Multiple external representations for executive functions: a systematic mapping study

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Abstract. *The use of multiple external representations (MER) in the empowerment of executive functions (EF) was identified and characterized through a systematic mapping. EF are part of the human learning triad, contributing to the development of complex executive skills. Learners may have difficulty developing EF, and can benefit from MER. Data from 18 articles were extracted. Most MER systems used two external representations, verbal-textual and visual-graphical, through desktop applications. In relation to EF, the most considered component was working memory. We identified the need for further research that considers the effects of MERs on cognitive flexibility and inhibition, and the impact of mobile devices to the exhibition of MERs.*

Resumo. *Foi identificado e caracterizado o uso de múltiplas representações externas (MRE) na capacitação de funções executivas (FE) através de um mapeamento sistemático. FE fazem parte da tríade da aprendizagem humana, contribuindo para o desenvolvimento de habilidades executivas complexas. Alunos podem ter dificuldade nas FE, beneficiando-se das MRE. Dados de 18 artigos foram extraídos. A maioria dos sistemas MRE utiliza duas representações externas, verbal-textual e visual-gráfica, por meio de aplicativos desktop. Em relação às FE, o componente mais considerado foi memória de trabalho. Há necessidade de pesquisas sobre os efeitos das MRE na flexibilidade cognitiva e inibição e o impacto de dispositivos móveis para a exibição de MRE.*

1. Introduction

In the learning process, it is understood the importance of, when presenting concepts to people, resorting to the use of representations [de Vries, 2012]. External representations (ER) can be described as "symbolic elements" which represent real entities and phenomena, making them tangible, manipulable, and available for thought, imagination, and action [Pande, 2020]. Students need to be exposed to the same concept repeatedly to favor learning [Prain & Waldrip, 2006]. We can use different ways to represent these entities or phenomena, and that is when multiple external representations (MER) arise [Tytler et al., 2007].

Developing effective representations may require substantial effort. The Conceptual Framework Deft [Ainsworth, 2006] establishes a set of five design parameters which are applied exclusively to MER: (a) the number of representations, (b) the form of information distribution, (c) the format of each representation, (d) the presentation sequence of representations, and (e) the support for the alternation between the representations. In

DOI: 10.5753/sbie.2022.224711

addition, combining the type of ER with learning demands can significantly improve the performance and the student's understanding [Ainsworth, 2006].

Texts, math symbols, images, graphics, animations, and videos are good examples of ER. Wu and Puntambekar (2012) present a taxonomy of multiple representations, namely: verbal-textual (used to categorize linguistic words and symbols, for example), symbolic-mathematical (e.g., signs, symbols and mathematical conventions), visual-graphical (graphics, figures, animations, and videos) and actional-operational (demonstrations and manipulatives). Researches have been conducted on the effect of MER on the cognitive functions of individuals [Malone et al., 2020; Moritz, 2019; Pande & Chandrasekharan, 2017; Renkl & Scheiter, 2017]. Nevertheless, the system of cognitive functions is only a part of the functional triad of human learning, along with executive functions and conative functions [Fonseca, 2014]. In this study, we chose to address executive. People who have failures or delays in the development of EF tend to have learning disabilities [Corso et al., 2013], such as children diagnosed with dyslexia disorder and/or dyscalculia disorder [Shakouri & Hashemi-Razini, 2019]. Students with learning disabilities have limitations to solve problems efficiently, difficulties in concentrating, difficulties in classifying, organizing and prioritizing information [Meltzer & Krishnan, 2007].

Executive functions (EF) are characterized in three basic components: cognitive flexibility, inhibition, and working memory [Archambeau & Gevers, 2018; Miyake & Friedman, 2012; Miyake et al., 2000]. Cognitive flexibility refers to the ability of an individual, who can change their perspectives, change their thinking about something, adjust to new demands or priorities [Diamond, 2013]. Inhibition allows the individual to inhibit or delay an instinctual reaction, resist the interference of distractions that cause the loss of attention during the performance of an activity [Fitó, 2012]. Working memory is the ability to hold information in the mind and manipulate that information [Hoskyn et al., 2017]. When these three basic components are integrated, the development of other complex executive skills, such as problem-solving, planning, decision-making, and reasoning, is possible [Krause, 2020].

Understanding how MER affects the development of EF can be beneficial for people with learning disabilities. Thus, this article presents a systematic mapping study (SMS) that aims to identify and characterize the use of MERs in the empowerment of EF. This article is organized as follows: the next section describes the protocol used to perform this systematic mapping. The results obtained are presented and discussed below. Finally, conclusions and future work are presented in the last section.

2. Method

A SMS provides an overview of a research area, aiming to establish the existence of studies on a particular topic, thus making it possible to obtain an indication of the amount of evidence and possible gaps [Kitchenham & Charters, 2007]. In the current study, the SMS was used to identify the state of the art of research and identify topics of interest, without the need for an in-depth analysis. The method was based on the guidelines proposed by [Kitchenham & Charters, 2007].

The main objective of this systematic mapping was developed from Goal-Question-Metrics (GQM) paradigm [Basili & Rombach, 1988], aiming to *analyze* primary studies, *with the purpose of* characterizing, *in relation to* the use of MER in the empowerment of EF, *from the point of view of* researchers in Computer Science, *in the context of* publications available in the digital libraries ACM DL, APA PsycNet, Engineering Village, IEEE Xplore, PubMed. The choice of libraries was based on the popularity of search engines of computer science, health science and psychology.

The main research question is *"How have multiple external representations been used in the empowerment of executive functions?"*. Thus, to answer the main question, research sub-questions (SQ) were develop, as follows: **SQ1** - How many external representations were used in the study?; **SQ2** - What is the combination of external representations used in the study?; **SQ3** - How is information distributed between external representations?; **SQ4** - How is the sequencing of the presentation of external representations performed?; **SQ5** - What technology is used in the presentation of MER?; **SQ6** - What components of EF are covered by the study?; **SQ7** - What disciplinary contents are covered by the study?; **SQ8** - In which context was the study applied and evaluated?; **SQ9** - What is the age group considered in the study?.

The current SMS made use of the PIO criteria (Population, Intervention, Output) [Kitchenham & Charters, 2007] to define the search string: *("executive functions" OR "cognitive flexibility" OR "shifting" OR "inhibition" OR "working memory") AND ("multiple external representations" OR "multiple representations" OR "multimodal representations") AND ("learning" OR "education" OR "teaching")*. Primary studies written in English were taken into consideration, since it is the predominant language in the research field. The search in the databases was carried out on the 15th of January 2021, and no restriction was established regarding the date of publication of the studies. Each article obtained through the SMS was, independently, analyzed by two researchers (R1 and R2), who decided on the selection of each paper. Two filters were applied: In the first, only the title, abstract, and keywords were explored; and in the second, the full reading of the article was carried out.

The inclusion criteria (IC) were: **IC1.** Articles that address two or more forms of external representations involving EF; and **IC2.** Articles aimed at enabling cognitive flexibility, inhibition, and/or working memory using MER. The exclusion criteria (EC) were: **EC1.** Publications that do not meet the search scope; **EC2.** Publications that are not in the English language; **EC3.** Publications that have already been selected in another database (duplicated publications); **EC4.** Publications belonging to gray literature (manuals, reports, theses, dissertations, and among others), excluding book chapters that are articles; **EC5.** Publications representing secondary or tertiary studies; and **EC6.** Publications that are not fully available for reading.

During first filter aplication, articles were excluded by consensus among researchers. In case of discrepancy, the article was included to apply the second filter. The Kappa statistical test was used to assess the degree of agreement between researchers [McHugh, 2012]. The value of (κ) for the first filter was 0.85, indicating an almost perfect agreement. Discrepancies in the selection of articles during the application of the second filter were resolved by consensus among researchers after the completed reading. The second filter obtained a value of 1 in the Kappa coefficient, indicating perfect agreement.

Initial search in selected libraries returned 188 publications. After 1st filter execution, 63 publications were selected. Applying the 2nd filter, 18 publications were selected for data extraction, resulting in 9.57% of the total. The extracted data were grouped in an electronic spreadsheet, using Google Sheets. The spreadsheets related to the 1st [1] and 2nd [2] filter are available for viewing. Gnuplot software was used to generate graphics.

2.1. Threats to Validity and Limitations

Considering the most popular threats to validity presented in Ampatzoglou et al. (2019), we sought to mitigate data extraction and research bias by carrying out the process by two researchers, who independently evaluated the studies, and met periodically to discuss the selection process. Regarding the study inclusion/exclusion bias, the SMS protocol was created, analyzed and discussed by two researchers. We sought to define inclusion and exclusion criteria to select articles that could fully answer the research questions.

Regarding the construction of the search string, the PIO methodology [Kitchenham & Charters, 2007] was defined, widely used for the construction of secondary studies. To mitigate the threat of Selection of Digital Libraries, we seek to diversify digital libraries in relation to the area of knowledge. Therefore, popular databases that focus on computer science, health science and psychology were selected. Also, as limitations of this study, it is understood that the limited number of selected search engines may be an impediment to a broader selection of studies that would fit the objectives of this SMS. Another limitation is related to other possible article recovery techniques, such as snowballing, which were not used in the process.

3. Results and discussion

Data were extracted from 18 articles, which were published between 1989 and 2020. However, there has been a slight increase in the number of publications in recent years, with the largest number of publications occurring in 2020 [Hansen & Richland, 2020; Tomlinson et al., 2020; Blanchard et al., 2020]. This demonstrates that there is still research on the subject being carried out today. The articles were published in 6 journals and in 10 conferences.

3.1. Number of external representations

SQ1 sought to investigate the amount of ER used by each publication obtained in the SMS. Among the design parameters applied exclusively to multi-representational systems, the number of representations must be analyzed [Ainsworth, 2006]. The number of ER used varied between 2 and 7. In the SMS, 44.44% publications used two ER [Hansen & Richland, 2020; Coste et al., 2011; Begolli et al., 2018; Bodemer & Faust, 2006; Huff et al., 2010; Schank & Hamel, 2004; Fan et al., 2016; Blanchard et al., 2020]. One of the reasons why most studies use two ER may be related to the dual-coding theory discussed in the study [Fan et al., 2016]. The dual-coding theory understands that, to facilitate learning, information needs to be transmitted in two ways, verbal associations, which represent textual elements, and non-verbal, which represent visual elements. [Clark & Paivio, 1991].

The other amounts of ER used in publications have values closer to each other, being 16.67% with four ER [Pande & Chandrasekharan, 2014; Plass et al., 2003; Neuwirth

[1] `https://shorturl.at/uIOY6`
[2] `https://shorturl.at/vRST9`

& Kaufer, 1989], 16.67% with five ER [Husted et al., 2014; Vainio et al., 2005; Vieira et al., 2017], 11.11% of the publications used three ER [Carlson et al., 1990; Davis et al., 2017] and, with 5.56% each, publications that used six [Tomlinson et al., 2020] or seven [Giordani et al., 2012] ER. When analyzing this data, it can be observed that there was a preference for a smaller number of ER involved in the multi-representational system. Above all, it is recommended to use a minimum number of representations, which should correspond to the established pedagogical function, considering the cognitive tasks involved in the addition of ER [Ainsworth, 2006].

3.2. Combination of external representations

The second element belonging to the design parameters, according to Ainsworth [Ainsworth, 2006], is the presentation format of the MER. Thus, SQ2 aimed to identify the different types of ER that were used in the publications obtained in this SMS. Integration between external representations and the scientific processes involved in learning can maximize the benefits of each representation. Furthermore, this integration can allow the limitations contained in a given representation to be compensated through others [Wu & Puntambekar, 2012].

To categorize the ER contained in the articles, we chose to use the taxonomy presented by [Wu & Puntambekar, 2012]. The taxonomy contains some categories: verbal-textual, symbolic-mathematical, visual-graphical, and actional-operational. Each ER was placed in one of these categories. So, the articles used external representations that might be classified in one or more categories. Half of the publications [Hansen & Richland, 2020; Giordani et al., 2012; Plass et al., 2003; Coste et al., 2011; Begolli et al., 2018; Bodemer & Faust, 2006; Blanchard et al., 2020; Neuwirth & Kaufer, 1989; Vainio et al., 2005], did use ER, applying a combination of verbal-textual and visual-graphical representation. Some ER contained in these categories and used by the selected studies are text, descriptive audio, oral propositions, images, videos, photos, tables, and animations.

Combination of the external representations of the verbal-textual, symbolic-mathematical, and visual-graphical was present in 22.22% [Husted et al., 2014; Carlson et al., 1990; Tomlinson et al., 2020; Vieira et al., 2017]. It is observed that the main combination, verbal-textual and visual-graphical, was present, isolated, or associated with another category, in 72.22% of the studies. This happened because when images are used adjunct to text, they can improve text memorization, as images can represent the text content and provide a non-verbal representation that can be retrieved [Robinson, 2002].

Publications that presented ER in other categories, represent 5.56% each, being symbolic-mathematical and visual-graphic [Pande & Chandrasekharan, 2014], verbal-textual and actional-operational [Fan et al., 2016], visual-graphical [Huff et al., 2010], verbal-textual [Schank & Hamel, 2004] and symbolic-mathematical and actional-operational [Davis et al., 2017].

3.3. Distribution of information between external representations

The flexibility regarding the way that information is distributed between the ER impacts the complexity of each external representation and the redundancy of information between them [Ainsworth, 2006], that is, if the information present in the representations differs (non-redundant), the same information is present in the various representations (redundant) or the representations contain part of the information (partially redundant). Thus, SQ3 aimed to identify how the information was distributed in each study, given that this item is part of the design parameters established in DeFT. In 38.89% of the studies had partially redundant content among the MER [Husted et al., 2014; Begolli et al., 2018; Bodemer & Faust, 2006; Huff et al., 2010; Tomlinson et al., 2020; Neuwirth & Kaufer, 1989; Vainio et al., 2005]. The information was presented redundantly in 38.89% of the studies [Hansen & Richland, 2020; Plass et al., 2003; Carlson et al., 1990; Schank & Hamel, 2004; Fan et al., 2016; Blanchard et al., 2020; Davis et al., 2017]. There was no redundancy of information between multiple representations in 5.56% of the studies [Coste et al., 2011].

In 5.56% of the studies [Pande & Chandrasekharan, 2014], a combination of two forms of distribution of information between the MER was used. In this case, there were ER groups, with and without information redundancy, that made up each group. It was not possible to identify the form of distribution of information in 11.11% of the studies [Giordani et al., 2012; Vieira et al., 2017]. Although most articles redundantly present information, this form is only suggested when the information, in isolation, is unintelligible; otherwise, it is recommended to omit the redundancy. Processing the same information more than once can make students use unnecessary cognitive resources and have their learning compromised [Cook, 2006].

3.4. Presentation's sequencing of the external representations

Sequencing another element of the DeFT design parameters [Ainsworth, 2006] concerns how MER should be presented or constructed, necessarily when representations are not presented simultaneously. Futhermore, the user or the system must decide when a new ER will be presented or when a switch between existing MER will occur. Besides, MER sequencing is considered a critical approach when learning certain concepts and can affect students' focus on explanations and shape their perceptions of representations [Hsu & Wu, 2015; Wu et al., 2012]. Thus, SQ4 sought to identify how the ER presentation sequencing occurs in the studies obtained by the SMS.

In 33.33% of the studies [Coste et al., 2011; Carlson et al., 1990; Tomlinson et al., 2020; Fan et al., 2016; Blanchard et al., 2020; Davis et al., 2017] performed simultaneous presentation of MER. In 11.11% of the articles [Pande & Chandrasekharan, 2014; Begolli et al., 2018] the ER was presented sequentially, with the alternation being performed by the system itself, while in 16.67% of the articles [Husted et al., 2014; Huff et al., 2010; Schank & Hamel, 2004], this switching was performed by the user. Users were able to access the ER freely (in no defined order) in 16.67% of the studies [Giordani et al., 2012; Plass et al., 2003; Neuwirth & Kaufer, 1989]. A combination of sequencing possibilities was used in 16.67% [Hansen & Richland, 2020; Bodemer & Faust, 2006; Vainio et al., 2005]. It was not possible to identify the sequencing of external representations in 5.56% of the studies [Vieira et al., 2017].

3.5. Technology used in the exhibition

The technology used to support the alternation between the MER is considered as a design parameter of DeFT, as it can automatically offer the translation between representations and has several ways to indicate the connection between the ER [Ainsworth, 2006]. Thus, SQ5 aimed to identify the type of technology used for presentation of MER, identified technologies developed for desktop, tangible interface, printed material, and web.

Among the articles obtained by this SMS, only one publication [Begolli et al., 2018] did not specify the technology involved in the presentation of ER. The use of computers (notebook, PC, among others) was the predominant feature in the exhibition. Above all, 11 publications [Pande & Chandrasekharan, 2014; Husted et al., 2014; Plass et al., 2003; Coste et al., 2011; Bodemer & Faust, 2006; Carlson et al., 1990; Huff et al., 2010; Fan et al., 2016; Blanchard et al., 2020; Davis et al., 2017; Neuwirth & Kaufer, 1989] showed use of software on a desktop platform, while 6 publications [Hansen & Richland, 2020; Giordani et al., 2012; Tomlinson et al., 2020; Schank & Hamel, 2004; Vainio et al., 2005; Vieira et al., 2017] made use of software on a web platform.

The use of tangible interface [Fan et al., 2016; Davis et al., 2017] and printed material [Pande & Chandrasekharan, 2014; Husted et al., 2014] was presented in two publications each. Although the Web platform allows access through mobile devices (smartphone and tablet), it was noted that there was no specific use of the mobile platform. When analyzing the correlation between the technology used and the type of external representation (Figure 1), it is observed that there was no experimentation involving tangible interfaces and visual-graphical representations, also it had little integration between the desktop platform and actional-operational representations.

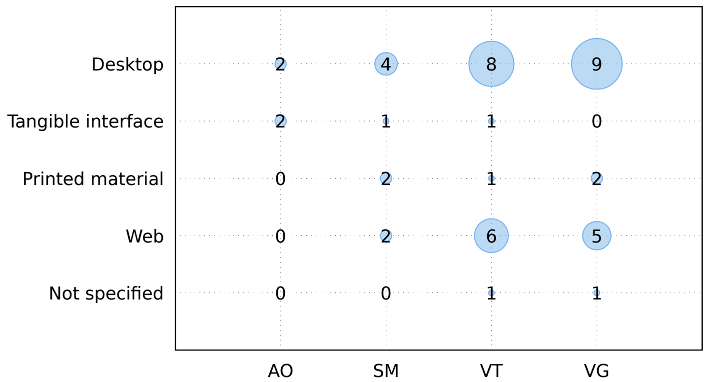

Figure 1. Correlation between the technology used and then type of external representation. AO: Actional-operational; SM: Symbolic-mathematical; VT: Verbal-textual; VG: Visual-graphical

3.6. Components of executive functions

The SQ6 aimed to answer which components of EF were addressed in the publications. In 66.67% of the publications addressed the working memory component [Pande & Chandrasekharan, 2014; Plass et al., 2003; Bodemer & Faust, 2006; Carlson et al., 1990; Huff et al., 2010; Tomlinson et al., 2020; Schank & Hamel, 2004; Fan et al., 2016; Blanchard et al., 2020; Davis et al., 2017; Neuwirth & Kaufer, 1989; Vieira et al., 2017], while the cognitive flexibility component [Giordani et al., 2012; Husted et al., 2014; Vainio et al., 2005] was addressed in 16.67% of the publications.

In 16.66% of the publications [Hansen & Richland, 2020; Coste et al., 2011; Begolli et al., 2018], EF were addressed as a set of components (working memory, cognitive flexibility, and inhibition), identified here as Combined. No publication discussed the inhibition component in isolation. Although the publications addressed the components of EF, only four publications evaluated the component(s) during the study. To evaluate the working memory, in the article [Huff et al., 2010], a working memory span test was performed and, in the article [Carlson et al., 1990], the evaluation of the state of the output of electronic circuits was made at regular time intervals.

The studies that evaluated the three components of EF used standardized tests. In [Coste et al., 2011] the Plus/Minus task test was used to assess cognitive flexibility, the Running Span task to assess working memory, and the Stroop task to assess inhibition. The article [Begolli et al., 2018] used the Automated Working Memory Assessment battery to assess working memory, The Hearts and Flowers task to assess cognitive flexibility and, to assess inhibition, used The Stop-Signal task test.

When establishing a correlation between the number of ER and the component of EF addressed (Figure 2), it is possible to notice that, when considering the working or combined memory components, the studies used a smaller amount of external representations. However, when taking into consideration only the cognitive flexibility component, a greater number of external representations was used. Analyzing the correlation between the type of the used external representation and the EF component addressed, as shown in Figure 3, it is noted that, for the action-operational category, it was evaluated only by the working memory component. It is also possible to observe that there were no studies that simultaneously considered more than one component of the EF using ER contained in the actional-operational and symbolic-mathematical categories.

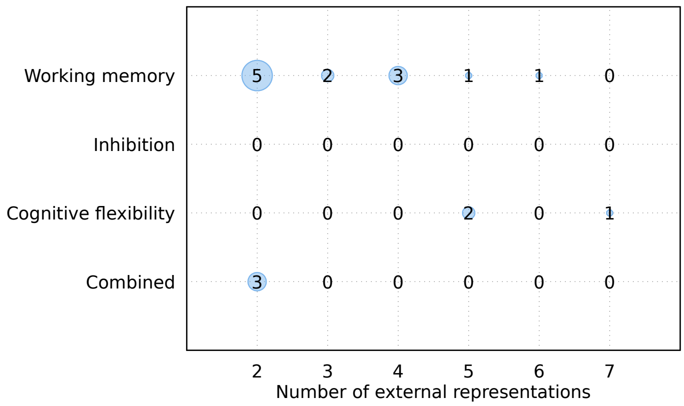

Figure 2. Correlation between the number of used representations and executive functions.

3.7. Disciplinary contents covered

The SQ7 investigated the disciplinary content addressed during the experiments reported in the articles. According to the data obtained, MER can be explored in the teaching and learning of different disciplines, in different areas of knowledge. However, it was not possible to identify the disciplinary content in 5.56% of the studies [Coste et al., 2011].The most used disciplinary content was Physics, addressed in 16.67% of the studies [Bodemer & Faust, 2006; Huff et al., 2010; Tomlinson et al., 2020]. For that matter

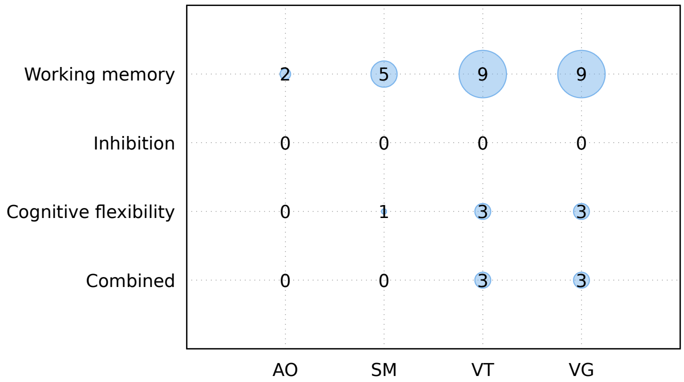

Figure 3. Correlation between the type of used representations and executive functions. AO: Actional-operational; SM: Symbolic-mathematical; VT: Verbal-textual; VG: Visual-graphical

11.11% are the subject contents of Mathematics [Begolli et al., 2018; Davis et al., 2017] and Computer Programming [Blanchard et al., 2020; Vieira et al., 2017], each.

Other disciplinary contents used in the studies represent, each representing 5.56% of the total, being Literacy [Fan et al., 2016], Balance of Materials [Husted et al., 2014], Biology [Hansen & Richland, 2020], Digital Electronic Circuits [Carlson et al., 1990], Software Engineering [Schank & Hamel, 2004], Synthesis Writing [Neuwirth & Kaufer, 1989], Foreign Language [Plass et al., 2003], Medicine [Vainio et al., 2005], Chemistry [Pande & Chandrasekharan, 2014] and Corporate Training [Giordani et al., 2012]. Identifying the disciplinary contents covered in the use of MER allows to understand which areas have been beneficial for most of these resources. It is observed that there was a greater use of MER in instructional content related to the area of exact sciences, especially Physics, Mathematics, and Computer Science.

3.8. Application Context

The SQ8 investigated what context the studies were carried out in, which means the environment in which the study participants carried out the experiments. According to the data obtained, most publications used the university environment as the application context [Pande & Chandrasekharan, 2014; Husted et al., 2014; Plass et al., 2003; Bodemer & Faust, 2006; Carlson et al., 1990; Huff et al., 2010; Blanchard et al., 2020; Neuwirth & Kaufer, 1989; Vainio et al., 2005; Vieira et al., 2017], totaling 55.56%. The school environment was used as the context for applying 11.11% of the [Hansen & Richland, 2020; Davis et al., 2017] publications.

Both the enterprise environment [Giordani et al., 2012] and the clinical [Coste et al., 2011] were considered as application contexts in 5.56% of the publications, each. It was not possible to identify the application context of 11.11% of the publications [Begolli et al., 2018; Tomlinson et al., 2020; Schank & Hamel, 2004; Fan et al., 2016]. No study has performed experiments in the participants' homes or in more than one environment (combined).

3.9. Age group

Investigating the age range of study participants was the objective of SQ9. According to the data obtained, most publications [Pande & Chandrasekharan, 2014; Husted et al., 2014; Plass et al., 2003; Coste et al., 2011; Bodemer & Faust, 2006; Carlson et al., 1990; Huff et al., 2010; Tomlinson et al., 2020; Blanchard et al., 2020; Neuwirth & Kaufer, 1989; Vainio et al., 2005; Vieira et al., 2017] performed the study with adults, being 66.67% of the studies. The Adolescents age group was considered by 16.67% of the studies obtained [Hansen & Richland, 2020; Begolli et al., 2018; Davis et al., 2017], while the Children age group was considered by only 5.56% of the [Fan et al., 2016] publications. It was not possible to identify the age group in 11.11% of the publications [Giordani et al., 2012; Schank & Hamel, 2004].

4. Conclusions

The present SMS was developed with the objective of answering the following research question: *"How have multiple external representations been used in the empowerment of executive functions?"*. After data extraction, it was possible to identify that research on MER and EF has been developed over the years, with greater emphasis in recent years and published mainly in scientific events. The experiments have been carried out, mainly, with adults in university environments, covering disciplinary contents related to the area of Science, such as Physics, Mathematics, and Computing. Multi-representational systems, preferentially, use two external representations, which are mostly characterized in the verbal-textual and visual-graphical combination, using, especially, desktop applications. The representations had information, which was partially or fully redundant and simultaneously presented to users. The main underlying theory was cognitive flexibility theory. Regarding EF, the most considered component was working memory, although few articles assess EF.

It was possible to identify some gaps, which require further research. It is noted that it is necessary to carry out research that considers children and adolescents as participants, given that the EF develop from childhood to adulthood [Fitó, 2012]. In addition, the suggestion of developing research in the school environment is valid, thus favoring the learning of children and adolescents. We also identified the possibility of developing research on the effects of MER on the cognitive flexibility and inhibition components, above all, by varying the number of external representations used in the multi-representational system. Furthermore, we believe it is important to verify the efficiency of MER on these components, using the types of actional-operational and symbolic-mathematical representations. Finally, a lack of research on the effect of the use of mobile devices, when used in the presentation of the MER for the training of EF, was diagnosed.

This article contributed to the identification and understanding of works carried out in MER and EF. As future work, it is understood the need for research that allows the provision of educational support (scaffolding), based on MER, for children who have learning difficulties, especially for those with deficits in EF. To this end, we propose the creation of an approach that can allow the development of multi-representational tangible interface systems, using techniques of intelligent tutoring systems, to be used for the training of students' EF. Furthermore, we expect that the results of this study can contribute to the development of the area and that the identified gaps can serve as a basis for further studies.

References

Ainsworth, S. (2006). Deft: A conceptual framework for considering learning with multiple representations. *Learning and Instruction*, *16*(3), 183–198. Doi: https://doi.org/10.1016/j.learninstruc.2006.03.001

Ampatzoglou, A., Bibi, S., Avgeriou, P., Verbeek, M., & Chatzigeorgiou, A. (2019). Identifying, categorizing and mitigating threats to validity in software engineering secondary studies. *Information and Software Technology*, *106*, 201-230. Doi: https://doi.org/10.1016/j.infsof.2018.10.006

Archambeau, K., & Gevers, W. (2018). (how) are executive functions actually related to arithmetic abilities? In A. Henik & W. Fias (Eds.), *Heterogeneity of function in numerical cognition* (pp. 337–357). Academic Press. Doi: https://doi.org/10.1016/B978-0-12-811529-9.00016-9

Basili, V. R., & Rombach, H. D. (1988). The tame project: Towards improvement-oriented software environments. *IEEE Transactions on software engineering*, *14*(6), 758–773.

Begolli, K. N., Richland, L. E., Jaeggi, S. M., Lyons, E. M., Klostermann, E. C., & Matlen, B. J. (2018). Executive function in learning mathematics by comparison: incorporating everyday classrooms into the science of learning. *Thinking & Reasoning*, *24*(2), 280–313. Doi: 10.1080/13546783.2018.1429306

Blanchard, J., Gardner-McCune, C., & Anthony, L. (2020). Dual-modality instruction and learning: A case study in cs1. In *Proceedings of the 51st acm technical symposium on computer science education* (p. 818-–824). New York, NY, USA: Association for Computing Machinery. Doi: 10.1145/3328778.3366865

Bodemer, D., & Faust, U. (2006). External and mental referencing of multiple representations. *Computers in Human Behavior*, *22*(1), 27–42. (Instructional Design for Effective and Enjoyable Computer-Supported Learning) Doi: https://doi.org/10.1016/j.chb.2005.01.005

Carlson, R. A., Khoo, B. H., Yaure, R. G., & Schneider, W. (1990). Acquisition of a problem-solving skill: Levels of organization and use of working memory. *Journal of Experimental Psychology: General*, *119*(2), 193–214.

Clark, J. M., & Paivio, A. (1991, September). Dual coding theory and education. *Educational Psychology Review*, *3*(3), 149–210. Doi: 10.1007/bf01320076

Cook, M. P. (2006). Visual representations in science education: The influence of prior knowledge and cognitive load theory on instructional design principles. *Science Education*, *90*(6), 1073–1091. Doi: https://doi.org/10.1002/sce.20164

Corso, H. V., Sperb, T. M., de Jou, G. I., & Salles, J. F. (2013, March). Metacognição e funções executivas: relações entre os conceitos e implicações para a aprendizagem. *Psicologia: Teoria e Pesquisa*, *29*(1), 21–29. Doi: 10.1590/s0102-37722013000100004

Coste, C., Agar, N., Petitfour, E., Quinette, P., Guillery-Girard, B., Azouvi, P., & Piolino, P. (2011). Exploring the roles of the executive and short-term feature-binding functions in retrieval of retrograde autobiographical memories in severe traumatic brain injury. *Cortex*, *47*(7), 771–786. Doi: https://doi.org/10.1016/j.cortex.2010.07.004

Davis, R. L., Orta Martinez, M., Schneider, O., MacLean, K. E., Okamura, A. M., & Blikstein, P. (2017). The haptic bridge: Towards a theory for haptic-supported learning. In *Proceedings of the 2017 conference on interaction design and children*

(p. 51-–60). New York, NY, USA: Association for Computing Machinery. Doi: 10.1145/3078072.3079755

de Vries, E. (2012). Learning with external representations. In N. M. Seel (Ed.), *Encyclopedia of the sciences of learning* (pp. 2016–2019). Boston: Springer. Doi: 10.1007/978-1-4419-1428-6_675

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*(1), 135–168. Doi: 10.1146/annurev-psych-113011-143750

Fan, M., Antle, A. N., & Cramer, E. S. (2016). Design rationale: Opportunities and recommendations for tangible reading systems for children. In *Proceedings of the the 15th international conference on interaction design and children* (p. 101—112). New York, NY, USA: Association for Computing Machinery. Doi: 10.1145/2930674.2930690

Fitó, A. S. (2012). *Por que é tão difícil aprender?: o que são e como lidar com os transtornos de aprendizagem.* São Paulo: Paulinas.

Fonseca, V. d. (2014, 00). Papel das funções cognitivas, conativas e executivas na aprendizagem: uma abordagem neuropsicopedagógica. *Revista Psicopedagogia*, *31*, 236–253. Retrieved from `https://www.revistapsicopedagogia.com.br/detalhes/62`

Giordani, P., Cipriani, E., Fabiano, S., Moroni, C., Ravazzani, S., Di Renzo, M. R., & Mormino, S. (2012). Multimedia educational pills (meps) for corporate training: Methodology and cases. In *2012 ieee 12th international conference on advanced learning technologies* (pp. 427–429). Doi: 10.1109/ICALT.2012.141

Hansen, J., & Richland, L. E. (2020). Teaching and learning science through multiple representations: Intuitions and executive functions. *CBE—Life Sciences Education*, *19*(4), 1–15. (PMID: 33259277) Doi: 10.1187/cbe.19-11-0253

Hoskyn, M., Iarocci, G., & Young, A. (2017). *Executive functions in children's everyday lives: A handbook for professionals in applied psychology.* Oxford University Press. Retrieved from `https://books.google.com.br/books?id=cMPXDQAAQBAJ`

Hsu, Y.-S., & Wu, H.-K. (2015, August). Development and evaluation of technology-infused learning environments in taiwan. In *Science education research and practices in taiwan* (pp. 211–232). Springer Singapore. Doi: 10.1007/978-981-287-472-6_11

Huff, M., Bauhoff, V., & Schwan, S. (2010). A closer look at the split attention effect: Integrated presentation formats for troubleshooting tasks. In *Proceedings of the 9th international conference of the learning sciences - volume 1* (p. 174—181). International Society of the Learning Sciences.

Husted, S., Ramirez-Corona, N., Lopez-Malo, A., & Palou, E. (2014). A creative experience for chemical, food, and environmental engineering students in a material balances course. In *Asee annual conference and exposition, conference proceedings* (pp. 24.40.1–20.40.14). Indianapolis, IN, United states. Doi: 10.18260/1-2--19932

Kitchenham, B. A., & Charters, S. (2007). *Guidelines for performing systematic literature reviews in software engineering* (Tech. Rep. No. 2.3). Keele and Durham: Software Engineering Group, EBSE Technical Report, Keele University and Department of Computer Science University of Durham.

Krause, K. K. G. (2020, 5). Jogos digitais e funções executivas: funções executivas (2nd ed.) [Computer software manual]. Joinville. (Produto Educacional)

Malone, S., Altmeyer, K., Vogel, M., & Brünken, R. (2020). Homogeneous and heterogeneous multiple representations in equation-solving problems: An eye-tracking study. *Journal of Computer Assisted Learning*, *36*(6), 781–798.

McHugh, M. L. (2012). Interrater reliability: the kappa statistic. *Biochemia Medica*, 276–282. Doi: 10.11613/bm.2012.031

Meltzer, L., & Krishnan, K. (2007). Executive functions difficulties and learning disabilities: undestandings and misunderstandings. In L. Meltzer (Ed.), *Executive function in education: From theory to practice* (pp. 77–105). New York: Guilford Press.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science*, *21*(1), 8–14. (PMID: 22773897) Doi: 10.1177/0963721411429458

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100. Doi: https://doi.org/10.1006/cogp.1999.0734

Moritz, J. (2019). *The influence of representation control on task performance and learning* (Doctoral dissertation, Eberhard Karls Universität Tübingen, Tübingen). Doi: 10.15496/publikation-35237

Neuwirth, C. M., & Kaufer, D. S. (1989). The role of external representation in the writing process: Implications for the design of hypertext-based writing tools. In *Proceedings of the second annual acm conference on hypertext* (p. 319–341). New York, NY, USA: Association for Computing Machinery. Doi: 10.1145/74224.74250

Pande, P. (2020). Learning and expertise with scientific external representations: an embodied and extended cognition model. *Phenomenology and the Cognitive Sciences*, 1–20.

Pande, P., & Chandrasekharan, S. (2014). Integration of multiple external representations in chemistry: A requirements gathering study. In *Proceedings of the 22ndinternational conference on computers in education* (pp. 732–737). Nara, Japan.

Pande, P., & Chandrasekharan, S. (2017). Representational competence: towards a distributed and embodied cognition account. *Studies in Science Education*, *53*(1), 1–43. Doi: 10.1080/03057267.2017.1248627

Plass, J. L., Chun, D. M., Mayer, R. E., & Leutner, D. (2003). Cognitive load in reading a foreign language text with multimedia aids and the influence of verbal and spatial abilities. *Computers in Human Behavior*, *19*(2), 221–243. Doi: https://doi.org/10.1016/S0747-5632(02)00015-8

Prain, V., & Waldrip, B. (2006). An exploratory study of teachers' and students' use of multi-modal representations of concepts in primary science. *International Journal of Science Education*, *28*(15), 1843–1866. Doi: 10.1080/09500690600718294

Renkl, A., & Scheiter, K. (2017). Studying visual displays: How to instructionally support learning. *Educational Psychology Review*, *29*(3), 599–621.

Robinson, D. H. (2002). Spatial text adjuncts and learning: An introduction to the special issue. *Educational Psychology Review*, *14*(1), 1–3. Doi: 10.1023/a:1013135325190

Schank, P., & Hamel, L. (2004). Collaborative modeling: Hiding uml and promoting data examples in nemo. In *Proceedings of the 2004 acm conference on computer supported cooperative work* (p. 574—577). New York, NY, USA: Association for Computing Machinery. Doi: 10.1145/1031607.1031704

Shakouri, M., & Hashemi-Razini, H. (2019). Is there any difference in executive function and social adequacy between the children with dyslexia or dyscalculia disorder? *Chronic Diseases Journal*, *7*(3), 214–218. Retrieved from http://78.39.227.18/index.php/cdj/article/view/456

Tomlinson, B. J., Walker, B. N., & Moore, E. B. (2020). Auditory display in interactive science simulations: Description and sonification support interaction and enhance opportunities for learning. In *Proceedings of the 2020 CHI conference on human factors in computing systems* (pp. 1–12). New York, NY, USA: Association for Computing Machinery. Doi: 10.1145/3313831.3376886

Tytler, R., Prain, V., & Peterson, S. (2007). Representational issues in students learning about evaporation. *Research in Science Education*, *37*(3), 313–331.

Vainio, T., Hakkarainen, K., & Levonen, J. (2005). Visualizing complex medical phenomena for medical students. In *Chi '05 extended abstracts on human factors in computing systems* (p. 1857–1860). New York, NY, USA: Association for Computing Machinery. Doi: 10.1145/1056808.1057040

Vieira, C., Magana, A. J., Falk, M. L., & Garcia, R. E. (2017, August). Writing in-code comments to self-explain in computational science and engineering education. *ACM Trans. Comput. Educ.*, *17*(4). Doi: 10.1145/3058751

Wu, H.-K., Lin, Y.-F., & Hsu, Y.-S. (2012, May). Effects of representation sequences and spatial ability on students' scientific understandings about the mechanism of breathing. *Instructional Science*, *41*(3), 555–573. Doi: 10.1007/s11251-012-9244-3

Wu, H.-K., & Puntambekar, S. (2012). Pedagogical affordances of multiple external representations in scientific processes. *Journal of Science Education and Technology*, *21*(6), 754–767.