allows working with different types of media and formats, for its epistemological flexibility, and the various learning characteristics explored in the next subsection.

2.2 Mind map benefits as a learning tool

The concept of mind maps has been applied in different areas of knowledge, such as medical education (Farrand et al., 2002), nursing (Rezapour-Nasrabad, 2019; Wu and Wu, 2020), biology (Kurniasih and Irpan, 2019), physiology (Vanags et al., 2012), economics (Lacurezeanu et al., 2018), early childhood education (Yang et al., 2020), languages learning (Kalizhanova et al., 2020), teacher training (Munoz Gonzalez et al., 2020), among several others.

The purposes of using mind maps in education are also varied. Kokotovich (2008) proposes to use mind maps to work with problem-solving and design thinking framework. He emphasizes the flexibility of mind maps as opposed to concept maps that, although they are free

1 Available at: https://cmap.ihmc.us

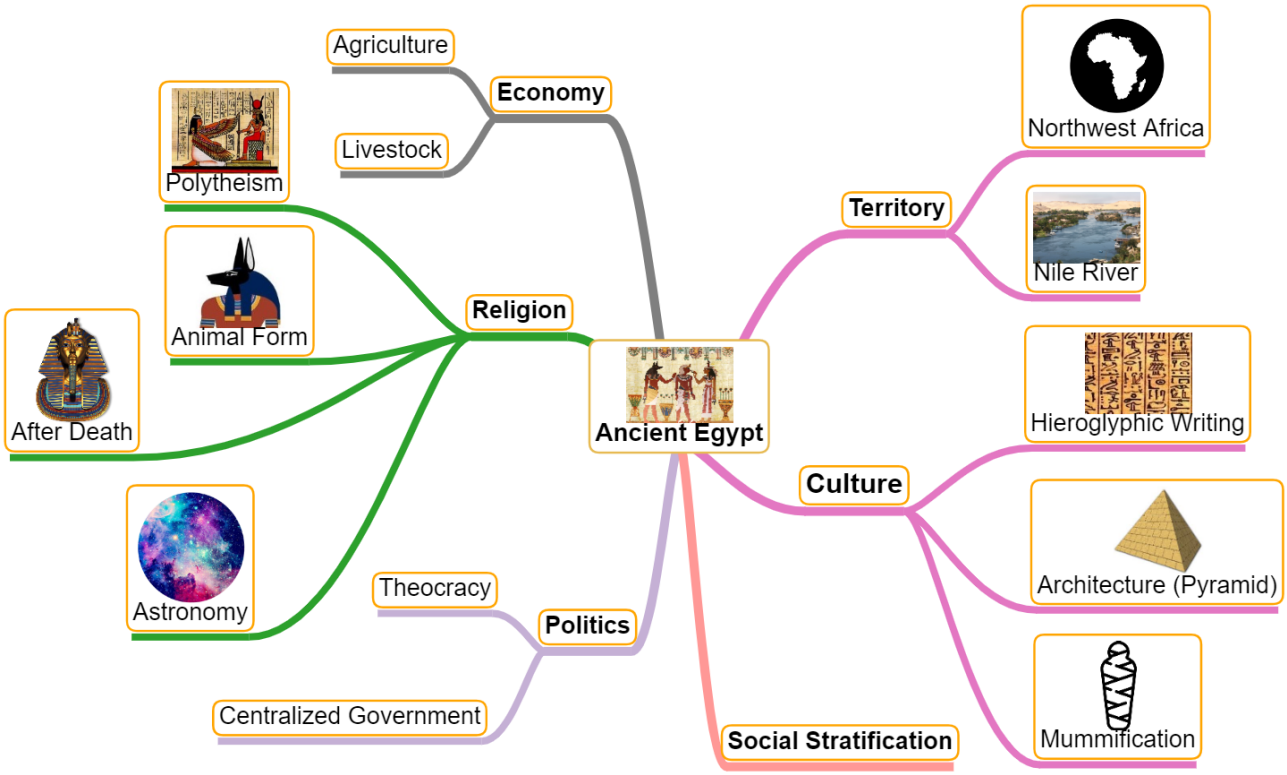

Figure 1: Mind map example about Ancient Egypt (History).

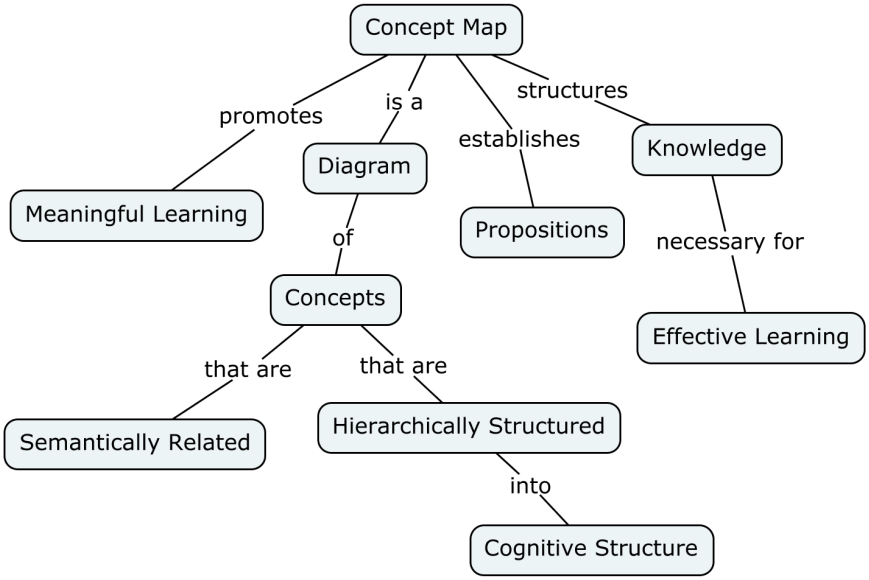

Figure 2: Concept map example.

to develop the links and, subsequently, the information related to the links, they limit how the graphical representations of the links can occur. Farrand et al. (2002) conducted a study with medical students showing that the use of mind mapping techniques significantly improve recall when compared to simple note-taking or rote rehearsal. Stankovic et al. (2011) say that mind maps help us to organize knowledge properly, and its visualization facilitates interpretation. They further state that the mind map stimulates creativity and promotes active learning.

During their experiment, students were more motivated when working with mind maps.

Michalko (2001) presents some advantages for the mind mapping technique: ordering thoughts, establishing relationships between information units, providing an overview of the subject, providing a clear view of the details, providing focus and concentration on a particular subject, group and compare concepts, transform a short-term memory into long-term memory.

Davies (2011) shows that one of the advantages of the mind map is its free form, without restrictions, as there are no limits to the ideas and the links that we can create. The author also comments on the use of the mind map for brainstorming and to promote creative thinking.

For Novak and Gowin (1984), the act of mapping is a creative activity in which the student strives to clarify meanings, identifying structures, concepts, and relationships within a domain of knowledge. Buzan and Buzan (1994) highlight creative thinking as one of the applications of mind maps. As seen before, the maps structure the concepts in a network format, breaking with the linear paradigm that is ordinarily standard in learning and creating a higher power of synthesis.

Lacurezeanu et al. (2018) point out the following benefits in its use as a learning tool: they help students visualize and express concepts, clarify relationships between concepts, develop relationships between different ideas, develop critical thinking and promote greater engagement in learning activities. Mind maps enable the representation of students' and teachers' understanding of knowledge and enable the joint and shared construction of knowledge between different authors.

2.3 Interactivity

Interactivity is a concept with broad definitions, and we adopt the Quiring (2016) definition. The author states that its first root comes from the term (social) interaction, which means mutual human actions, directed towards each other. Furthermore, its second root would be the subdiscipline human-computer interaction (HCI) from computer science. This subdiscipline focuses on mediated communication by human-machine interaction.

According to Quiring (2016), as nowadays, the interaction term has broadened to the relations between human beings, between human beings via technological systems, and between human beings and technological systems, in what follows the term interactivity is used to describe a quality that manifests itself within these relations.

Combining interactivity with the concept of mind maps enhances the advantages of the mind map technique as a pedagogical tool. According to Torres Diaz et al. (2015), interactivity, from a technical perspective, is one of the axes that integrate the future of learning. Patten et al. (2006) explain that the development of interactive applications allows constant student interactions with the tool, providing dynamic learning, and exploring creativity.

New digital media, such as the Internet, are increasingly integrating previous media, such as text, audio and video, and adding new components, such as interactivity. The result is richer media, as different media have different educational potentials. The interactive mind map proposal is precisely a composite media, a rich media because it aggregates different types of media (text, image, video).

2.4 *Data visualization*

Thinking about more dynamic and objective interfaces to deal with the large volume of information we currently work on is another issue involved in our conception. The visualization of contents through an interactive mind map seeks dynamism and objectivity. Therefore, one area that supported our proposal was data visualization.

The theory of data visualization is a relatively new field of knowledge, it had its origin in the 1950s, with an impulse from the end of the 1980s that continues to the present day with advances in computational power and increased volume of information we worked on, as explained by Post et al. (2003). Few (2013) defines it as the graphic display of abstract information for two purposes: data analysis and communication.

Data visualization aims to communicate information clearly and efficiently by using statistical graphs, plots, and graphical information, among other resources. Data visualization makes complex data more accessible, understandable, and usable, according to Aparicio and Costa (2015). It is a theory that involves a certain creative sense necessary to arrange the data for clean and objective reading.

2.5 A new conception for mind maps

This work's research problem was to investigate the potential of mind maps and discover how to add value to their representation through technology, making them more suitable for the digital environment.

Our work's more significant innovation is to propose using technology and visualization techniques to add interactivity to mind maps. In this way, we concept a new tool: the interactive mind map. The interactive mind map increases the tool's possibilities and makes it more dynamic and appropriate for digital media and new generations.

In the next sections, we will develop our methodology, discuss the mind map's concepts relevant to our work, and present a prototype and an implementation model to the interactive mind map.

3 Material and methods

The present work is a qualitative exploratory study in which we investigate the use of mind maps in education and propose to unite data visualization techniques to enhance mind maps' potential. According to Stebbins (2001), the exploratory findings are always hypothetical, so we created a model and a prototype to expose our hypotheses for better learning through a dynamic and interactive tool. Our research is divided into four stages:

1. The search for data visualization solutions for learning and the recognition of an existing demand;
2. A bibliographic survey of mind maps in education;
3. The search for features that could add value to a visualization-based educational tool;
4. The implementation model and a prototype to serve as a proof of concept to our proposal.

These steps will be detailed in the next subsections.

3.1 Demand and motivation

The demand for this work was identified, first, by raising data visualization solutions applied in education. We noted that little had been innovated in more generic solutions to meet a range of educational applications. There is much linearity in teaching, and innovative solutions are usually meant to fulfill a more specific purpose

Considering the work of Tavares et al. (2015), an interactive tool in a tree format applied to image processing but also used for didactic purposes, an insight emerged for the development of an interactive data visualization tool applied to teaching/learning. The choice for the mind map format was because this concept is an already consolidated pedagogical resource.

3.2 Survey of mind maps

To raise theories and previous works of mind maps in education, we searched on platforms Google Scholar and Web of Science. Web of Science is a commercial database widely used internationally, of a multidisciplinary nature and covering around 12,000 high impact journals (Chen et al., 2012; Pelicioni et al., 2018). Google Scholar is a free open-access database, which indexes papers available on the Internet (Falagas et al., 2008), expanding our search possibilities quantitatively.

We conducted a topic search in which the works should present the terms mind map and education. In the search filter, we also restrict the results to the last 20 years (from 2000 to 2020), papers from journals and conferences, books and chapters, and only works education-related.

After listing the articles, we performed a textual analysis. We sought to identify the area of knowledge involved, the type of application of the mind map, the benefits pointed out, and the particular mind map's characteristics each work enhances. Figure 3 shows the steps of the mind map survey methodology.

The theoretical background section addressed the fundamental concepts, applications, and advantages of mind maps in education found in our survey. However, in the Results and Discussion section, we will summarize and discuss the findings and highlight the ones that inspire our tool conception.

3.3 Data visualization research

In order to extend the potential of the mind map, we search for data visualization concepts and principles that could add value to our proposal. Interactivity was one of the key concepts that guided our research to think about a more dynamic education and promote active learning.

In our conception, the relevant media principles described by Mayer (2009) were also considered, among which are:

coherence (avoiding irrelevant contents next to the relevant contents);

signaling (people learn more when there is signaling of the organization of the content, its relationships);

- objectivity (avoid redundancy);
- spatial continuity (related issues are close);
- fragmentation (using short content, visual blocks);
- multimedia (use of rich and composite media).

These principles favor the construction of more objective and intuitive graphic interfaces.

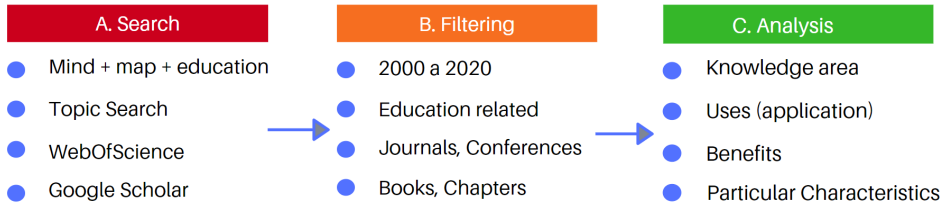

Figure 3: Mind map's survey methodology.

3.4 Model and prototype

We conceived a technological extension for the mind map. Then we developed an implementation model for it since this tool can be implemented in different learning environments and using different technologies.

A small interface prototype, representing a final interactive mind map available to students, was developed to elucidate graphic design issues and suggestions for the system's architecture and to serve as a proof of concept for our hypothesis.

It is important to emphasize that a detailed technical study to outline the technologies used in the system, its modules, and development phases can bring more efficiency to the implementation process. In order to develop the prototype for the tool, we adopt a development methodology based on prototyping. As explained by Sommerville (2010), this means that the tool has undergone successive increments until reaching the desired result.

In the next section, we present the model and the prototype and discuss our work's findings.

4 Results and discussion

Below we summarize the main findings of this study, which we will later develop with further details:

We performed a mind map survey in which we concluded that a mind map is a pedagogical tool with several applications and benefits that favors active learning, creativity, critical thinking, collaborative work, among others;

We concluded that it is possible to aggregate value on integrating the mind map tool to interactivity and technology, increasing the tool's potential and possible achievements. When integrated with technology, the mind map is a tool to promote the digital skills required in today's society.

We developed an implementation model and a prototype for the interactive mind map to serve as a proof of concept, which has confirmed our hypothesis of adding more advantages to the tool and bringing it closer to the student's technological reality.

4.1 Mind map's findings

Based on the bibliographic survey we carried out on the mind map, we developed a textual analysis of the articles seeking to identify the applications of mind maps, knowledge areas involved, benefits pointed out by the researchers and remarkable characteristics. This analysis brought us concepts we use as insight for the conception of our interactive mind map tool.

Table 1 summarizes the researched works highlighting the primary use for the mind map and knowledge area. Works that deal with mind maps in a broader sense were defined as "general".

When viewing the literature works presented in table 1, we can observe the immense diversity of knowledge areas that employ mind maps. Considering this perception, our work is not restricted to a specific field. On the contrary, we developed a general-purpose conception, both in the knowledge areas and in the methodological aspect.

Mind maps are also used for different applications. We identified many benefits of the mind map in education from the works studied, for instance, as a useful technique for promoting skills needed in our digital age, such as critical thinking (Polat and Aydin,2020), problem-solving (Tushko et al., 2020), creativity (Munoz Gonzalez et al., 2020), and collaborative work (Chen et al., 2020).

From the consulted works, we took advantage of the benefits highlighted by Davies (2011) in the mind map's free format as an insight to our tool. We developed a conception that could support traditional radial network format and other formats such as tree. In this way, it allows a better arrangement of content according to the organization of the subject's concepts. Furthermore, flexibility allows authors more space for creativity.

Considering the works of Araujo and Gadanidis (2020); Kalizhanova et al. (2020); Lacurezeanu et al. (2018); Yang et al. (2020), we have also incorporated iconographic

Table 1: Mind map survey.

Works	Main Use	Area
Araujo and Gadanidis (2020)	Collaborative working	Mathematics
Chen et al. (2020)	Collaborative working	Engineering
Dwijayanti et al. (2020)	Learning material	History
Kalizhanova et al. (2020)	Learning material	Languages learning
Munoz Gonzalez et al. (2020)	Learning material	Pedagogy
Tushko et al. (2020)	Learning material	Military Education
Wu and Wu (2020)	Critical thinking tool	Nursing
Yang et al. (2020)	Infographics	Health education
Stokhof et al. (2020)	Learning material and evaluation	Nursing
Polat and Aydin (2020)	Critical thinking tool	Preschool education
Signoretti et al. (2020)	Learning material	Geosciences
Allen et al. (2019)	Learning exercise	Chemistry
Kurniasih and Irpan (2019)	Learning material	Biology
Lin (2019)	Learning exercice	Languages learning
Rezapour-Nasrabad (2019)	Critical thinking tool	Nursing
Suardana et al. (2019)	Critical thinking tool	Science Education
Lacurezeanu et al. (2018)	Learning material	Economics
Petrova and Kozarova (2018)	Learning material	Languages learning
Selvi and Chandramohan (2018)	Recall technique	Engineering
Sarmah et al. (2017)	Exercise and revision	Medical education
Lai and Lee (2016)	Learning material	Engineering
dos Santos and Pedro (2016)	Learning material	Geography
Shrieber (2016)	Systematize information	Students with ADHD
Tee et al. (2014)	Note taking	Secondary school
Vanags et al. (2012)	Spacial memorization	Psychology
Stankovic et al. (2011)	Learning material	Business
Davies (2011)	General	General
Richter (2011)	Learning exercice	Geography
Buzan (2009)	General	General
Buzan (2006)	General	General
Eppler (2006)	General	General
Farrand et al. (2002)	Recall technique	Medical education
Michalko (2001)	Creative tool	General

nodes, not just textual information as is the case with part of the traditional mind maps. This is a way to diversify the representation of ideas and their relationships.

As Novak and Cañas (2006) explained, the mind map also has flexibility in the epistemological approach to support its use. So, we think of the interactive mind map as a flexible authoring tool. Thus, the teacher will be free to develop its content without feeling bound by any bias.

Kalizhanova et al. (2020) states that in recent years, mind maps' potential has been enlarged through the development of relevant software. Technology enables the creation of digital mind maps. So, our conception is a model for a software tool that allows the author to use different media and add interactive resources to the mind map.

According to Lai and Lee (2016) mind maps, by summarizing content to be made available to students, avoid cognitive overload, which occurs when students are presented with too much information at a very complex level or too quickly for adequate absorption. This inspired us to make the visualization of our tool even more modular. The interactive mind map shows part of the content only after interacting with the concept node and avoids long content.

Davies (2011) explains that the work involved in creating maps requires active engagement on the student's part. The authors Lacurezeanu et al. (2018); Wu and Wu (2020); Yang et al. (2020) also cite an increase in student interest, participation, and motivation when using mind maps.

So the mind map is a rich tool, with many benefits, suitable for working with numerous subjects, suitable for our technological reality. We took advantage of ideas about technology, structure, format, and flexibility from our survey. Moreover, our work's great innovation is to propose to combine interactivity with mind maps when demonstrating a prototype and to propose an implementation model, shown in the next subsection.

4.2 Interactive mind map prototype and implementation model

This proposal unites the mind map's pedagogical characteristics to technological aspects, graphics aspects, and interactivity. To validate the model that we propose, we create a prototype to illustrate the final result of an interactive mind map to be made available to students. The prototype can be accessed at http://mindmap.website/oes/; it is an example of an interactive mind map, built to study the concept of design thinking. The prototype has few forms of interaction, making it possible to think and add many other interactive resources to this model. It was built using the d3js library (Bostock et al., 2011), a JavaScript library very rich in visual resources and interactivity.

To understand the proposed model, we can see Figure 4. The model aimed at creating a modern, minimalist, and flexible interface to represent the elements of the mind map and their relations (left side of Figure 4). When observing the elements and their relations, the student will be able to interact through the nodes (for example, using double click), having access to new blocks of content (right side of Figure 4). Although in this prototype, user interaction takes place through a double click, other actions or buttons can be implemented according to the content and the need.

The mind map technique is a flexible structure, it is possible to add several shapes, figures, and other representations in its implementation. The same applies to the spatial arrangement of the elements. Thus, it favors creating interfaces with innovative layouts.

According to Buzan (2009), the mind map breaks with the usual linear pattern. So, by using interactive mind maps, the student will be able to study the themes based on their intrinsic relationships and no longer based on a linear sequence of contents.

In this work, we highlight the potential of two aspects that we can observe on the prototype: data visualization inspired us to create a fragmented content tool, and interactivity added dynamism to the mind map. Visual and interactive aspects are fundamental to the development of new tools to support education.

There are many positive points when choosing interactive media as teaching resources because, according to Bates (2015), intense interaction with learning resources increases the time students spend learning. Tori (2010), states that in virtual activities, interactive technologies influence the feeling of distance (transactional distance), helping students increase the feeling of closeness. It also states that interactivity has the potential to change the student's posture from passive to interactive. In his view, interactivity is part of the concepts that permeate the education of the future.

Our proposal can be considered rich media, as it combines textual content, images, interactivity, and technology (different media modalities). According to Bates (2015), the use of different media and rich media allows greater personalization of learning, using different stimuli to serve students with different styles and learning needs.

Although the prototype developed was intended to highlight interactive mind maps' potential, what we propose is creating an authorial tool for their construction.

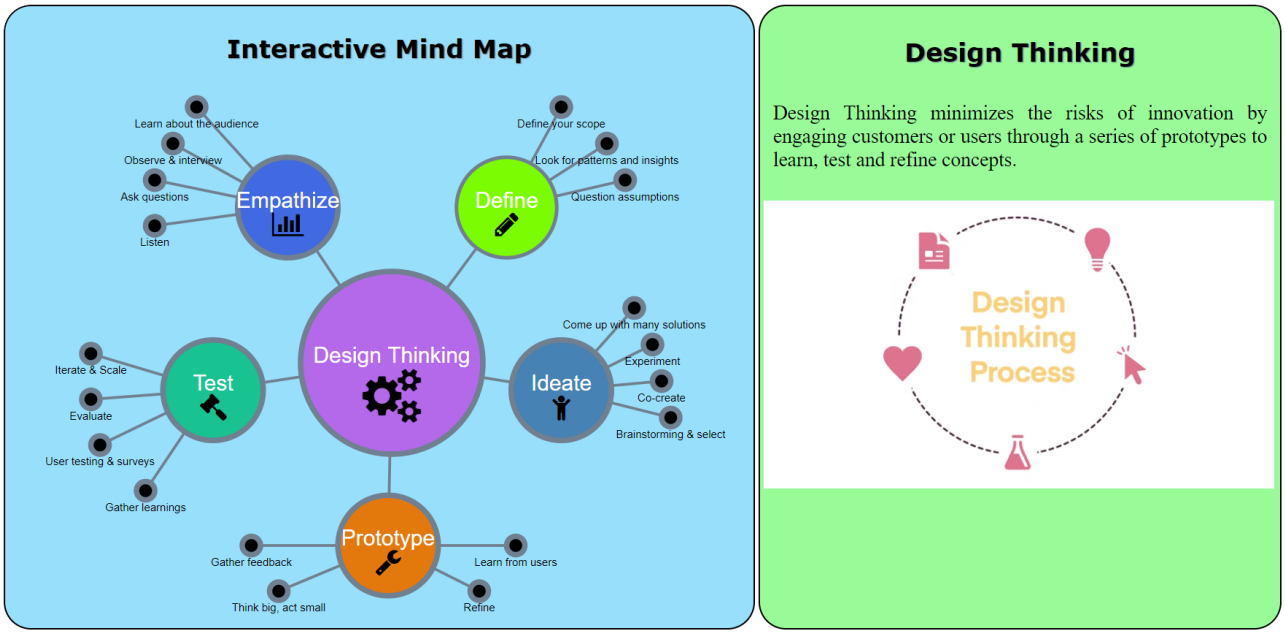

Figure 4: Prototype of interactive interface for mind map.

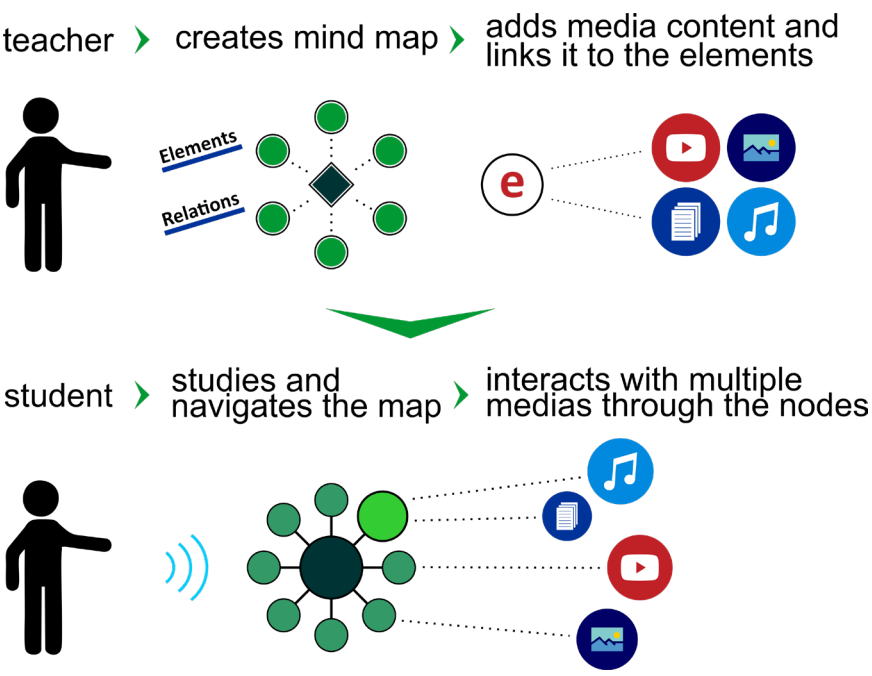

Figure 5: Implementation model.

Figure 5 shows the implementation model. In this way, the teacher would have at his disposal a tool to create these rich and interactive media to work on their learning contents (like the example shown in Figure 4). Tavares et al. (2019) states that an advantage of an authorial tool is to provide freedom so that the teacher can adapt the resource to his class script, without being stuck with inflexible made materials.

Tavares et al. (2019) comment that technological evolution has made evident the need for pedagogical and methodological restructuring of teaching practices and the restructuring of daily school activities. Therefore, the interactive mind map proposal aims to bring teaching practices closer to the dynamic and interactive reality experienced by new generations.

5 Conclusion

The present work presented a new conception of the mind map, extending the mind map concept to an interactive technology to support learning. The characteristics and potentials of mind maps were exposed, including as a pedagogical tool.

We sought to highlight two critical aspects of developing educational applications with technology: visualization and interactivity. Taking advantage of the positive aspects of data visualization and interactivity, we seek to add value to the mind map, proposing a model that uses this concept for a new conception as an authorial tool for teachers and an interactive learning tool for students.

A prototype of the final interactive mind map interface was developed and detailed to demonstrate the proposed model and its characteristics that favor dynamic learning. Then we spot the advantages of combining technological and interactive aspects with learning tools to break the traditional linear paradigm.

As future work, we have some suggestions: implementing this model in online learning environments; researching students' perceptions and engagements when using the proposed tool; creating interactive mind maps for different study subjects; and experiment with new features and media to increase the interactive mind map possibilities.

Conflict of interest: Authors state no conflict of interest.

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