Doctoral School of Psychology

Evolutionary and Cognitive Psychology Doctoral Program

The Role of Individual Differences in Attention in Multimedia Learning Across Different Age Groups

Doctoral (PhD) dissertation

Cintia Bali

Consultant:

Dr. András Norbert Zsidó, PhD

2024

Pécs

Table of Contents

Acknowledgements

I want to start by expressing my gratitude to my supervisor, Dr. András Norbert Zsidó, for encouraging and supporting me in my chosen topic long before I began my PhD studies. I am thankful for the many years of working together, during which I had the opportunity to learn and grow from your guidance. Most of all, thank you for all the effort you put into boosting my self-confidence over the years. This was probably our most challenging project.

I am deeply grateful to my fellow Ph.D. students and colleagues Julia Basler, Botond Kiss, Rebeka Orbán, Fanni Őry, Adrián Fehér, Diána Pakai-Stecina, Petra Horváth-Polgár, Gyömbi Csapó, Tímea Matuz-Budai for always being there for me (to take me out for ice-cream and being my chocolate dealers) and creating the best support system that I could ever wish for.

I also want to express my gratitude to my former professors, who are now my colleagues at the Institute of Psychology at the University of Pécs. This work would not have been possible without the knowledge I gained from you.

I am grateful to the students who assisted me with their dedicated work throughout these projects. Special thanks to Vivien Balogh, Zsanna Csibi, Gréti Gáspár, Hanna Farkas, Anna Göde, Rawan Hamed, Anna Takáts, Krisztina Takács, and Buket Tasdelen. Your hard work, dedication and enthusiasm for the projects were invaluable, and your contributions have greatly assisted this research.

Thanks of course to my family and friends for their support. Finally, thank you Renáta Rajczi for proof-reading all my first drafts (even though you were not really interested in them) and Kata Hári for your endless patience and support throughout this journey.

1. General Introduction

The use of digital devices to enhance learning is becoming increasingly popular among parents and educators (Hockenson, 2020; Wylie, 2023). Most parents believe that children will benefit from using devices, especially for general knowledge acquisition and creativity (Fenstermacher et al., 2010). Teachers are almost expected to integrate technology into the teaching process (Vega & Robb, 2019). Parents and educators have endless possibilities to incorporate technology into classroom learning, as nowadays various digital presentation software (e.g., Prezi, PowerPoint, Canva), educational applications, and LMS systems are easily available through smartboards, computers, or touchscreen devices. However, their variety is the reason why it is increasingly challenging for both teachers and parents to choose or create the appropriate digital aids to facilitate learning (Kucirkova, 2017; Vaala & Lapierre, 2014). As a response, a scientific need emerged to understand how these tools work and how young children and students can benefit from using them. In line with this need, the purpose of this research is to make precise recommendations on the use of digital technologies for educational purposes based on empirical research findings.

The Cognitive Theory of Multimedia Learning (CTML) (Mayer, 2002), which serves as the basis for explaining the potential advantages and disadvantages of technology use in education, was described long before the rapid development of digital technology. Indeed, it originally focused on the interplay between text and pictures in traditional illustrated textbooks. However, the CTML has now evolved to encompass a wider range of technologies, including various sites on internet, smartphones, augmented reality (AR), and virtual reality (VR) (e.g., Barrow et al., 2019; Makransky et al., 2021; Parong & Mayer, 2018). This theory derives from the idea that it is easier to build mental representations when text and images are presented simultaneously. Therefore, using text and pictures together supports memory encoding and information retrieval (Mayer, 2002). CTML is based mainly on Paivio's (1990) dual code theory and Baddeley's (1992) working memory model. Consequently, it assumes that visual (e.g., pictorial) and auditory (e.g. spoken text) information is processed through different processing systems (or channels). This dual-channel processing helps to avoid the increased cognitive load during simultaneous information processing (Mayer, 2014). Educational applications and digital presentations can be highly beneficial because they can utilize the CTML by incorporating multimedia elements and interactive features. Multimedia elements offer the advantage of dual representation, which can help to illustrate abstract concepts, convey emotions, and guide attention (Altun, 2018; Danaei et al., 2020). On the other hand, interactivity mainly relies on the advantages of content-congruent activities and the active involvement of the users (Varga, 2014). To benefit from multimedia elements and interactivity learners must engage in an active form of learning, ultimately leading to improved learning outcomes (Mayer, 2014).

While multimedia elements and interactivity are surely beneficial, they have some limitations that must be considered. Multimedia learning is a complex process involving detecting, organizing, and integrating multiple information, making it cognitively demanding (Ayres & Sweller, 2014). This is an important factor as CTML acknowledges the limited capacity available for processing information simultaneously (Sweller & Chandler, 1994) and suggests multiple ways in which cognitive load can and should be reduced (R. E. Mayer & Moreno, 2003). Temporal synchronicity and content congruency are the main principles of CTML (Moreno & Mayer, 1999); however, it also claims that the instructional design of a presentation or an educational app should always consider the cognitive capacity constraints of the learners (Ayres & Sweller, 2014). One challenge in multimedia learning is determining when the instructional design becomes overwhelming for learners. In other words, it is unclear how many multimedia elements or interactive features are too many. Therefore, one of the objectives of the thesis is to study the effects of the number of multimedia elements on processing and memory encoding.

It is common, especially in digital presentations, that only certain parts of the spoken text are visually displayed (text-and-picture information), while other parts are only spoken (text-only). E.g., the spoken text may contain more information than the pictorial information displayed on the corresponding slide. Previously, most studies have focused on overall recall performance (meaning that they did not differentiate between text-only and text-and-picture information), so we have limited information about how the presence of pictures impacts the encoding of text-only information (Herrlinger et al., 2017; Levie & Lentz, 1982). The cognitive load might primarily affect text-only information, as pictures may have a perceptual advantage over textual information (Mintzer & Snodgrass, 1999). In this scenario, pictures could be distracting and hinder simultaneous processes. This is a second gap that we are aiming to address in this present work.

Distraction is not only a problem for multimedia elements but maybe even more pronounced for interactive features (Parish-Morris et al., 2013; Takacs & Bus, 2016).

Interactive features rely on active involvement and are controlled by the user Multimedia elements are automatic (Varga, 2014); therefore, time synchronicity would not be an issue. However, with interactive features, there is a higher risk of the violation of it. If the synchronization between the verbal information and the corresponding interactive feature is hampered it can interfere with the integration of information from different sensory modalities (Ginns, 2005). This increases the risk of splitting attention between the interactive feature and the corresponding verbal information leading to higher levels of cognitive load (Ayres & Sweller, 2014). To benefit from using interactivity it is crucial to understand the contributing factors of successful learning when interactivity is available. Therefore, we aimed to test whether using answer-until-correct (AUC) feedback-type interactive features (as a well-established pedagogical technique) (Butler & Roediger, 2008; Ernst & Steinhauser, 2012) and signaling the location of interactive features with visual cues would help diminish cognitive load and improve learning efficiency (Albus et al., 2021; Mayer, 2001; Van Gog, 2014).

We believe that to fully understand the occurrence of cognitive load during multimedia learning is essential to consider the role of individual differences in core cognitive functions such as working memory or executive attention (Altun, 2022). These factors are often overlooked, and the few studies that have addressed working memory capacity or attentional mechanisms have mainly focused on their role in the processing of irrelevant content, for example, when spoken text is accompanied by task-irrelevant pictorial information (Sanchez & Wiley, 2006; Wiley et al., 2014). Good attentional mechanisms can prevent higher cognitive load when irrelevant information is presented, suggesting that these factors could be important in decreasing cognitive load and improving learning efficiency (Sanchez & Wiley, 2006). However, our knowledge is limited when only content-congruent information is being processed. Previous studies indicate that with attentional difficulties the ability for multimodal integration also decreases (Barutchu et al., 2019; Talsma et al., 2010). The higher levels of distractibility may cause divided attention and an earlier occurrence of cognitive overload. Therefore, we believe that the role of attentional mechanisms in multimedia learning is essential and requires further investigation.

Lastly, we aimed to test the efficiency of multimedia learning and the role of individual factors across multiple age groups. For this reason, our studies ranged from pre-school children to university students. The age of the learners is a factor that is important to consider as the maturation of the key cognitive functions (such as working memory capacity and executive attention) continue to develop through middle childhood (Alloway & Alloway, 2013; V. A. Anderson et al., 2001; Fry & Hale, 2000). This ongoing maturation may cause age-related differences in the recommendations.

In conclusion, the main objective of this dissertation is to explore the factors leading to cognitive overload and to identify presentation modes to prevent it. To achieve this, we tested various instructional designs across different age groups. Primarily, we focused on electronic storybooks – popular educational applications for young learners – and digital presentations. Ultimately, we aim to provide recommendations for creating effective digital learning environments tailored to the needs of specific age groups and learners.

The dissertation is focused on the following key objectives (an overview of the studies is provided in Table 1.1):

1. Exploring how individual differences in attention affect information processing when interactivity is included or when multiple information sources are presented simultaneously. This work specifically concentrates on content-congruent multimedia elements and interactive features, as previous studies mostly explored the role of individual differences in the presence of irrelevant multimedia elements. Based on the complexity of multimedia learning, learners are expected to have different needs for effective multimedia learning.
2. Addressing controversial findings on interactive features, testing the role of interactivity in general knowledge acquisition, and forming recommendations on how to implement interactivity in a way that is beneficial.
3. Understanding the limitations of the processing system when learning with multimedia across different age groups and providing precise recommendations for the optimal number of multimedia elements based on empirical results.
4. Investigating how content-congruent multimedia elements influence the processing of text-only information.

Table 1.1. – Overview of experiments presented in the dissertation.

Study nr.	**Experiment nr.**	**Sample**	**Aims**
Study I.	Narrative Review	-	Discovering the main contributors of efficient multimedia learning.
Study II.	Experiment 1.	Pre-schoolers	Investigating the long-term benefits of electronic storybooks.
	Experiment 2.		Investigating the role of individual differences in learning with electronic storybooks.
Study III.	Experiment 1.	Elementary school students	Testing whether the feedback-type interactive features decrease cognitive load when learning with electronic storybooks.

Study IV.	Experiment 1.	Elementary school students	Testing whether visual cues decrease cognitive load when learning with electronic storybooks
Study V.	Experiment 1.	University students	Investigating how the increasing number of multimedia elements impact learning.
	Experiment 2.		Same as exp. 1. with a differentiation between text-only and text-and-picture information.
Study VI.	Experiment 1.	High school students	Investigating how the increasing number of multimedia elements impact learning. Text-only and text-and-picture information is tested separately.

2. Optimizing Learning Outcomes of Educational Applications Enhanced with Multimedia and Interactive Features: A Review [1]

2.1. Introduction

Educational applications have great potential to facilitate learning in and outside of the classroom both in preschool and elementary school (or even later); however, using them effectively is often challenging. In the past few years, the educational application market has shown significant increases, peaking at approximately 1 billion downloads during the pandemic, and continuing since. This growth is reflected in both the number of applications available and the number of active users (Hockenson, 2020; Vega & Robb, 2019; Wylie, 2023). At present, this is one of the leading sectors on the market for applications with approximately 200,000 applications only in the AppStore (Curry, 2023). Parents agree on the educational value of these applications (McClure et al., 2017) and expect to see benefits in terms of general knowledge acquisition, enhancement of cognitive skills, and language learning (Fenstermacher et al., 2010). Educational applications can be useful in and outside of the classroom due to their playful nature and embedded multimedia elements (such as sound effects, or animations) that portray the learning material visually. Multimedia elements support learning primarily by delivering information through multiple sensory modalities (R. E. Mayer, 2002); however, when combined with relevant physical activities they can further improve the academic performance of children (Mavilidi et al., 2016, 2018; Petrigna et al., 2022). This further increases the potential of educational applications as the touchscreen allows the use of embedded interactive activities.

The selection of applications that genuinely facilitate learning and serve as an aid for educators, however, is difficult because of the wide availability of applications labeled educational. This is due to the considerable differences in quality between these applications as many applications with educational labels have poor quality and fail to deliver the expected learning outcomes (Meyer et al., 2021; Vaala & Lapierre, 2014a). A large body of research examines the effectiveness of these applications and forms recommendations to help teachers make their choices based on empirical evidence (e.g.,

[1] This chapter is based on the following book chapter:
Bali C., Zsido A.N. (2024). Optimizing Learning Outcomes of Educational Applications Enhanced with Multimedia and Interactive Features: A Review. In: Papadakis, S., Kalogiannakis, M. (eds) *Education, Development and Intervention. Integrated Science*, vol 23. Springer, Cham. https://doi.org/10.1007/978-3-031-60713-4_11

Papadakis and Kalogiannakis 2017; Montazami et al. 2022; Bali et al. 2023b). The field, however, lacks a consensus on the definition of these applications, and the properties the studies test are often not well defined. Hence, in the present chapter, we sought to provide an overview and assistance for the effective use of educational applications by identifying the key research studies in the field and reviewing their results and recommendations.

Educational applications are not a one-size-fits-all solution to enhance children's learning capabilities and academic achievements. The specifications of educational applications need to be tailored to the group of individuals who are going to use them. Individual differences in core cognitive functions have been shown to influence how users benefit from using educational applications. Processing information through embedded multimedia elements and interactive features requires simultaneous information processing, task switching, and sharing attention (Ayres & Sweller, 2014; R. E. Mayer, 2002; Takacs et al., 2015). To benefit from educational applications, children are often forced to hold the upcoming information in their working memory and integrate it into their already existing knowledge. This might be an overwhelming task for those with more limited working memory capacity and less mature attentional mechanisms (Anmarkrud et al., 2019; Doolittle & Mariano, 2008; Wiley et al., 2014). Although recommendations on how to avoid cognitive overload and make the process less demanding are available in the literature (e.g., Moreno and Mayer 1999; Mayer and Moreno 2003), most of these studies fail to recognize the importance of considering individual differences among children in core cognitive functions such as working memory capacity and executive attention. Understanding the underlying mechanisms for processing multimedia elements and interactive features is crucial, as it can serve as guidance in choosing the appropriate applications that suit the educational goals and the needs of the children. Therefore, in the present chapter, we will attempt to explore the cognitive mechanisms involved in learning through educational applications and offer techniques to decrease the potential influence of individual differences.

We aim to provide insight into the current state of literature and introduce the main principles of using educational applications to promote learning. We will discuss the definitions of the different educational applications, seek to offer insight into the available embedded features and provide a possible solution to the mixed results of past studies in this field. Throughout the chapter, we will pay particular attention to the cognitive processes involved in learning through educational applications. This is crucial to understanding how these applications can be used to support children with learning disabilities and to select the right apps for the individual needs of the students. Finally, we will aim to provide some practical advice to practitioners on how to choose the right applications for educational purposes and introduce the main principles of using technology to promote learning. We believe that this paper has important contributions to theory, methodology, and application. Individual differences are often neglected in the research of educational applications, suggesting that children would benefit equally from using them. Teachers and parents are encouraged to use educational apps; however, they are often not properly informed. If these apps are not used correctly and are tailored to the needs of the children or the group, we may even widen the gap between children instead of supporting them. Therefore, we aim to point out the gaps in the literature, drawing researchers' attention to the need to address them. Exploring these areas is necessary to fine-tune the recommendations based on the existing literature. It is the responsibility of the researchers to make recommendations based on sound methodology and communicate them to parents and practitioners. At the end of the chapter, we attempt to make recommendations from the perspective of individual differences, building on earlier studies (e.g., Mayer and Moreno 2003). Future studies, however, should address these recommendations and provide further specifications regarding them.

2.2. Multimedia learning

2.2.1. The theory of multimedia learning

Using multimedia elements to improve students' engagement and their learning outcomes is not a new idea. This phenomenon is known as the cognitive theory of multimedia learning (R. E. Mayer, 2002), and it appeared well before the widespread availability of smart devices and touchscreen technology. The theory claims that learning is more efficient with the help of words and pictures compared to using purely verbal information. It is also easier for the students to recall and apply the knowledge they have acquired in this way. Initially, the theory covered the joint use of text and images (possibly animations), however, technological advances have now extended the boundaries of multimedia learning. Beyond static illustrations (that you can see in plain textbooks) designers can easily add narration, animations, and sound effects to the learning material with the help of smart devices (Varga, 2014). In addition, touchscreen technology allows the children to interact with the device (Kucirkova, 2017) or obtain immediate personalized feedback through the applications (Tärning, 2018).

2.2.2. Multimedia elements

Educational applications often use multimedia elements to convey the intended learning material. The first things that come to mind when we see the word "multimedia" are the stunning images and the various animations or videos, however, there is much more to this category. Multimedia includes embedded narration, background music, sound effects, or animations (Takacs et al., 2015; Varga, 2014). Of these, visual elements are the most studied and have the most impact on learning. Images and animations have the potential to illustrate the learning material well and accurately which results in deeper understanding and, consequently, enhances encoding and retention of that material in long-term memory (Bali, Matuz-Budai, et al., 2023). This not only makes recall easier but also helps to understand abstract words and phrases (Kulasekara et al., 2011). Multimedia elements embedded in electronic storybooks, together with background music and sound effects, easily capture the atmosphere of a story and the emotions of the characters, which improves the comprehension of the story and the understanding of complex emotions. These findings suggest that beyond expanding lexical knowledge multimedia elements also improve perspective-taking and the recognition of mental states and emotions (Altun, 2018; Danaei et al., 2020; Kucirkova, 2019). The impact of animations (movements), among the multimedia elements, seems to be the most pronounced, as the motion of the figures alone has the potential to support understanding and learning without other multimedia effects (Takacs & Bus, 2016). Movement triggers an automatic attentional orientation (Girelli & Luck, 1997; Shi et al., 2010) therefore, animated figures have the potential to highlight the key points for understanding the learning material by orienting attention through automatic processes. All this shows that educational applications are promising, as many of them rely on the phenomenon of multimedia learning by embedding multimedia elements.

2.2.3. Cognitive aspects

While numerous studies have demonstrated the effectiveness of multimedia learning, it also poses challenges as it requires simultaneous information processing and students have to hold all incoming information in their (limited) working memory. Educational applications usually contain plenty of multimedia elements (Furenes et al., 2021a; Takacs et al., 2015; Varga, 2014) which puts a strain on working memory and attentional processing. Executive attention is essential to highlight information and allocate attention toward information sources that are aligned with the current aims of the user (Petersen & Posner, 2012a). Many applications feature multiple sources of information (e.g., figures, animations, etc.) that are presented simultaneously. In these cases, users are forced to select the ones that are actually important to them.

To avoid cognitive overload (and possible resulting performance loss) there are a few criteria that these applications must meet. In accordance with the *contiguity principle* the cognitive load is decreased when multimedia elements (animations, illustrations, etc.) are relevant to the learning material and their timing is adjusted to the narration or the upcoming information in general (Moreno & Mayer, 1999). This can reduce the need for splitting attention and release cognitive capacity by reducing the resources devoted to integrating each modality (Ayres & Sweller, 2014). Since multimedia elements are displayed automatically, with proper timing they can correspond well to this principle. Indeed, automatic animations can be great tools to keep textual and visual information in sync when designed with awareness since they elicit an automatic orientation and direct attention toward the relevant part of the screen (Takacs & Bus, 2016). Even though multimedia elements are activated automatically (Takacs et al., 2015) when they are presented simultaneously there is still a chance that they will violate the contiguity principle. Electronic storybook applications might be good examples of this. In these applications, one page often contains several figures, animations, and interactive features at the same time. These elements might all be relevant to the overall content of the page, however, the child might have chosen to attend a part of the screen that will be relevant only later when the narrative gets to that point. Therefore, in this instance, the visual and the corresponding textual information are not delivered at the same time. This may place an additional burden on working memory processes.

The number of multimedia elements is also an important factor in the effectiveness of multimedia learning. The heavy use of multimedia elements can be overwhelming (Parong & Mayer, 2018) and distract attention (Bali, Matuz-Budai, et al., 2023) resulting in poor-quality processing. To date, there are no precise recommendations for the optimal number of multimedia elements. A recent study (Bali & Zsido, 2023) found that simple and relevant multimedia facilitates learning with up to three elements presented at a time. However, the results also showed that students with worse language proficiency performed worse when the learning material was accompanied by a high number of elements. This underscores that individual differences in cognitive performance affect dealing with a higher number of multimedia elements. It should be noted, however, that the study investigated up to three multimedia elements and focused on university students which limits the generalizability of the results. Nonetheless, it clearly demonstrates that designers and educators must consider the target group's current level of development in core cognitive functions as a point of reference. For instance, maintenance and manipulation in verbal and visuospatial working memory undergo substantial changes between the ages of 5 and 19 years (Alloway & Alloway, 2013). Therefore, holding and integrating a higher number of multimedia elements can become more efficient in adolescence and later. Maturation of processing speed is also ongoing during middle childhood contributing to age-related changes in working memory functions (Fry & Hale, 2000). Inhibition and conflict resolution mature rapidly during preschool and become more or less stable with slower changes after the age of 8-10 years (P. Anderson, 2002). This makes older students more resistant to distractions and helps maintain actual learning goals. Children with ADHD (attention-deficit/hyperactivity disorder), however, show a different developmental trajectory and a delay in the maturation of executive functions (Skogli et al., 2017). Executive functions consist of inhibitory control, working memory, and cognitive flexibility, constructs that are needed for maintaining voluntary attention and inhibiting distractors (Diamond, 2013) An impairment in these functions makes it necessary to consider the specific needs of children with ADHD when creating a technologically enhanced learning environment. Although using multimedia can be a powerful tool to illustrate and provide a first-hand experience of the learning material (Bujak et al., 2013), it must be used carefully, considering its limitations and its target group.

2.2.4. Future applications

Beyond touchscreens, newer technologies such as extended reality (XR) including augmented reality (AR), virtual reality (VR), or mixed reality (MR) further expand the possibilities for multimedia learning. Such technologies can ensure a three-dimensional representation of learning materials that are not accessible for direct experience. Although these technologies are all intended to make the learning material tangible and facilitate learning through this, they might vary in their level of efficacy. For instance, while AR allows more focused learning, VR might be more distracting as it contains many elements that are easy to get lost in.

The strength of AR technology is that it allows the connection of virtual elements to the real physical environment which gives students a hands-on experience and allows a deeper understanding of the learning material (Bujak et al., 2013). AR technology in education is available in many forms. Yuen and colleagues (2011) identified five directions of AR applications: Discovery-based Learning, Object-Modeling, AR Books, Game-Based Learning, and Skills training. While these are somewhat different from each other, they are similar in the way that they try to make the subject material tangible to the observer and combine the real world with virtuality. For instance, Langer and colleagues (2020), developed an AR application to improve the understanding of the concept of vectors. Their mobile app named Vektor AR3 enables a real-world depiction of vectors and allows interactions with these otherwise abstract concepts. This results in easier understanding as it connects abstract concepts to our real world. AR technologies have further benefits. Students using AR not only performed better at school but also reported a lower level of math anxiety which offers further evidence of its effectiveness (Y. C. Chen, 2019). Math anxiety research has a long history (Dowker et al., 2016) and its importance has not diminished to date. Students with math anxiety typically have difficulties performing well in the classroom, show low engagement in math-related problems, and perform poorly in mathematics (Barroso et al., 2021; Quintero et al., 2022). These results, however, raise the possibility that the use of digital technology can motivate students to practice outside the classroom and reduce school subject-related anxiety and avoidance (Berkowitz et al., 2015). This is extremely important as anxiety consumes cognitive capacity and thus places a greater burden on cognitive processing resulting in worse academic performance (I.-J. Chen & Chang, 2017). Therefore, using these newer technologies in the classroom is an emerging opportunity to reduce anxiety related to school subjects.

VR technology, similar to AR, can also be used to connect students with the material they are learning. An excellent example would be a previous study (see Parong and Mayer 2018) in which students had to learn about the functioning of the cardiovascular system with the help of immersive virtual reality or a traditional slideshow. Even though using VR was more enjoyable compared to the slideshow, students using virtual reality experienced difficulties in focusing attention and they felt distracted from the learning material. The learning outcome also decreased when students used VR. This confirms that the heavy use of multimedia elements can be distracting and reduce the quality of information processing. Using VR might also increase the cognitive load (Kállai et al., 2023) and diminish the quality of processing. The segmentation of the VR lessons, and writing a summary following each segment, however, led to improved performance when students learned with VR technology. Segmentation and summarizing prompts might decrease the cognitive load and guide students' attention (Parong & Mayer, 2018). Makransky and Petersen (2021) argue that the level of self-regulation might be a crucial factor in the success of learning in a technologically enhanced environment which underlines the importance of individual factors when learning with multimedia. Self-regulation allows us to maintain goal-oriented behavior in the presence of distractors (Hofmann et al., 2012; Parry et al., 2020), thus it enables students to select information from their environment that aligns with their learning goals. This is particularly important in an immersive environment such as VR. In addition to AR and VR the term mixed reality (MR) is also present in the literature. MR as a concept is not sharply distinguished from AR as its main principle is mixing the real world with virtuality incorporating a high amount of interactivity (Pan et al., 2006). All these results shed light on the strength of involving virtuality in classroom learning, while also drawing attention to its limitations. Virtuality is a powerful tool to enhance the understanding of abstract concepts, but just like other educational applications utilizing virtuality requires awareness from educators and designers.

2.3. Learning through activity – Interactive features

The development of XR technologies and the wide availability of touchscreen devices allow educational applications to deliver the learning material in an interactive way relying on playfulness and user activity. Interactivity is a key feature of educational applications. Beyond the different types of games (e.g., puzzles, memory, coloring pages, etc.), dictionaries, and exercises executed through the touchscreen, feedback-type interactions are also available providing personalized feedback for students (Fabio et al., 2019). While interactive features are available in various forms, they are designed with the same aim to increase the active involvement of the user and make them active agents in the learning process (Varga, 2014). The major advantage of using interactive features, apart from their playful nature, is that they add physical activity to the learning process. Adding relevant physical activities in teaching is a powerful way to enhance the learning outcome of children, even without the use of technological advances (Mavilidi et al., 2016, 2017, 2018). In one study by Mavilidi and her colleagues (2017), preschoolers learned about the solar system in the classroom. One group of children traveled around the solar system by running to each planet from the sun in the classroom, while others ran randomly or had been seated during the class. Children running toward the planets in a specific order learned more about the solar system compared to those who ran in random directions or had been seated. The benefits of using interactive features as a form of relevant activities have been reported in several previous studies mainly in terms of vocabulary growth, better comprehension, and retention (Bali, Csibi, et al., 2023; Bali, Matuz-Budai, et al., 2023; Smeets & Bus, 2015; Xu et al., 2021; Zipke, 2017). Children are also able to apply the acquired knowledge in new situations outside the digital world (Huber et al., 2016; F. Wang et al., 2016). In one study children could successfully solve a task in the real world after practicing it virtually with the help of an iPad (Huber et al., 2016). This suggests that children could transfer smoothly what they have learned previously on the touchscreen which might expand the boundaries of learning with educational applications. As a bonus, learning with the help of interactive apps is more engaging and entertaining for students (Richter & Courage, 2017) and this joyful experience might also contribute to improved academic achievement (Çetin & Türkan, 2022). Interactive features also have the potential to provide immediate feedback which might contribute to maintaining attention and improved learning outcomes (Fabio et al., 2019), while students also have a chance to learn with the help of corrective feedback. Immediate corrective feedback informs the students about the correctness of an answer and allows them to correct themselves as it delivers at least a cue regarding the correct answer (Butler & Roediger, 2008). Immediate feedback can also serve as reinforcement, enhancing the encoding of the correct answers (Ernst & Steinhauser, 2012). Interactive features, therefore, expand the boundaries of multimedia learning and facilitate learning by engaging and actively involving students in the learning process.

Despite these benefits, the impact of interactive features is not yet clear. Past studies (Parish-Morris et al., 2013; Reich et al., 2016; Takacs et al., 2015) frequently considered interactive features detrimental since they are distracting and require switching attention between tasks (e.g., dictionary functions or puzzles). This can hinder the highlighting of relevant content on the screen and the integration of the presented information, which might result in worse learning outcomes. Furthermore, using interactive features can cause a time lag between the upcoming verbal information and interactive features violating the contiguity principle and, consequently, increasing the cognitive load (Ayres & Sweller, 2014; Ginns, 2005). As interactive features are activated by the user (instead of playing automatically) this happens when children activate them before or after the corresponding information appears. Furthermore, since these features are usually entertaining and exciting, user control allows for hedonic use. Children enjoy utilizing interactivity; thus, sometimes they might be more engaged by the feature itself than by the content it communicates. This hedonic distraction can impair the quality of processing (Makransky et al., 2021). One further issue with studying interactive features lies in their high variability (e.g., puzzles, games, dictionaries, feedback, activities related to the story, etc.). Therefore, combining and studying them together is unfeasible. Unfortunately, past studies investigating their efficiency in learning tend not to specify the exact type they are using (Kucirkova, 2017); it is difficult to make comparisons between studies or draw general conclusions regarding interactive features. We certainly do not wish to claim that all interactive features are harmful, but we need to distinguish between possible ways of use and explore this issue from the perspective of cognitive processing.

2.4. Minding individual differences (in the classroom)

The use of educational applications is almost inevitable nowadays in and outside of the classroom, which can be challenging for teachers and students alike. Past studies have mainly focused on the possible impact of excessive amounts of screen time on attentional processing (e.g., Christakis et al. 2004; Stevens and Mulsow 2006; Gentile et al. 2012); however, numerous important new issues have recently emerged. It is not clear whether the extreme digitalization of education is truly beneficial for all. Is the success of processing information through educational applications a function of the current developmental state of core cognitive skills? Can these applications be utilized to help students with learning disabilities, or would they find it difficult to process and integrate the different stimuli they receive at the same time? Currently, we do not have enough empirical data to provide a conclusive answer to these questions; however, we can form some ideas based on a review of the literature.

Although the use of educational applications is strongly encouraged, neurodiverse students might not benefit from them as much as their neurotypical peers. For instance, ADHD is associated with impairments in executive functions such as working memory or inhibition (Krieger & Amador-Campos, 2018; Martel et al., 2007). Consequently, students with ADHD are characterized by higher distractibility and shorter attention span. Interactive features are attractive and highly engaging; therefore, they might distract attention and increase the cognitive load in neurodiverse children. While students are engaged with interactive features, they might not scan the whole screen or listen to the content at all which leads to less efficient information processing when interactions are used. The maturation of executive attention is essential for top-down mechanisms and sustaining attention while distractors are present (Petersen & Posner, 2012a), thus using educational applications might be exceptionally difficult for neurodiverse users. Educational applications often contain multiple sources of information simultaneously. In such cases, the user must decide – not necessarily on purpose – which information to attend. This is where top-down mechanisms become important, as they facilitate the selection of a stimulus that corresponds to one's current goals and inhibit distractors (Desimone & Duncan, 1995). For now, it should be clear that this is a challenging task for those with immature executive functions such as executive attention or working memory capacity. Hence the use of educational applications might be less beneficial for students with ADHD. The maturation of the executive attention network is related to the emergence of self-regulation (Posner & Rothbart, 2005) which could increase the risk of hedonic use in neurodiverse children. Consequently, it is exceptionally important to learn more about how to adjust these applications to the needs of neurodiverse children.

Despite these risks, there is evidence that multimedia elements have the potential to enhance the learning outcomes of students with ADHD. For instance, in a study by Fabio and Antonietti (2012) 12 to 14-year-old children learned about the origin of the solar system with the aid of a hypermedia tool involving texts, sounds, graphics, and pictures. Students with ADHD performed nearly as well as their typically developing peers on a memory retention test after using digital learning material with multimedia elements. The authors explained their results partly with motivational factors and partly with the specific characteristics of multimedia elements. Another study showed that in the presence of highly motivating stimuli, the performance of children with ADHD can reach the level of their neurotypical peers (Slusarek et al., 2001). Considering that device use in itself can be rewarding (Evans et al., 2011; Kabali et al., 2015), the extra motivational factor introduced by multimedia elements might further improve the learning outcome of children with ADHD. It seems plausible to claim that children are more engaged and enjoy using apps with multimedia elements and interactive features more than their traditional counterparts. Observational data suggest that children are less distracted when using devices (Richter & Courage, 2017; Zipke, 2017). Therefore, motivational factors might have a substantial impact, especially when we consider that children with ADHD often have lower academic motivation which might affect their academic performance (Smith & Langberg, 2018). It should be stressed, however, that a higher commitment to the device does not necessarily lead to improved academic achievement (Makransky et al., 2021; Makransky & Petersen, 2021).

Overall, device use alone can increase academic motivation in students, which might help sustain attention and increase resistance to distractors. Various multimedia elements can also be used to orient attention and aid the selection of information which might improve recall performance and comprehension. An eye-tracking study found that animations guide attention which makes the selection of information easier and improves the integrated processing of verbal and nonverbal information through the app resulting in more efficient learning (Takacs & Bus, 2016). Neurodiverse children, thus, have a great chance to benefit from using educational applications, however, considering the current developmental state of executive functions might be crucial for them. Consequently, educational applications must be tailored to the specific needs of these children.

2.5. Practical advice

While educational applications are promising for facilitating learning and have the potential to complement classroom work, many factors can undermine their effectiveness. It is therefore essential to utilize them with care and awareness even if it can be challenging to choose because of their wide variety. Researchers need to make recommendations based on their research and results that might help parents and teachers in the selection and proper use of educational applications. For instance, the work of Mayer and his colleagues (1999, 2003, etc.) produced excessive research on the topic of how to decrease cognitive load during multimedia learning in general. Here, we attempted to cover the most significant issues in terms of applications and individual differences in their use. The following recommendations can provide guidance to practitioners, however, they should be developed and refined by future research.

Embedded multimedia elements and interactive features must be relevant to the learning materials. This means that the different multimedia elements and game-like activities are strictly related to the knowledge to be learned (R. E. Mayer, 2002; R. E. Mayer & Moreno, 2003). On the market, many applications are available that contain colorful, entertaining, and attention-grabbing illustrations, animations, or interactive features that are not or only slightly related to the learning material (Takacs et al., 2015). Although there is research that found that simple irrelevant interactive features (and presumably multimedia elements) are not necessarily more demanding than relevant ones (Etta & Kirkorian, 2019) we still cannot recommend using applications containing such elements. Since executive functions (such as executive attention or working memory capacity) are determinants of how distractible someone is, we can assume that there is a large variance in the success of effective information processing when irrelevant distractors are present. Irrelevant elements increase cognitive load as they increase the number of elements to be processed at the same time.

The number of embedded multimedia elements and interactive features should correspond to the current developmental state of executive functions of the target group (R. E. Mayer & Moreno, 2003). Past studies found that even relevant multimedia elements and interactive features can increase cognitive load and, thus, decrease the efficacy of learning when there are too many of them (Bali, Matuz-Budai, et al., 2023; Parong & Mayer, 2018). While recommending the ideal number of multimedia elements and interactive features is difficult as it depends on the actual developmental stage of the target group, it is certainly worth keeping them low, especially for younger age groups. A recent study (Bali, Csibi, et al., 2023) suggests that 1 or 2 multimedia elements or interactive features presented on the screen at the same time are beneficial at the age of 8-10 years. These benefits seem independent of individual factors such as working memory capacity and sustained and selective attention. Therefore, the goal is to keep the number of multimedia elements and interactive features low and only use them to highlight a few key terms that are important to learn or essential for understanding the material (Bali and Zsido 2023; Xu et al. 2021).

The simplicity and low number of interactive features should decrease the necessity of task switching and attention sharing. As the user controls the interactive features using them might lead to the violation of the contiguity principle, they also increase the cognitive load by requiring task switching and attention sharing (Ayres & Sweller, 2014). Again, these issues may be avoided by using a maximum of 2 simple interactive features at a time (Bali, Csibi, et al., 2023). Instead of embedded games, activities that elicit actions that are related to the subject material seem to be more effective (Tarasuik et al., 2016; F. Wang et al., 2016; Xie et al., 2018), taking advantage of the fact that learning is easier through relevant physical activities (Mavilidi et al., 2016, 2017). In addition, interactive features based on well-established pedagogical techniques – such as the answer-until-correct feedback-type interactions – also proved to be beneficial (Bali, Csibi, et al., 2023). These recommendations might contribute to the decreased hedonic use of interactive features. The hedonic use of these activities might be joyful and motivating for the students while increasing engagement, however, instead of productive use students might be tempted to prolong their use (Makransky & Petersen, 2021). Careless use of interactive features might violate the precise timing between the interactive features and the corresponding verbal information.

Timing is crucial in successful multimedia learning, therefore multimedia elements and interactive features should be synchronized with the information delivered verbally. When temporal co-occurrence is achieved, it helps to connect information received in different modalities, which reduces cognitive load and promotes learning (Ayres and Sweller 2014; Mayer and Moreno 2003). When applications are not designed with awareness beyond interactive features, multimedia elements can create a time lag. Since moving figures elicit reflexive attentional orientation which is exceptionally difficult to inhibit voluntarily (Shi et al., 2010; Takacs & Bus, 2016), a poorly timed animation can easily become a distraction. In such cases, those with better executive functions might have an advantage in processing as they are more resistant to distraction but the performance of those with poorer executive functions will suffer widening the gap between individuals.

The risk of cognitive load is decreased when the different types of information sources do not rely on the same sensory modality. The most common example of this is when a piece of information is presented as a visual illustration and as a written text at the same time. Since both presentation forms are processed visually, sharing attention is almost inevitable. Switching the written text to a read-a-loud narration can resolve this issue allowing students to simultaneously observe the illustration while listening to the narration without the need to switch attention (R. E. Mayer & Moreno, 2003). These recommendations illustrate how complex the issue of using educational applications is. The effectiveness of learning with applications is influenced by many factors, however, first and foremost, it is important to ensure that the applications are always aligned with the current target group and educational purpose (for a brief summary of our recommendations see Table 2.1). The recommendations we proposed here are mostly applicable to children with attentional difficulties or self-regulatory problems. Sticking to them might help to minimize the impact of individual differences and narrow the gap between neurotypical and neurodiverse children making educational apps beneficial even in a heterogeneous group.

Table 2.1 – A brief summary of the recommendations and their impact.

Recommendation	Definition	Benefits/impacts
Relevance	In simultaneous presentations, multimedia elements, interactive features, and narration communicate the same content	Facilitate the integration of information received in different modalities. Decrease cognitive load.
Number of embedded multimedia elements/ interactive features	The number of embedded multimedia elements and interactive features should correspond to the target group's actual developmental state of executive functions.	A low number of interactive features will decrease the cognitive load. 1 to 2 in preschool or elementary school. Highlight the key terms.
Simplicity	It is worth using 1 or 2 interactive features at a time, which are simple, and thus can be used effortlessly.	Decrease the necessity of task switching and attention sharing.
Timing	Multimedia elements and interactive features should be synchronized with the information delivered verbally.	It helps to connect information received in different modalities. Decrease cognitive load.
Modality effect	The different types of information sources should not rely on the same sensory modality.	Decrease the necessity of task switching and attention sharing.

2.6. Conclusion

The market for educational applications is one of the leading sectors on Google Play or AppStore, with promising benefits in numerous fields, such as general knowledge acquisition, language learning, and vocabulary growth, but many of them cannot deliver. One plausible explanation is that individual differences in working memory capacity, executive attention, and self-regulation influence the efficiency of learning using these apps. The design of educational applications is often based on the cognitive theory of multimedia learning (R. E. Mayer, 2002), which requires simultaneous information processing and holding information in working memory. This might be a challenge for neurodiverse children with impaired executive attention or self-regulation as a stimulus-laden digital environment might be overwhelming and distracting for them. In addition to using multimedia elements, these apps often take advantage of the fact that learning is easier and more entertaining through playful and relevant activities which can easily lead to hedonic use and become a source of distraction. We argued that multimedia elements and interactive features can only be beneficial and have the potential to increase students' engagement and promote learning if practitioners consider a few criteria to reduce the impact of individual differences between children when using them. Throughout the chapter, we discussed the most important conditions and issues emerging around educational applications and offered many ways to resolve them. We found that when using educational applications, the focus should be on choosing applications that were designed in such a way that they do not increase the cognitive load in the users. A few techniques such as using only a small number of simple and relevant multimedia elements and interactive features, or the precise timing of the elements can decrease the cognitive load and the impact of individual differences. We also advise designing interactive features based on existing pedagogical techniques (e.g., immediate feedback). Incorporating these methodological considerations could make educational applications even more promising tools to support students with learning difficulties. Overall, carefully designed educational apps have the potential to improve the learning outcome and the emotional attitude toward the subject or the learning material if practitioners address the issues discussed throughout the chapter before bringing them into the classroom.

3. Executive attention modulates the facilitating effect of electronic storybooks on information encoding in preschoolers [2]

3.1. General Introduction

A wide range of applications with supposedly educational benefits is available with the purpose to help young children's knowledge acquisition. Currently, the most popular applications available on Google Play are labeled as educational, with 60% of them targeting preschoolers (Shuler et al., 2012). For educational applications, the best examples include electronic storybook applications, that use multimedia elements and interactive features to adapt traditional storytelling for touchscreen devices (Varga, 2014). Electronic storybooks are user-friendly and easy to use even for pre-readers which makes them increasingly popular with parents and teachers (Zipke, 2017). Although electronic storybooks provide some benefits for emergent literacy and general knowledge acquisition the results are controversial (Takacs et al., 2015). In addition, applications with an educational label do not always deliver the educational outcome that they promised (Vaala & Lapierre, 2014b). Empirical studies are therefore crucial to guide teachers and parents to find applications designed for effective knowledge acquisition (Papadakis, 2020; Papadakis et al., 2020).

3.2. Experiment 1.

3.2.1 Introduction

The popularity of electronic storybooks is not surprising considering that embedded multimedia elements and interactive features are excellent tools for playful learning. Multimedia elements – including narration, animated illustrations, background music, sound effects, and camera effects – can support general knowledge acquisition in many ways (Takacs et al., 2015). Animated illustrations are effective tools for guiding attention

---

[2] This chapter is based on the following article:
Bali, C., Matuz-Budai, T., Arato, N., Labadi, B., & Zsido, A. N. (2023). Executive attention modulates the facilitating effect of electronic storybooks on information encoding in preschoolers. *Heliyon*, *9*(1). https://doi.org/10.1016/j.heliyon.2023.e12899
CB: Conceived and designed the experiments; Performed the experiments, Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data, Wrote the paper, TMB; NA; BL: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper. ANZS: Conceived and designed the experiments; Performed the experiments; analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data, Wrote the paper.

toward relevant information on the screen (Takacs & Bus, 2016). Supplemented by sound effects and background music, they have further potential to promote understanding of abstract words (Takacs et al., 2015) and recognition of emotions and mental states (Altun, 2018; Kucirkova, 2019). Using interactive features activated through the touchscreen can provide further benefits. The purpose of interactive features is to actively involve the user in the presented story through embedded activities strongly related to the plot (Varga, 2014). For example, helping a cartoon figure make pancakes by putting all the ingredients into a bowl using the touchscreen (see Berry and Dolly – Summer Tale: Pancake Party; ONCE Digital Arts Ltd). Learning, accompanied by relevant physical activities can enhance understanding and recalling (Mavilidi et al., 2016, Mavilidi et al., 2018; Petrigna et al., 2022). Recent studies in the field of embodied learning also emphasize the importance of integrating physical movements into the learning process (Georgiou & Ioannou, 2021; Jusslin et al., 2022; Ng & Ye, 2022). Overall, children seem to learn easier through interactive applications with embedded multimedia and can transfer the acquired knowledge to the physical world (Çetin & Türkan, 2022; Huber et al., 2016; Wang et al., 2016, Wang et al., 2021).

There are an increasing number of studies regarding the potential benefits of electronic storybooks on vocabulary or story comprehension (see Smeets & Bus, 2015; Takacs & Bus, 2016; Xu et al., 2021; Zipke, 2017), however still little is known about the long-term advantages. Furenes and colleagues (2021) emphasize that most of the studies approach electronic storybooks in the context of learning, yet the number of longitudinal studies is extremely low. Furthermore, the exact processes behind the benefits are not well-understood. For instance, we do not know whether the alleged benefits of using electronic storybooks come from more efficient coding or mitigated forgetting. In the framework of the *cognitive theory of multimedia learning* (Mayer, 2014) it may be assumed that the multimodal communication of information (multimedia elements) and the physical activity through interactive features have an immediate effect on coding new information. However, we still do not know for certain that the information gained by electronic storybooks will be better stored in long-term memory (Furenes et al, 2021; Savva et al., 2022). Increasing the number of longitudinal studies in this field is extremely important, only studies with such a design can tell how effectively these applications can support learning outcomes in the long term.

Thus, in Experiment 1, we sought to investigate the *long-term effects* of electronic storybooks on recall performance in preschoolers. We measured long-term outcomes after three weeks, as it can be assumed after this period, we would assess information consolidated in the long-term memory (Cowan, 2008). We selected electronic storybooks containing interactive and multimedia elements relevant to the story that facilitate engagement in the plot. This is important to highlight as the variety of interactive features and the lack of operationalization can make it more difficult to interpret the data regarding interactive features (Kucirkova, 2017). The multimedia elements and interactive features in the selected electronic storybooks were not just relevant, but also simultaneously presented with the narration. This is one of the key features of avoiding cognitive load and enhancing information processing (Ayres & Sweller, 2014; Eng, et al., 2020; Liu et al., 2022; Mayer & Moreno, 2003). Because of the huge age-related differences in the maturation of executive functions (Jones et al., 2003; Rueda et al., 2005) in our study we targeted a narrow age spectrum between 5 to 6 years. As was pointed out (Furenes et al., 2021b), to date, there is little known about the long-term advantages of electronic storybooks in the context of learning. Thus, in Experiment 1, we aimed to test a possible long-term improvement after using an electronic storybook with multimedia elements and interactive features. We hypothesized that children using an interactive electronic storybook will recall more accurate details than children who heard the experimenter read aloud the same story. We predict that improvement will be observed both immediately after the exposure and three weeks later.

3.2.2. Materials and methods

In our first experiment, we used a design similar to the study of Richter & Courage (2017). They used traditional and electronic storybooks to present stories to children and then asked short questions immediately following the exposure to assess their recall performance. In addition to this, besides the short questions, we also asked the children to retell the story. Both methods are well-established in the literature on electronic storybooks (Furenes et al., 2021b). Furthermore, we also did a follow-up measurement three weeks after the first assessment to investigate the persistence of changes in recall performance. Such follow-up tests are necessary because they show whether the improvement is due to better encoding or a more efficient retrieval of the information.

3.2.2.1. Sample

We recruited a total of 33 children (14 girls) between the ages of 5 and 6 ($M = 5.55$; $SD = .506$). The sample size for this experiment was determined by computing estimated statistical power. We conducted an a priori power analysis using G*Power software (Faul et al., 2007) to test for repeated measures GLM (within-between interaction) with 4 (2 x 2) correlating repeated measures ($r = .45$). The analysis, based on previous studies (Takacs & Bus, 2016; Zipke, 2017) indicated a required total sample size of 16 (f = .40, 1-ß = .80). We recruited children through kindergartens. We contacted the principals of the kindergartens and gave them a detailed description of our study. If the principal agreed to participate, we asked for contact with the kindergarten teachers. If a teacher also agreed to help us, we asked them to hand out informed consent forms to the parents of each child in their group. Although the parents of 47 children signed the consent form, a total of 14 children were excluded from the final sample. Ten of them had previous knowledge about the story used in the experiment, three of them could not be reached for the follow-up session and one child failed to follow the instructions. All the participants were typically developing children, and no neurological or other disorders were reported by their parents; 75% of the children use smartphones or tablets at least on a weekly basis, and the rest of them had no earlier experiences with touchscreen devices. All children involved in our study were prereaders.

Children were randomly assigned into two groups: an interactive application group ($N = 16$) and a print book group ($N = 17$). Members of the interactive application group were introduced to a story by an interactive storybook application, while the print book group listened to it traditionally. Data were collected individually in both groups. The study was approved by the local ethics committee (2020-108) and was carried out under the Declaration of Helsinki. All children have verbally agreed to participate.

3.2.2.2. Instruments

3.2.2.3.1. The storybook

We selected a Hungarian folktale (The Little Rooster and His Diamond Halfpenny) for the exposure. The tale is commercially available both in paper book format and as an interactive storybook. Each version is the same length and contains 468 words. It presents a simple story about a little rooster who finds a diamond halfpenny. The greedy Sultan takes the diamond halfpenny from the rooster therefore the rooster must outwit the Sultan to get the halfpenny back. The *interactive storybook application* we used in this study was developed by TechLab of Moholy-Nagy University of Art and Design (http://techlab.mome.hu/). The interactive storybook has 10 pages and each of them contains 46.8 words and 2 interactions on average. Read-aloud function and sound effects (like the sound of the bees or birds singing) are included as well. The interactive storybook was presented using a Lenovo TAB2 A10-30 10" touchscreen device. The *print book version* was read aloud by the experimenter from a Hungarian folktale collection by Laszlo Arany (1995). The print book version was presented without any illustration. The texts of the electronic storybook and the print book version were identical.

3.2.2.3.2. Recall performance

We used two methods to measure recall performance. First, children were asked to retell the story (henceforth named *retelling*) as best as they could remember; then they were asked to answer nine questions (henceforth named *short Q&A*) related to characters and the plot (e.g., "What did the little rooster find?" and "Where did the little rooster find it?"). We always started with the retellings to avoid the potential influence of the short Q&A on the number of recalled words. Retellings were evaluated by counting the number of recalled words from the story. The children recalled 8 (SD = 7.16) words on average; the minimum number of words was 0, and the maximum was 25. The answers to the short Q&A were rated using a three-point scale between 0 to 2. Wrong answers meant 0 points, correct but incomplete answers meant 1 point, and correct answers meant 2 points. Children could achieve a maximum of 18 points by answering all 9 questions correctly. All answers were scored by two independent scorers. One of the scorers was the first author of this paper, the other one was a faculty member of the University and blind to the aim of the study. The achieved points ranged from 1 to 18 points (M = 9.22; SD = 4.15). The agreements between the scorers were tested using Kendall's coefficient of concordance. Inter-rater reliability was 0.895; with a 77% agreement ($p < .001$) that indicated substantial correspondence between the scorers.

3.2.2.3.3. Working memory (WM) capacity

WM capacity was measured using the Hungarian version of the *Listening Span Task* (Janacsek et al., 2009). Children were asked to listen carefully to a few sets of sentences then decide if the statements are true or false then repeat the last word of each sentence.

The number of sentences increases by one in each set. The first set contains two sentences. If the child cannot correctly recall the last word of all the sentences in the same set the examiner stops there and switch to the next block. The task consists of three blocks. Children received points separately in each block which was equal to the number of sentences in that set where they could correctly recall the last words of each sentence. Finally, the WM capacity was indicated by the mean values of the points received in the three blocks. *Listening Span Task* can be used between the ages of 4-89 years; therefore, the task is suitable for the young sample of the study. The results of the Listening Span Task were used as an indicator of the children's WM capacity. The achieved scores by the children ranged from 0 to 2.33 points. Higher scores indicate better performance.

3.2.2.3. Procedure

We used a between-subjects design; thus, children were randomly assigned into two groups. Members of the interactive application group were introduced to the story by an interactive storybook application on a Lenovo tablet (with a 10-inch screen). In this group, children could freely explore the application, while the story was presented by the read-aloud function. In the print book group, the story was read aloud by the first author without any further illustration. Immediately after the exposure, the children retold the story, and then answer the short Q&As (Time 1). The answers of the children were recorded for later analysis.

The study was conducted in a spare, quiet room at the preschool. The children participated individually, only the experimenter was present during the story exposure and the data collection. The experimenter established rapport through a small conversation with the child, then explained what would happen during the task. The child was informed that participation is voluntary and there are no negative consequences of withdrawal from the study. Participation required the verbal consent of the child. Children were also asked if they were familiar with the story. If they answered yes, we asked them to recall as many elements from the story as they could. Those with previous knowledge were excluded from the data analysis. Recalling correctly at least one element served as an exclusion criterion.

Three weeks after the story exposure and the first measurement of the recall performance, a second data collection was conducted (Time 2). Children were, again, asked to retell the story, and then answer the same nine questions, similarly to the first time. The story was not repeated during the second meeting. Children also completed the Listening

Span Task at this phase of the study. All children received a small reward for their participation. Participation lasted about 30 minutes in Time 1 and 15 minutes in Time 2. See the full experimental design in Figure 3.1.

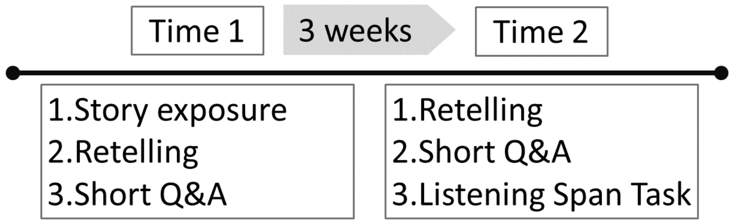

Figure 3.1 – The experimental design of Experiment 1. In the figure, the exact measurements are shown belonging to the first (Time 1) and second (Time 2) data collection. Three weeks passed between Time 1 and Time 2. At Time 1 children listened to a story or used an electronic storybook with interactive features, then we asked them to retell the story and complete a short questionnaire (Short Q&A) with open-ended questions regarding the story. At Time 2, the children retold the story and completed the Short Q&A once again. They also completed the Listening Span Task as a measurement of working memory capacity.

3.2.2.4. Data analysis

Statistical analyses were performed using the JAMOVI Statistics Programme (Version 1.2.27.0 for Windows). Outliers (number of recalled words more than 2 SD from the mean) were excluded, approximately 9 % of all the collected data.

First, we analyzed the data from the retellings, then the ratings of the short answers to the questions. In both cases, we performed a General Linear Model (GLM) analysis with the number of recalled words (retelling) or total points (short Q&A) as the dependent variables, respectively. The book format (interactive storybook or print book) was the between-subject factor and the time of the measurement of the recall performance was entered as a within-subject factor. We used WM capacity (results of the Listening Span Task) as the covariate variable.

3.2.3. Results

Regarding the *number of recalled words (retellings)*, the two groups did not differ (F (1,23) = 1.42, p = 0.246). Neither the main effect of the time of the measurement (F (1,23) = 1.33, p = .260) nor the interaction between the time of the retelling and the book format was significant (F (1,23) = .02, p = .901). WM capacity had no significant effect on the performance (F (1,23) =1.22, p = .281). Means and standard deviations are reported in Table 3.1.

Regarding the *ratings received to the short Q&A*, we found a significant difference between the two groups (F (1,29) = 4.65, p = .039; ηp^2 = .138). The members of the interactive application group reached higher scores on the nine questions compared to those of the print book group. As expected, we found a significant main effect of time (F (1,29) = 6.404, p = .017, ηp^2 = .181), as the performance dropped over time, and children of both groups recalled fewer details about the story in Time 2 compared to Time 1. The interaction (F (1,29) = .369, p = .548) and the effect of WM capacity was nonsignificant (F (1,29) = .29, p = .598). The two groups did not differ regarding the scores gained on the Listening Span Task (t (31) = -.207; p = .837). Means and standard deviations are reported in Table 1. Distributions of the data regarding recall performance on the short Q&A are reported in Figure 3.2. The Benjamini–Hochberg false discovery rate procedure was used to correct for multiple comparisons (Benjamini & Hochberg, 1995; Glickman et al., 2014; Verhoeven et al., 2005).

Table 3.1. – Means and standard deviations of the Listening Span Task and recall performance in terms of the number of recalled words (Retelling) and points received to the short answers (short Q&A), separately for Time 1 (immediately after hearing the story) and Time 2 (three weeks later), Interactive application and Print book format.

Task	Phase	Group	Mean	SD
Retelling	Time 1	Interactive app	9.07	7.69
		Print book	6.08	6.49
	Time 2	Interactive app	8.80	8.25
		Print book	4.85	5.94
Short Q&A	Time 1	Interactive app	10.9	4.03
		Print book	7.76	3.78

	Time 2	Interactive app	9.27	3.28
		Print book	6.82	4.56
Listening Span Task		Interactive app	.586	.794
		Print book	.643	.775

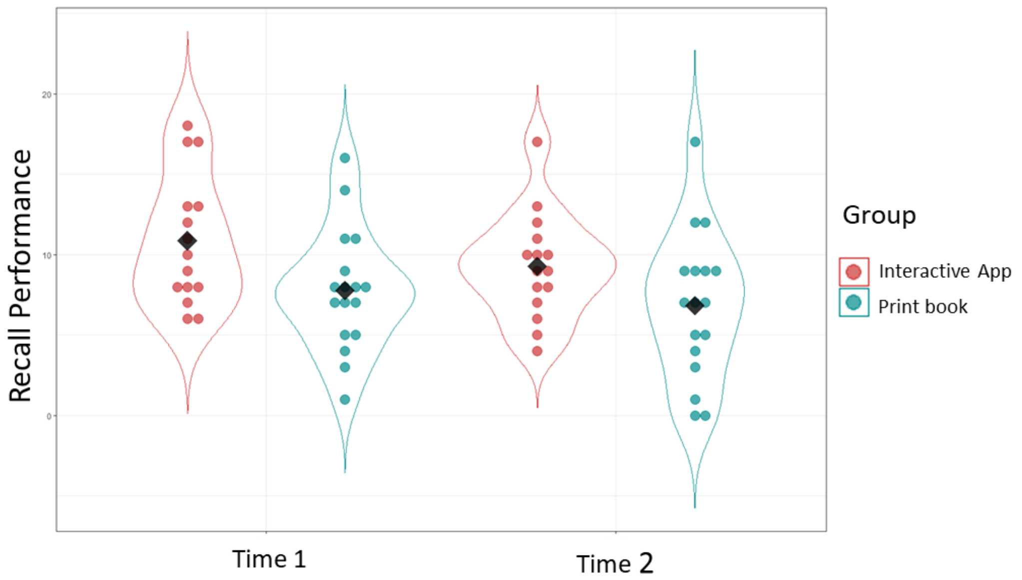

Figure 3.2 – The distributions and means of recall performance on the Short Q&A (number of correct answers) right after the story exposure (Time 1) and three weeks later (Time 2), separately for the interactive application group and the print book group. Black diamonds show the mean scores, dots represent the actual score of participants.

3.2.4. Discussion

In Experiment 1 we aimed to test the possible long-term benefits of using an electronic storybook. Children in the *interactive application group* performed better than those in the *print book group* considering the result of the short Q&A. This is in line with previous studies showing the potential benefits of electronic storybooks on story comprehension (Danaei et al., 2020; Takacs & Bus, 2016; Zipke, 2017) and supports the idea that young children may benefit from interactive features and multimedia elements in knowledge acquisition. However, we did not find a significant difference in the efficiency of retelling between the *interactive application* and the *print book group*. Although retelling is a frequently used method to measure recall performance (Furenes et al., 2021b), considering the less efficient narrative competencies of preschoolers (Mäkinen et al., 2014) reconstruction of the story might be more challenging than answering short questions. Since retelling rather reflects the narrative competencies than recall performance (Gazella & Stockman, 2003), in our second study we used exclusively the short Q&As.

The interaction between time and book format was nonsignificant, that is, children in the *interactive app group* performed better than those in the *print book group* even after three weeks – since the initial group difference did not diminish in the short Q&A. Thus, we may assume that the improvement in recall performance results from the more efficient encoding of new information rather than better memory consolidation. Hence, we decided to drop the follow-up measurements and focus more on encoding in Experiment 2. Also, considering these results the next question to address is whether individual cognitive factors (for instance WM capacity or attention) influence the encoding of new information. Previous studies showed the importance of individual differences in attention and WM capacity in the success of encoding new information and integrating information from multiple sources (Awh et al., 2006). However, here, we did not find evidence of the influence of WM capacity. Although the Listening Span Task is a validated tool to measure WM capacity from 4 years of age, in the present sample we found that it did not differentiate between participants. This is because the task and instructions were hard to understand and follow. Thus, in Experiment 2, we used a different, more widely used task to assess the WM capacity of the children.

The characteristics of multimedia elements and interactive features can also affect the efficiency of information processing through electronic storybooks. Interactive features compared to multimedia elements might be more demanding for the limited cognitive capacities and immature executive functions of preschoolers (Ayres & Sweller, 2014; Parong & Mayer, 2018). For testing this, in our second experiment, we introduced a multimedia-only application condition besides the interactive and audio conditions.

3.3. Experiment 2.

3.3.1. Introduction

Although Experiment 1 in line with many earlier studies proved that electronic storybooks could facilitate general knowledge acquisition, benefits are not always observed (Etta & Kirkorian, 2019). An important, yet often overlooked factor in understanding the influence of electronic storybooks on knowledge acquisition is the current developmental state of executive functions (Altun, 2021; 2022). During the preschool years (and even later) the maturation of executive functions, such as working memory (WM) capacity and the executive attention network, is still ongoing, thus preschoolers are characterized by high distractibility and a short attention span (Garon et al., 2008; Petersen & Posner, 2012b; Rothbart & Posner, 2015). Since the maturation of the executive attention network is a key to top-down attention and maintaining attentional focus in the presence of distractors, focusing on relevant information may be particularly difficult for those with less efficient attentional mechanisms (Petersen & Posner, 2012). Besides executive attention, WM capacity might also have a great role in the inhibition of distractors and focusing attention. Individuals with higher WM capacity may show more efficient learning in a digital environment with distractors (Kane et al., 2007). Individual differences in the maturity of executive functions may very well explain why the advantages of electronic storybooks are not always reflected in performance. In a multimedia learning setting where multiple information sources are presented simultaneously focusing on and allocating attention toward relevant information might be difficult for those with less effective attentional mechanisms and WM capacity. Later on, this might result in reduced quality of information processing and worse recall performance. However, there is only a little evidence supporting these claims, and a recent systematic review (Booton et al., 2021) calls for further research in this area.

Processing information while using interactive features might be particularly difficult, as they often require switching between tasks and sharing attention (Takacs et al., 2015). Since interactive elements are controlled by the user, there could be a time lag between interactive features and upcoming information. This time lag makes it more challenging to integrate information from different modalities which may decrease the quality of information processing (Ayres & Sweller, 2014; Ginns, 2005). Compared with interactive features, multimedia elements play automatically and simultaneously with the narration, thus, there is a decreased risk of interference between information coming from different modalities (R. E. Mayer & Moreno, 2003). A few studies (e.g., Eng et al., 2020; Fabio et al., 2019; Fabio & Antonietti, 2012) have also reported that the academic performance of children with a lower level of attention regulation improved after using multimedia-only subject materials. Presumably, multimedia elements improve academic performance by orienting attention toward relevant information, while using digital devices can maintain motivation (Çetin & Türkan, 2022; Takacs & Bus, 2016). Although multimedia elements were shown to be useful even for those with less efficient executive functions, how interactive elements affect processing has not yet been explored. Nevertheless, it can be assumed that interactive features can interfere with information processing by providing a source of distraction and reducing temporal contiguity.

The aim of Experiment 2, therefore, was to explore how individual differences in the maturation of executive functions might influence the benefits of using electronic storybooks. Understanding how individual differences in executive functions affect the processing of multimedia elements and interactive features might guide developers, educators, and parents to create an appropriate digital environment for learning while accounting for the individual needs of the children. Therefore, in Experiment 2, we investigated how individual differences in attentional performance and working-memory capacity can influence encoding new information by using both interactive and multimedia-only electronic storybooks. We used an interactive storybook condition (same as in Experiment 1) and a multimedia-only electronic storybook (without interactive features) condition to differentiate between the effect of multimedia elements and interactive features on recall performance. We hypothesized that using interactive features will be more demanding for those with less matured attentional mechanisms and a smaller WM capacity, which will result in poorer recall performance in the interactive condition. However, we expected that in the multimedia-only condition the improvement in recall performance will not be affected by individual differences in cognitive factors.

3.3.2. Materials and methods

The procedure was highly similar to Experiment 1. The four key differences were that (1) we used a within-subject design, in which each child participated in three conditions. Children participated in three conditions because (2) we included an additional, multimedia (henceforth named multimedia-only, without interactive features) storybook condition to separate the effect of multimedia and interactive features on recall performance. Further, (3) we only used the short Q&A to measure recall performance since we did not find any differences in retellings across conditions in Experiment 1. Furthermore, (4) we decided not to conduct a follow-up test and move the focus of Experiment 2 to explore the differences between conditions. We decided to leave out the follow-up tests, because in Experiment 1 there was no significant interaction between time and book format, suggesting that differences between conditions can be measured immediately after the exposure.

3.3.2.1. Sample

We recruited a total of 32 (16 girls) children between 5 to 6 years of age (M = 5.56; SD = .619). We conducted an a priori power analysis using G*Power software (Faul et al., 2007) to test for repeated measures GLM (within factors) with 3 (1 x 3) correlating repeated measures (r = .45). The analysis, based on Experiment 1 indicated a required total sample size of 13 (f = .40, 1-ß = .80). We recruited children through kindergartens. We contacted the principals of the kindergartens and gave them a detailed description of our study. If the principal agreed to participate, we asked for contact with the kindergarten teachers. If a teacher also agreed to help us, we asked them to hand out informed consent forms to the parents of each child in their group. Parents of 40 children signed the consent form, however, 8 children were excluded because they had previous knowledge about the presented stories. All the participants were typically developing children, and no neurological or other disorders were reported by their parents; 84% of the children use smartphones or tablets at least on a weekly basis, and the rest of them had no earlier experiences with touchscreen devices. All children involved in our study were prereaders. The study was approved by the local ethics committee (2020-108) and was carried out under the Declaration of Helsinki. All children have verbally agreed to participate.

3.3.2.2. Instruments

3.3.2.3.1. The storybooks

Since in Experiment 2 we used a within-subject design we needed stories that could be compared with each other therefore we selected the *Berry and Dolly: Four Seasons Book* by Erika Bartos. The selected book contains four stories with similar styles featuring Berry, the snail, and Dolly, the ladybug. Each story is related to a particular season (Winter Tale, Spring Tale, Summer Tale, and Autumn Tale) and presents a simple story about it (e.g., building snowmen, planting flowers, making pancakes, or visiting a grape harvest). The stories are age-appropriate and commercially available both in print book format and as an interactive storybook. The print book was published by Pozsonyi Pagony publishing house in Hungary. The *interactive storybook* versions were developed by the ONCE Digital Arts Ltd. and they are available through Google Play and AppStore in Hungarian and English (e.g., https://apps.apple.com/us/app/winter-tale-berry-and-dolly/id1208958373). Each story has 13 pages, one page contains 32 words and 3.3 interactions on average. Multimedia elements like animations, sound effects, and narration were available as well. The stories were equal in the terms of complexity, vocabulary, and the number of interactive features and multimedia elements. Further information about the stories is presented in Table 3.2. For the *multimedia-only condition*, we made screen videos of each interactive storybook to exclude the interactive features and keep the multimedia elements including the narration. We presented these screen videos to the children. Audio recordings of the interactive storybook applications were also made for the *audio condition*. Audio recordings were used to ensure the same auditory input for each child. The stories were presented using a Meizu M6 Note 5.5” touchscreen device. For the exposure three story were selected randomly from the available four.

Table 3.2. – Descriptive data of the stories in Berry and Dolly: Four Seasons Book by Erika Bartos.

Tale	Pages	Words	Words/pages	Interactions
Winter Tale: The Snow Owl	13	411	31.6	3.2
Spring Tale: Dolly’s flower	12	408	34	3.8
Summer Tale: Pancake Party	13	423	32.54	3.4
Autumn Tale: Harvest	13	417	32.1	2.8

3.3.2.3.2. Recall Performance

We asked children to answer ten questions (henceforth named *short Q&A*) related to the plot of the story (e.g., “What did Berry make?” and “What ingredients were used for the pancake?” etc.). Answers were rated on three-point scales between 0 to 2 points by the experimenter and two additional independent scorers. The same rating system was used as in Experiment 1. The agreements between the scorers were tested using Kendall's coefficient of concordance. Inter-rater reliability was .923 ($p < .001$), indicating high correspondence between the scorers.

3.3.2.3.3. ADHD Rating Scale-IV Preschool Version

One caregiver of each child was asked to complete the Hungarian version of the ADHD Rating Scale-IV (Perczel et al., 2005) about the children. The 18-item questionnaire measures inattention, hyperactivity, and impulsivity between the age of 5-18 years (McGoey et al., 2007) on two subscales: inattention and hyperactivity/impulsivity. Each item is rated on a 4-point Likert-type scale ranging from 0 (never or rarely) to 3 (very often) according to which number best describes the behavior of the child over the past six months. The questionnaire has excellent psychometric properties, in this study the McDonald's ω was .949 for the inattention and .926 for the hyperactivity/impulsivity subscale.

3.3.2.3.4. Attentional performance

We used the Chair-lamp Task (Porkolabne, 1998) to measure the attentional performance of the children. This is a timed paper-and-pencil test to assess sustained and selective attention in children from the age of 5. The task requires resistance to fatigue and high concentration. It consists of a test sheet that portrays 399 black-and-white simple figures (e.g., lamps, chairs, flowers, fruits, etc.) on both sides of the paper. Children are asked to mark as many chairs and lamps as they can find with a single line and ignore the other figures. They have 5 minutes to work on the task. To evaluate their performance the total number of attended figures (N), the total number of errors (E), and the total number of omissions (O) were registered. We used these measures to calculate the attention quality index (AQI) using the following equation: ((E+O)/N)100. Note, that higher scores indicate *worse* performance. Achieved scores in this study ranged from 0.2 to 11.42 points.

3.3.2.3.5. Working memory (WM) capacity

The Digit Span Task (Nagyne Rez et al., 2007) was used to measure the WM capacity of our participants. Children were asked to listen carefully to a sequence of digits and then repeat them in the same order. The number of digits increases by one after every two sequences. The task ended if the child made errors in two consecutive same-length sequences. The total number of correctly recalled sequences was used as an indicator of WM capacity. Higher scores indicate greater WM capacity. According to Wechsler's rating system children could achieve 16 points on both versions. Achieved scores ranged between 4 and 11 points.

3.3.2.3. Procedure

Children were introduced to three different stories from the book in three different formats in separate sessions. The interactive and multimedia stories were presented using a Meizu M6 Note touchscreen device (with a 5.5-inch screen). The interactive storybook condition was identical to Experiment 1, and in the audio condition (which served as the control condition) children listened to an audio recording of the story. In the multimedia-only storybook condition children held the mobile device and watched the storybook without interactions. Data were acquired in three separate sessions. In each session, children were exposed to one story, directly

followed by a short Q&A; then in the first session, we assessed their WM capacity, and in the second session their attentional performance. All the children participated in each session. The order of the stories was counterbalanced across children and conditions. Each session lasted about 30 minutes. Similarly, to Experiment 1 the study was conducted in a spare, quiet room at the preschool. The children participated individually, only the experimenter was present. All children received a small reward for their participation.

3.3.2.4. Statistical analysis

Statistical analyses were performed using the JAMOVI Statistics Programme (Version 1.2.27.0 for Windows). Outliers (number of recalled words more than 2 SD from the mean) were excluded, approximately 1 % of all the collected data.

First, to test the effect of the book format on recall performance we used a GLM analysis, where the within-subject factor was the medium of the book (audio, multimedia only, interactive). Follow-up pairwise comparisons were adjusted for multiple comparisons using Tukey's procedure. Afterward, we performed four separate GLMs to test if individual differences in WM capacity, attentional performance, and hyperactivity/impulsivity influenced recall performance. Digit Span Task scores, AQI scores, and the sum totals of the Inattention and Hyperactivity/Impulsivity subscales of the ADHD Rating Scale-IV were entered as covariates, in separate analyses. We used Pearson correlations to follow up on the significant covariation effects.

3.3.3. Results

As expected, we found a significant main effect of book format (*F* (2,62) = 9.57; $p < .001$; ηp^2 =.236). Tukey corrected pairwise comparisons revealed that children's recall performance was better both in the multimedia only (*t* (31) = -3.98; $p < .001$) and in the interactive storybook conditions (*t* (31) = -2.92; *p* = .017) compared to the audio condition. The multimedia only storybook condition and the interactive storybook condition did not differ (*t* (31) = -1.76; *p* = .200).

The Inattention subscale of ADHD Rating Scale-IV (*F* (1,30) = 6.97; p = .013; ηp^2 = .189) had a significant effect on the recall performance. Since we did not found interaction between inattention and recall performance (*F* (2,60) = 2.38; *p* = .101) we used the mean performance values for the follow-up Pearson correlation. The correlation revealed a moderate negative relationship between inattention and the mean values of recall performance. For the exact statistical values see Table 3.3.

AQI scores (*F* (1,29) = 5.47; *p* = .026; ηp^2 = .159) had a significant effect on the recall performance and the interaction between recall performance and the covariate variables occurred for the AQI scores was also significant (*F* (2,58) = 3.23; *p* = .047; ηp^2 = .100). AQI showed a moderate negative correlation with the recall performance in the interactive and the multimedia only conditions, but not in the audio conditions. For the exact statistical values see Table 3., results are reported visually in Figure 3.3.

The Hyperactivity/Impulsivity subscale of ADHD Rating Scale-IV (*F* (1,30) = 3.03; *p* = .092) and WM capacity (*F* (1,30) = 3.71; *p* = .064) had no significant effect on the recall performance of the children. Interactions were nonsignificant regarding to Hyperactivity/Impulsivity (*F* (2,60) = 1.56; *p* = .219) or WM capacity (*F* (2,60) = 2.84; *p* = .066). Means and standard deviations are reported in Table 3.4. The Benjamini–Hochberg false discovery rate procedure was used to correct for multiple comparisons (Benjamini & Hochberg, 1995; Glickman et al., 2014; Verhoeven et al., 2005).

Table 3.3. – Pearson follow-up correlational coefficients and *p* values between recall performances (total, and separately for the three book formats) and the four covariate variables used in the GLMs. Significant main effects and interactions regarding the GLMs are labeled in italics.

	Book Format							
	Total		Audio		Interactive		Multimedia only	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Hyperactivity/Impulsivity	-.303	.092	-.038	.838	-.333	.062	-.332	.064
Inattention	*-.434*	*.013*	-.185	.309	-.509	.003	-.278	.125
AQI	*-.398*	*.026*	*-.045*	*.810*	*-.456*	*.010*	*-.430*	*.016*
Working memory	.332	.064	.164	.369	.456	.009	.095	.606

Table 3.4. – Means and standard deviations of the recall performance for the Audio, Interactive, and Multimedia only conditions. Means and standard deviations regarding the two subscales of the ADHD Rating Scale IV, attention quality index (AQI) of the Chair-lamp Task, and scores on the Digit Span Task are also reported.

Task		Mean	SD
Book Format	Audio	10.7	2.60
	Interactive app	12	2.95
	Multimedia only app	12.9	2.18
	Total	12	2.13
ADHD Rating Scale-IV.	Inattention	8.06	5.89
	Hyperactivity/Impulsivity	6.91	5.88
	Total	15	11
Chair-lamp Task	AQI	3.66	2.81
Digit Span Task	Forward	5.97	1.86

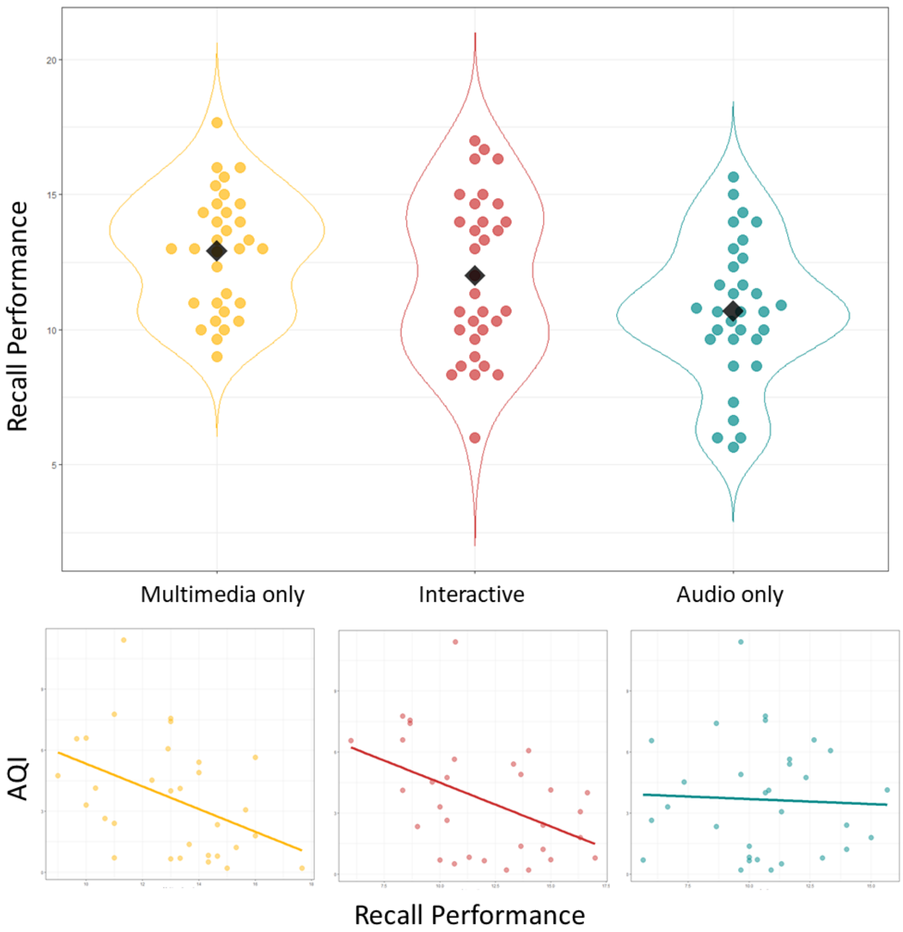

Figure 3.3 – Top panel: The distributions of recall performance on the Short Q&A (number of correct answers) in the three conditions (multimedia only, interactive and audio). Bottom panel: The correlations between Attentional Quality Index (AQI) and recall performance by the same three conditions. Higher values are corresponding to worse performance on the AQI. The same colors indicate the same conditions. Black diamonds show the mean scores, dots represent the actual score of participants.

3.3.4. Discussion

In Experiment 2 we aimed to test whether individual differences in the maturation of executive functions affect the efficiency of encoding new information when using electronic storybooks. In line with the result of Experiment 1, and the framework of the cognitive theory of multimedia learning (Mayer, 2005), multimedia elements and interactive features significantly improved recall performance compared to the audio condition, underscoring their importance in knowledge acquisition. Furthermore, in line with earlier studies (see Altun, 2021; Lim et al., 2021), we found that children with less efficient selective and sustained attention skills performed worse on the short Q&As in comparison to those without attentional difficulties. However, results on the ADHD Rating Scale-IV showed no relationship between inattention and recall performance across conditions. The ADHD Rating Scale-IV measures inattention as a broad phenomenon. Besides children's behavior is rated by the caregiver which might bias our results. In contrast, the chair lamp task provides a more accurate view of the attentional abilities of the children as it is based on their actual performance rather than the caregivers' perception and it focuses solely on sustained and selective attention rather than a broad range of inattention symptoms. According to our results, it seems that recall performance is influenced equally by inattention in all three conditions, however, recall performance in multimedia and interactive conditions depends more on that how well children can sustain their attention and select relevant stimuli between distractors. This supports our hypothesis that focusing on relevant information in the presence of multiple multimedia elements and interactive features can be demanding for children with attentional problems. The loss of performance may occur from the potential temporal discrepancy between narration and interactive features (Eng et al., 2020; Ginns, 2005). Unlike multimedia elements, interactive features are controlled by the user (Takacs et al., 2015) and thus, the narration and interactive features may dissociate in time. That is, there is a time lag between interactive features and upcoming information. The dissociation may result in a higher cognitive load and might also be a source of distraction. Based on the *cognitive load theory* (Ayres & Sweller, 2014), the simultaneity of elements of different modalities in the terms of content and time is a prerequisite for efficient multimedia learning and diminishes cognitive load. In the present study, the extraneous load might arise from the high number of simultaneously presented multimedia elements and from the interactive features that can be repeated indefinitely. Future studies should test these assumptions. In the audio condition, neither WM nor attentional mechanisms influenced recall performance. Hyperactivity and impulsivity had no effect in either condition. The influence of individual differences on information processing was already proven to be relevant regarding factors like the level of self-efficacy (Wang et al., 2022), however, our results gave further significance to the importance of examining individual differences in this area.

3.4. General Discussion

Electronic storybooks have a growing popularity among parents and educators. These applications provide a great opportunity for playful learning (e.g., Huber et al., 2016; F. Wang et al., 2016, 2021), but the benefits of the multimedia elements and interactive features used in these applications are not always evident, especially in the long term (Furenes et al., 2021; Savva et al., 2022). It is still not known whether the multimedia elements in a storybook facilitate the encoding of new information or mitigate forgetting it. A possible reason behind the mixed result is that the efficiency of information processing through electronic storybooks varies greatly as there are great individual differences in the maturity of executive functions (e.g., attentional control and WM capacity) in children. Hence, we designed two experiments to investigate how multimedia and interactive features in electronic storybooks improve recall performance in children, accounting for individual differences in attentional processing and WM capacity. In Experiment 1, we focused on the long-term effects of using an electronic storybook application to test whether multimedia elements and interactive features affect encoding or forgetting. We hypothesized that children using interactive electronic storybooks will recall more accurate information than children in the Print Book group and this improvement will persist over time. As we predicted the recall performance in the short Q&As of children in the interactive application group was significantly better compared to the Print Book group. In line with Schweppe & Rummer (2014) this improvement persisted over time, i.e., the difference between the groups did not change three weeks later. Thus, the multimedia features facilitated encoding but did not mitigate forgetting. Besides being an important addition to the literature that lacks longitudinal data (Furenes et al., 2021), this also suggests that electronic storybooks can be effectively used to *transfer* new knowledge and the acquired information is better retained in long-term memory.

In Experiment 2, we were interested in the cognitive factors accounting for efficient encoding. We hypothesized that using interactive features will be more demanding for those with less matured executive functions, while multimedia elements will improve recall performance regardless of individual differences in executive functioning. We replicated the results of Experiment 1, as interactive features, and multimedia elements improved recall performance in children between the age of 5 and 6 years. However, we also found that children with poorer sustained and selective attentional abilities performed worse in multimedia and interactive conditions. These results only partially support our hypothesis because, contrary to our assumption, the processing of multimedia elements is also affected by the maturity of executive functions. Our results are in line with the attention as a "gatekeeper" for WM theory (Awh et al., 2006; Schmicker et al., 2016). Taken together we showed that although multimedia elements and interactive features can support encoding, individual factors – such as sustained and selective attention – also have an important role in the efficiency of encoding. This also broadens our understanding of precisely what executive functions are important to focus on for teachers if they use multimedia and interactive features in their classes. These results could also be used by developers of electronic storybook applications to build an environment that can be customized based on individual needs and differences.

Our second experiment supports that in electronic storybooks with embedded multimedia elements and interactive features, the ability to select relevant information and ignore the irrelevant ones may have particular importance. Information processing is most effective when children can orient their attention toward those stimuli presented on the screen that are relevant to the current activity. This highlighting is modulated by the efficiency of top-down control functions (Moore & Zirnsak, 2017) which is determined by the maturation of the executive attention network (Petersen & Posner, 2012b). It has been shown that information processing is more stimulus-driven in children with less matured executive attention network (and, hence, poorer cognitive control functions), therefore they are more easily distracted by salient stimuli on the screen compared to those with stronger cognitive control functions (Gathercole & Alloway, 2009; Rothbart & Posner, 2015). In the case of electronic storybooks, if a child attends to a piece of irrelevant information and only switches their attention toward the relevant stimulus later in time, there will be a mismatch between the narration and the embedded multimedia element. This mismatch may interrupt the integration of information coming through different modalities, which increases the cognitive load and decrease the quality of encoding – reflected in recall performance (Ayres & Sweller, 2014; Liu et al., 2022; Parong & Mayer, 2018; Schmicker et al., 2016).

Although touchscreen devices easily capture and sustain the attention of the user (Richter & Courage, 2017), how visual attention is oriented within the screen is the concern here. Our results also point to the limitations of applying multimedia learning. Although multimedia learning is effective only under specific conditions, such as the congruency between narration and multimedia elements (Ayres & Sweller, 2014; Mayer, 2005), our results suggest that individual differences in attentional control processes may modulate its effectiveness. This also underscores that the individual needs of children should be taken into account when choosing the right applications for (multimedia) learning. This is an important practical addition that parents and educators need to keep in mind, and developers need to address.

Although our findings are novel, we should acknowledge certain limitations in the current investigation, and encourage conceptual replication of our work using other techniques. Our first limitation is that, although we sought to get a complex view of participating children's cognitive abilities, we had to consider the limited attentional span and working capacity of preschool-aged children. To avoid mixed results due to fatigue, we limited the number of measurements involved in our study to an attentional and a WM test. In future measurements of verbal abilities and attentional networks, e.g., the child version of the Attention Network Test (Rueda et al., 2004), might be included. The latter would be helpful to draw more accurate conclusions about the relationship between various attentional mechanisms and the processing of interactive features and multimedia elements. To better understand the underlying mechanisms of multimedia learning measurements of cognitive load should also be involved in the future (Krieglstein et al., 2022) The second limitation is the laboratory setting which lessens the generalizability of our results. We sought to control as many variables as possible, and thus, the experiments took place in a laboratory setting, i.e., during the data collection only the child and the experimenter were present in a spare, quiet room. To increase the extent of generalizability of our results, and to gain more validity, future experiments need to explore the effectiveness of electronic storybooks in a more common environment, like at home or in a classroom. Finally, we assumed that processing multimedia elements and interactive features consume more attentional resources, but we have limited information about the underlying mechanisms. The third limitation is that we could not monitor eye movements and count the number of interactions used during the presentation of a storybook. These variables would prove to be useful to gain a deeper understanding of how individual differences affect information processing when using multimedia elements and interactive features. Finally, we need to highlight that, although we argue that electronic storybooks help the acquisition and retrieval of new knowledge from long-term memory, we only measured recall performance after three weeks. Future studies should measure performance after several months or a year to get more pronounced results in this field.

Despite these limitations, we have demonstrated that electronic storybooks have the potential to support knowledge acquisition in preschoolers by providing a playful learning environment with embedded interactions and various multimedia elements. This has also been shown to be persistent over time, providing further confirmation of the effectiveness of using electronic storybooks in learning. Since the results of Experiment 1 and Experiment 2 are highly similar even though they included two different samples and were collected with different methods, we think this also adds to the robustness and replicability of our results. The results of Experiment 2 also highlight that, children with poorer sustained and selective attention process information less efficiently through multimedia elements and interactive features than their peers. This may explain why the advantages of electronic storybooks are not observable in some cases and also draw attention to the importance of taking individual differences into account in this field of study.

These findings not only emphasize the importance of individual needs regarding digital educational environments but may also guide parents and educators on how to use them, and developers on how to develop them. Children can benefit from using electronic storybooks; however, the amount of improvement depends on the maturation of attentional processes. To reduce cognitive overload, developers should focus on temporal contiguity (see Eng et al., 2020; Liu et al., 2022) and lessen the number of potential distractors. Features supporting the orientation of attention toward relevant the relevant part of the screen should be implemented. Future studies should identify the traits that support focusing on relevant information and understanding the story. While interactive storybooks likely cannot replace the benefits of having a real-life mentor, the immediate feedback and the multisensory stimulation provided by these storybooks can still be useful. Future studies need to focus on understanding the exact mechanism of these features in learning and how this technology could be best utilized.

4. Feedback-type interactive features in electronic storybooks enhance learning regardless of cognitive differences [3]

4.1. Introduction

Electronic storybook applications offer a fresh and promising way to support general knowledge acquisition. According to the cognitive theory of multimedia learning (R. E. Mayer, 2014), the acquisition of new information is more efficient when the teaching material is delivered via multiple sensory modalities. For instance, during classes at school, children see visual media elements while listening to explanations from teachers. As electronic storybooks operate with embedded multimedia elements and interactive features (Takacs et al., 2015), they are excellent appliances for utilizing multimedia learning. Multimedia elements such as narration, animations, background music, or sound effects convey information through at least two sensory modalities while guiding attention and facilitating the understanding of abstract words, complex emotions, and abstract phrases (Altun, 2018; Takacs et al., 2015; Takacs & Bus, 2016). These elements are automatically displayed; therefore, with proper timing, they correspond to the contiguity principle (Moreno & Mayer, 1999), which states that temporal and spatial contiguity are essential for efficient multimedia learning.

In addition to multimedia elements, the properties of touchscreens expand the boundaries of multimedia learning and allow the use of interactive features. Interactive features are controlled by the user, and they aim to involve the children in the story with story-related activities (Varga, 2014). Integrating relevant physical activities in the learning process improves understanding and retention (Mavilidi et al., 2016, 2018; Petrigna et al., 2022) and helps children transfer acquired knowledge into their daily lives (Huber et al., 2016; F. Wang et al., 2016, 2021). Furthermore, a growing body of research emphasizes the advantages of playful learning in primary school (Jusslin et al., 2022; Kangas et al., 2017;

---

[3] This chapter is based on the following article:
Bali, C., Csibi, K. Z., Arato, N., & Zsido, A. N. (2023). Feedback-type interactive features in applications for elementary school students enhance learning regardless of cognitive differences [Manuscript submitted for publication]. Department of Cognitive and Evolutionary Psychology, University of Pécs.
CB – Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Supervision; Validation; Visualisation; Roles/Writing – original draft; Writing – review & editing, KZSCS – Conceptualization; Data curation; Investigation; Methodology; Roles/Writing – original draft; Writing – review & editing, NA – Conceptualization; Methodology; Supervision; Roles/Writing – original draft; Writing – review & editing, ANZS – Conceptualization; Data curation; Funding acquisition; Formal analysis; Methodology; Project administration; Supervision; Validation; Roles/Writing – original draft; Writing – review & editing

Randolph et al., 2016). Electronic storybook applications with embedded multimedia elements and interactive features therefore have the potential to facilitate learning and improve the learning experience.

Individual differences in cognitive processes might affect learning outcomes when using electronic storybook applications for educational purposes. This is especially true at a younger age (e.g., in elementary school) when the maturation of executive functions is still ongoing (P. Anderson, 2002; Best et al., 2009; Zelazo & Müller, 2010). The efficiency of multimedia learning depends on the success of parallel processing and the integration of stimuli from different sensory modalities (Ayres & Sweller, 2014; R. E. Mayer & Moreno, 2003). Individual differences in working memory (WM) capacity and attentional processes influence the success of both parallel processing and integration (Anmarkrud et al., 2019; Bali, Matuz-Budai, et al., 2023; Doolittle & Mariano, 2008; Wiley et al., 2014). Electronic storybook applications are typically rich in multimedia elements and interactive features (Kucirkova, 2017; Takacs et al., 2015; Varga, 2014); therefore, holding information (in the WM) and allocating attention (to the information to be learned) can be challenging for many. Children with better working memory capacity can hold more information at a time (and, presumably, for a longer period) and integrate it more efficiently (Ayres & Sweller, 2014; Cowan, 2010; Wiley et al., 2014). In addition, executive attention has a crucial role in highlighting relevant information and ignoring irrelevant content while using these apps (Petersen & Posner, 2012b). Considering this, it is no wonder that teachers often find it challenging to find the right applications (Vega &, 2019). Nevertheless, to date, most studies ignore individual differences in information processing when students learn with these apps (Altun, 2021, 2022). Thus, additional research is needed to explore the main characteristics of electronic storybooks that can be beneficial for everyone, regardless of individual differences in core cognitive functions.

A lower number of relevant (content congruent) and well-timed multimedia elements may make electronic storybook apps beneficial for children with varying cognitive abilities. Recommendations on what makes electronic storybook apps beneficial for all students are challenging tasks due to the mixed results of the large body of related research (Furenes et al., 2021a; Kucirkova, 2017; Takacs et al., 2015). The mixed results are partly because the market for electronic storybooks is highly diverse, making comparisons extremely difficult (Kucirkova, 2017), especially because studies tend to use diverse sets of storybooks and do not measure individual differences. Due to the lack of systematic testing of various features, it is difficult to create an appropriate digital learning environment that suits the needs of those with less mature executive functions. Nevertheless, regarding multimedia features, there are a few general recommendations that we sought to test in the present study. On the one hand, due to the contiguity effect, multimedia elements are effective when they are relevant to the story and are featured with appropriate timing adjusted to the narration (Moreno & Mayer, 1999). On the other hand, recent research (Bali, Matuz-Budai, et al., 2023) has demonstrated that even relevant multimedia elements and interactive features can lower the quality of information processing in the presence of weaker attentional performance. This is possible since relevant multimedia elements can be overwhelming when they are presented in high numbers (Parong & Mayer, 2018). This suggests that cognitive load must be kept low, which can be achieved by reducing the necessity of task switching and sharing attention and implementing the right number of multimedia elements (R. E. Mayer & Moreno, 2003). The latter is difficult because there is no precise suggestion on the extent to which multimedia elements should be used; however, we assume that a low number of elements (e.g., 1-2 elements per page) should be beneficial when they are content congruent and well timed. These recommendations are also general, and they do not consider the individual differences between children. In line with the findings of a recent systematic review (Papadakis, 2020), these findings all underline the need for more precise recommendations and evaluation criteria for educational applications.

Interactive features have an even greater potential than multimedia elements because they add relevant physical activities (Georgiou et al., 2021; Georgiou & Ioannou, 2021; Mavilidi et al., 2016, 2018) and provide feedback (Fabio et al., 2019) that improves learning outcomes and contributes to a joyful learning experience (Çetin & Türkan, 2022; Kosmas & Zaphiris, 2023; Mavilidi et al., 2017; Son et al., 2020; Stapp et al., 2021). While recommendations concerning multimedia features (small number, relevant, well-timed) can also be applied to interactive features, interactive features are controlled by the user, which makes them different from automatic multimedia elements (Varga, 2014). Using interactive features might cause a time lag between the upcoming verbal information and interactive features, which may violate the principle of contiguity and increase the cognitive load (Ayres & Sweller, 2014; Ginns, 2005). Past studies (Parish-Morris et al., 2013; Reich et al., 2016; Takacs et al., 2015) have frequently considered interactive features detrimental since they are distracting and require attention to be switched between tasks (e.g., dictionary functions or puzzles). This can hinder the highlighting of relevant content on the screen and the integration of the presented information, which might result in weaker learning outcomes. However, interactive features are available in a wide range of varieties (e.g., puzzles, games, dictionaries, feedback, activities related to the story, etc.), which makes it unfeasible to combine them and study them together. Furthermore, past studies investigating their efficiency in learning tend not to specify the exact type they are using (Kucirkova, 2017).

Feedback-type interactions may be an example of interactive features that aid learning outcomes. Immediate corrective feedback provides information about the correctness of an answer and allows the children to correct themselves, as it delivers at least one cue regarding the correct answer (Butler & Roediger, 2008). Immediate feedback can also serve as reinforcement, enhancing the encoding of correct answers (Ernst & Steinhauser, 2012). Furthermore, feedback-type interactions seemed to fit a broader audience, as this feature might have the potential to highlight the main points in the learning material while decreasing the probability of a time lag and reducing the need for switching attention. Consequently, the cognitive load is lower than that associated with other types of interactive features, which are crucial for successful information processing (R. E. Mayer & Moreno, 2003). Due to the lack of definitions of interactive features, it is difficult to determine what types of features are most beneficial. This calls for a systematic assessment of interactive features and suggests that it is worth focusing on one specific type of interaction at a time. According to the results of recent meta-analyses (Chang & Li, 2019; Mertens et al., 2022), the answer-until-correct (AUC) feedback type might be especially beneficial. The AUC is usually simple and easy to use, and it goes beyond the effect of simple reinforcement. Children, using the AUC, must re-evaluate their answers after each mistake, which promotes the integration of the new information with their prior knowledge. In addition, immediate feedback can increase students' engagement and learning motivation. Engagement has been shown to reduce distractibility regardless of task difficulty and, presumably, individual differences in cognitive abilities (Buetti & Lleras, 2016). Therefore, in the present study, we sought to test whether AUC feedback-type interactions have a beneficial effect on learning outcomes regardless of individual differences in WM capacity and attentional performance. The results might contribute to further recommendations on interactive features and might help teachers and designers utilize them in a way that is beneficial for learners regardless of individual differences.

Therefore, the aim of our study was to test whether interactive features with the right characteristics can be used for educational purposes, regardless of individual differences in working memory capacity and attentional performance. Understanding interactive features can guide teachers and parents in choosing suitable applications to facilitate general knowledge acquisition. In addition, digital devices are motivating and entertaining for children (Higgins et al., 2019), and if they are selected carefully, these apps can help them gain meaningful knowledge and experience success in and outside the classroom. In the present study, we focused on one specific type of interactive feature, namely, the AUC feedback-type interaction. We have chosen to do so as past studies—although dissimilar in scope and methods to ours—seem to pinpoint this type as the most beneficial to the wide audience. Furthermore, we used only multimedia elements and interactive features that were simple and relevant to the story. We hypothesized that children's learning outcomes would be better with the aid of interactive features than with multimedia elements (both animations and static illustrations) due to the positive effects of feedback-type interactions. We also presume that animations will improve recall performance compared to static illustrations. Furthermore, we expected these improvements to be observed regardless of individual differences in working memory capacity and sustained and selective attention.

4.2. Materials and methods

4.2.1. Sample

We recruited a total of 100 Hungarian children (55 girls), aged between 8 and 11 years (*M* = 9.60, *SD* =*0*.725), through elementary schools. The required sample size for this experiment was determined by computing the estimated statistical power (f =.40, $1\text{-}\beta$ =.80) using the pwr package of R (Champely et al., 2017; R Core Team, 2020) for a general linear model including nine predictor variables. The analysis indicated a minimum sample size of 63; thus, our study was adequately powered. All the children were typically developing with no neurological or other disorders according to their teachers and parents. Parents reported an average of 10.1 hours (*SD* = 8.97) of weekly screen time for their children, and 73 children owned at least one device. One child was excluded because of extensive knowledge of the presented topic. The children were randomly assigned to three groups: an interactive application group (*N* = 34), a video group (*N* = 33), and a picture group (as a control) (*N* = 33). The groups were matched for all study variables, including age, maternal education, weekly average screen time, and device ownership. For the descriptive data and exact statistical values, see Table 4.1.

The study was approved by the Hungarian United Ethical Review Committee for Research in Psychology (reference no. 2023-06) and was carried out under the Declaration of Helsinki. Parents and teachers were informed about the details of the study. Permission of the parents was requested through an informed consent form. All the children verbally agreed to participate.

Table 4.1. Descriptive data regarding demographic variables, device use practices, and cognitive variables were separated by group. The results of the statistical analyses performed to test group differences are also reported.

	Group	**N**	**Statistics**
Sex	Picture	33 (15 girls)	$\chi2$ (2) = 1.62; p = .445
	Video	33 (20 girls)	
	Interactive app	34 (17 girls)	
Device ownership	Picture	33 (21 yes)	$\chi2$ (2) = 2.30; p = .316
	Video	33 (25 yes)	
	Interactive app	34 (26 yes)	

	Group	**Mean**	**SD**	**Statistics**
Age (years)	Picture	9.55	0.754	F (2,97) = 0.163; p = .849
	Video	9.61	0.747	
	Interactive app	9.65	0.691	
Maternal education	Picture	2.94	0.982	F (2,94) = 0.010; p = .989
	Video	2.91	0.995	
	Interactive app	2.91	0.843	
Weekly Screen time (hrs)	Picture	10.9	9.47	F (2,96) = 2.52; p = .086
	Video	7.36	7.39	
	Interactive app	12.1	9.48	

Device use (age)		Picture	6.53	1.91	*F* (2,92) = 1.01; *p* = .367
		Video	6.92	2.05	
		Interactive app	7.18	1.51	
ADHD Rating Scale-IV.	Inattention	Picture	5.30	6.07	*F* (2,97) = 0.600; *p* = .551
		Video	4.82	7.10	
		Interactive app	3.71	5.06	
	Hyperactivity/ Impulsivity	Picture	3.27	5.23	*F* (2,97) = 0.944; *p* = .393
		Video	3.15	5.46	
		Interactive app	1.79	3.89	
Pieron Task	DI	Picture	6.99	6.84	*F* (2,97) = 2.72; *p* = .071
		Video	6.97	7.37	
		Interactive app	3.91	4.03	
Digit Span Task	Forward	Picture	7.70	1.38	*F* (2,97) = 0.097; *p* = .908
		Video	7.82	1.18	
		Interactive app	7.82	1.40	
	Backwards	Picture	6.00	1.71	*F* (2,97) = 0.813; *p* = .447
		Video	5.73	1.07	
		Interactive app	5.59	1.71	
Verbal fluency	Correct answers	Picture	37.2	5.35	*F* (2,97) = 0.511; *p* = .602
		Video	36.5	10.0	
		Interactive app	38.5	9.50	

Notes: Maternal education: 1 = Elementary school, 2 = Vocational school, 3 = High school, 4 = University

4.2.2. Study materials

4.2.2.1. The Storybook

For the storybook exposure, we used a commercially available storybook (Let's Explore Ocean by Lonely Planet Kids) from the BOOKR Kids application (https://bookrkids.com/). The storybook has 11 pages, one page contains 16 words, and one page has 1 interaction on average. The multimedia elements included animations, sound effects, and narrations (in the native language of the participants). In the *interactive application group*, the children could freely use the application while the story was presented by the read-aloud function. We used AUC feedback-type interactive features where children received questions containing information about animals. Multiple animals were proposed as potential answers, and children had to guess which animal the statement was true for. The children received feedback after each choice. The participants could continue guessing until they found the correct answer. For the *video group*, we made a video by recording the interactive storybook to exclude the interactive features and keep the multimedia elements, including the narration. In the video group, we presented this video to the children. Here, the children observed someone else executing choices and receiving feedback. In the *picture group*, we handed out printed illustrations from the storybook, while the same narration was read aloud by the experimenter. Here, we transcribed the questions into simple statements, and the children listened to the statements while they saw the illustrations printed from the app. The storybook exposure lasted approximately five minutes in all three groups. The interactive storybook originally contained two embedded games; however, when the children got to this part, the games were skipped by the experimenter to match the content of the storybook for the three groups.

4.2.2.2. Recall performance

As in previous studies (see Furenes et al., 2021; Richter & Courage, 2017), we asked the children to answer 14 questions (henceforth named *short Q&A*) related to the plot of the storybook (e.g., "Which fish is the fastest in the seas?", "Which species communicates by singing?") to measure recall performance. Answers were rated on a three-point scale between 0 and 2 points by three independent scorers. Wrong answers were assigned 0 points, correct but incomplete answers were assigned 1 point, and correct answers were assigned 2 points. The children could achieve a maximum of 28 points by answering all 14 questions correctly. The number of achieved points ranged from 7 to 23.7 (*M* = 15.8; *SD* = 3.81). The agreements between the scorers were tested using Kendall's coefficient of concordance. The interrater reliability was .948 (p <.001), indicating high correspondence between the scorers.

4.2.3. Questionnaires

4.2.3.1. ADHD Rating Scale-IV

The homeroom teacher (who spends most of the school day with the children) of each child was asked to complete the ADHD Rating Scale-IV (Perczel Forintos et al., 2005). We asked teachers, not parents, to evaluate the children because it was important for comparability that children in the same class be assessed by the same adult. In addition, teacher ratings are more reliable and better predictors of a child's attentional performance than parental ratings are (Tripp et al., 2006). The 18-item questionnaire measures inattention, hyperactivity, and impulsivity between the ages of 5 and 18 years (McGoey et al., 2007) on two subscales: inattention and hyperactivity/impulsivity. Each item is rated on a 4-point Likert-type scale ranging from 0 (never or rarely) to 3 (very often), according to which the number best describes the behavior of the child over the past six months. The questionnaire has excellent psychometric properties; in this study, McDonald's ω was .943 for the inattention subscale and .956 for the hyperactivity/impulsivity subscale.

4.2.3.2. Parental questionnaire

The parents completed a questionnaire that included demographic questions (age and sex of their children, maternal education), weekly average screen time and device ownership of their children.

4.2.4. Cognitive tests

4.2.4.1. Sustained attention test

We used the Toulouse-Pieron cancellation task (TP) (Lima et al., 2021) to measure the attentional performance of the children. The TP is widely used to measure sustained attention from the age of 8 years (Chaharsooghi et al., 2011; Nedelescu et al., 2022). The task requires resistance to fatigue and high concentration. It consists of an A4 test sheet that portrays 400 figures overall in 20 lines with 20 figures per line. The children were asked to cross out as many target figures as possible and ignore the nontargets. The four target figures are presented in the header of the test sheet. The figures are squares with a line attached to them in 8 different positions. The completion of the task took 5 minutes, and the amount of time was measured by the experimenter. To evaluate the performance on the test, the total number of attended figures (N), the total number of errors (E), and the total number of omissions (O) were registered. We used these measures to calculate the dispersion index (DI) using the following equation: DI = ([E+O]/N)*100]. Note that a higher DI indicates worse performance. The scores achieved in this study ranged from 0 to 34.8 points. In earlier studies, the test yielded excellent test-retest reliability for the DI, with a Pearson's correlation coefficient of .877 ($p < .001$) (Lima et al., 2019).

4.2.4.2. Working memory capacity

The backwards version of the digit span task (Nagyne Rez et al., 2008) was used to measure the WM capacity of the children. The children were asked to listen carefully to a sequence of digits and then repeat them in the same order in the forward version and reverse order in the backwards version. The number of digits increases by one after every two sequences. The task ends if the child makes errors in two consecutive same-length sequences. We used the total number of correctly recalled sequences as an indicator of WM capacity. Higher scores indicate greater WM capacity. According to Wechsler's rating system, children could achieve a maximum of 16 points in each version. The scores achieved in this study ranged between 5 and 11 in the forward version and between 0 and 10 points in the backwards version. According to the official Hungarian manual (Nagyne-Rez et al., 2008), the test shows excellent reliability. The split-half reliability was 0.83 for the forward version and 0.80 for the backwards version, while the test-retest reliability was 0.76 for the forward version and 0.74 for the backwards version.

4.2.4.3. Verbal skills

To control for the verbal skills of the children, we used the semantic fluency task (Sehyr et al., 2018; Socher et al., 2019). Children were asked to generate as many exemplars of a given category as they could under a predetermined time limit (one minute for each category). We used three categories, namely, 'animals', 'fruits', and 'clothing'. The task lasted three minutes, one minute per category. As an indicator of vocabulary, we calculated the overall number of correct responses across the three categories. Subordinate and superordinate responses were considered correct, while variations in the same item (e.g., plural forms, colour variations) were not counted. The total number of correct responses for the three categories ranged between 18 and 71. The test has good psychometric properties; in this study, McDonald's ω was .611. To test reliability, we used the number of correct answers for each category.

4.2.5. Procedure

The study was conducted in a quiet, spare room at the schools of the children. The children participated individually, and only the experimenter was present during the storybook exposure and the data collection. The experimenter established rapport through a small conversation with the child and then explained what would happen during the task. The child was informed that participation was voluntary and that there were no negative consequences of withdrawal from the study. Participation required the verbal consent of the child. Children were also asked if they were familiar with the presented topic. Children who could talk coherently about the topic in two or three sentences were excluded from the data analyses. This criterion concerned one child.

We used a between-subjects design, meaning that after the warm-up chat, the children were randomly assigned to one of the three experimental groups (interactive app, video, picture). Members of the interactive application group were introduced to the story by an interactive storybook application on a 6.5-inch smartphone. In this group, the children could freely explore the application while the story was presented by the read-aloud function. In the video group, the children held their smartphone in their hands and watched the storybook without interaction. In the picture group, the story was read aloud by the experimenter, accompanied by the printed illustrations from the interactive storybook. Immediately after the exposure, the children answered the 14 short Q&As. The answers of the children were recorded for later analysis. After the short Q&A, we assessed participants' WM capacity, attentional performance, and verbal skills. Children always started with story exposure followed by short Q&A, while the order of the cognitive tests was counterbalanced across children. One session lasted approximately 30 minutes. Only those children who were able to complete this 30-minute session without interruption were included in the study.

4.2.5. Data analysis

Statistical analyses were performed using the JAMOVI Statistics Program (Version 1.2.27.0 for Windows). Outliers were excluded if the recall performance scores on the short Q&A were greater than ±2.5 absolute deviations from the median (approximately 5% of all the collected data). All variables were normally distributed, as indicated by the absolute values of skewness and kurtosis (below 2).

First, we sought to explore the possible effects of demographic variables on general recall performance. We tested the relationships between recall performance and age, maternal education, weekly average screen time, and the age at which the children started using smart devices regularly (device use) via Pearson correlation analysis. We performed two additional independent sample t-tests to test the effect of sex and device ownership. This was necessary because we wanted to control for the possible nuisance effects of these variables when testing our hypothesis.

To test our predictions about the effects of the book format on recall performance, we used a general linear model analysis. The dependent variable was the score achieved on the short Q&A, while the medium of the book (picture, video, or interactive app) was entered as a between-subject factor. Furthermore, the forward and backwards digit span task scores, DI score, inattention and hyperactivity/impulsivity subscale scores, and number of correct answers in the verbal fluency task were entered as independent predictors. Demographic variables showing a significant relationship with recall performance were also entered into the model (sex and maternal education both as independent predictors) to control for their effects. Follow-up pairwise comparisons were adjusted for multiple comparisons using Tukey's test. The statistical results are presented in a table. The dataset that includes computed study variables is available on the Open Science Framework:
https://osf.io/s5k4t/?view_only=fcd6f1e2c0bd4fdfacf0225ffec7a30e

4.3. Results

Regarding the demographic variables, we found that only maternal education and sex were associated with recall performance. Maternal education had a weak positive relationship with total Q&As; that is, higher education was associated with higher scores on short Q&As. We also found sex differences. Compared to girls (M = 15, SD = 3.55), boys (M = 16.9, SD = 3.89) scored higher on the short Q&A. Other demographic variables showed no association with recall performance. For the exact statistical values, see Table 4.2. Since maternal education and sex were related to the recall performance of the children, we included these variables in the GLM analysis.

Table 4.2. The results of the Pearson correlations and independent samples t-tests test the effect of demographic variables (age, sex, maternal education, average weekly screen time, the age at which the children started using smart devices regularly, and device ownership) on recall performance in general. Significant correlations are labelled in italics.

	Age	**Sex**	**Maternal education**	**Weekly screen time**	**Device use**	**Device ownership**
Recall performance	r = .070	*t (93) = 2.53*	*r = .206*	r = -.068	r = .000	t (93) = -1.02
	p = .497	*p = .013; d = .522*	*p = .049*	p = .514	p = .997	p = .413

We hypothesized that multimedia elements and interactive features would improve recall performance compared to simple static illustrations, regardless of the individual differences in attentional mechanisms and WM capacity. As interactive features include relevant physical activity, we hypothesized that interactive features would have a more pronounced effect than automatic multimedia elements. As expected, we found a significant main effect of the groups. Tukey-corrected pairwise comparisons revealed that members of the interactive application group exhibited better recall performance (M = 17.5, SD = 3.12) than did those in the picture group (M = 14.8, SD = 3.90). The recall performance of the video group (M = 15.2, SD = 3.88) differed neither from that of the picture group nor from that of the interactive application group. The distributions of the scores achieved on the short Q&A are reported in Figure 4.1. For the exact statistical values, see Table 4.3.

As we expected, attentional mechanisms, WM capacity, and verbal skills had no effect on recall performance. We found neither significant main effects nor interactions. Regarding the demographic variables, only the main effect of sex remained significant. The interaction for sex was also nonsignificant, suggesting that sex differences are independent of book format. Our hypothesis was partially confirmed, as only members of the interactive (but not the video) group scored higher on the short Q&A than did members of the picture group, and the effect was independent of individual cognitive and demographic variables.

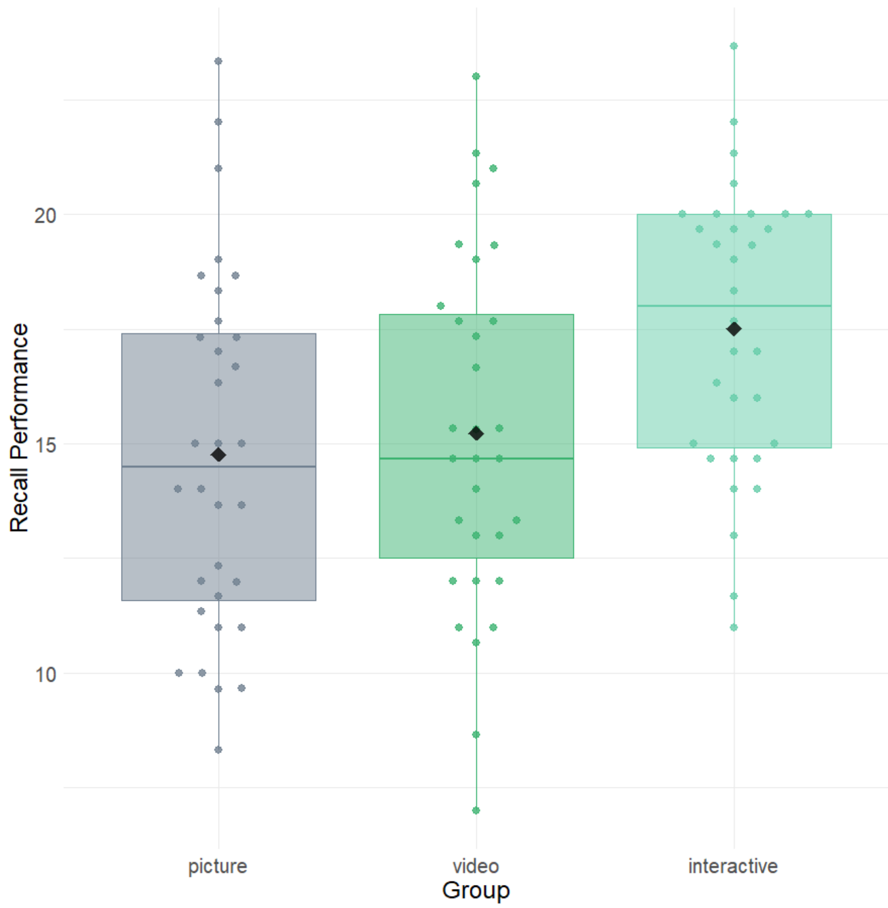

Figure 4.1. The recall performance on the short Q&A task (number of total points achieved) in the three experimental groups (picture, video, and interactive app). The black diamonds show the mean scores, and the colored dots represent the actual scores of the children.

Table 4.3. Detailed statistical results for the general linear model with main effects, interactions, and pairwise comparisons. Significant effects are highlighted in italics.

The main effect of group	**df**	**F**	**p**	**$\eta^2 p$**
	2, 91	*3.624*	*=.032*	*.100*
Pairwise comparisons		**df**	**t**	**p_{tukey}**
Interactive - Picture		*65*	*2.674*	*.025*
Interactive - Video		65	1.638	.237

	Video - Picture	65	0.876	.657

Main effects	**df**	**F**	**p**	**η²p**
Inattention	1, 91	1.218	.274	.018
Hyperactivity/Impulsivity	1, 91	2.158	.147	.032
DI	1, 91	0.444	.507	.007
Digit span Task (Forward)	1, 91	0.912	.343	.014
Digit span Task (Backwards)	1, 91	0.002	.964	.000
Verbal fluency	1, 91	0.085	.771	.001
Maternal education	1, 91	1.322	.254	.020
Sex	*1, 91*	6.973	*.010*	*.097*

Interactions	**df**	**F**	**p**	**η²p**
Group*Inattention	2, 91	0.333	.718	.010
Group*Hyperactivity/Impulsivity	2, 91	0.586	.559	.018
Group*DI	2, 91	0.407	.667	.012
Group* Digit span Task (Forward)	2, 91	0.719	.491	.022
Group* Digit span Task (Backwards)	2, 91	1.307	.277	.039
Group* Verbal fluency	2, 91	0.486	.617	.015
Group* Maternal education	2, 91	1.413	.251	.042
Group*Sex	2, 91	0.038	.962	.001

4.4. Discussion

Electronic storybooks with embedded interactive features can expand the boundaries of multimedia learning and offer great potential to improve the learning outcomes of children by allowing them to learn through physical activities, increasing their engagement with tasks, and providing personalized feedback (Fabio et al., 2019; Mavilidi et al., 2016, 2018). However, these advantages are not independent of individual differences in cognitive processes (Bali, Matuz-Budai, et al., 2023; Wang et al., 2022; Wiley et al., 2014); thus, it is crucial to learn how to use these apps correctly. As individual differences are often great between children in elementary school, it is difficult to find and design applications suitable for the individual needs of every student. General recommendations on multimedia elements (R. E. Mayer & Moreno, 2003) provide some guidance to designers and teachers; however, interactive features call for more precise recommendations. Regarding interactive features, previous studies have shown mixed results (Etta & Kirkorian, 2019; Furenes et al., 2021a). Despite the supposed benefits, they can be distracting and might increase the cognitive load in children (Takacs et al., 2015). Furthermore, the diversity of interactive features and the lack of precise definitions across different studies hinder the establishment of general conclusions (Kucirkova, 2017).

The AUC feedback type interaction is a well-defined subtype and is potentially beneficial for students with a wide variety of cognitive abilities (Kim et al., 2017; Mertens et al., 2022). Therefore, the aim of our study was to test whether AUC-type interactive features can be more beneficial than multimedia elements and the static presentation of study material for a broader audience. As we predicted, AUC-type interactive features resulted in the best learning outcomes in elementary school children. Our findings underscore that interactive features with the right characteristics can be used for educational purposes regardless of cognitive differences. These results can guide teachers and parents in choosing suitable applications to facilitate general knowledge acquisition.

Children using the electronic storybook with interactive features recalled significantly more information accurately on the short Q&A than did those seeing static illustrations from the app. As the recall performance in the video group did not differ significantly from that in the static illustration group accompanied by narration, we can assume that participating in feedback-type interactions followed by corrective feedback has a more pronounced impact on learning than observing others performing the task and receiving feedback. These results are in line with recent metanalytic results (Chang & Li, 2019; Mertens et al., 2022) that emphasize the effectiveness of AUC-type feedback. This type of immediate corrective feedback might lead to enhanced learning through the reinforcement of the correct answer (Ernst & Steinhauser, 2012), increased engagement (Chang & Li, 2019; Mertens et al., 2022), and active involvement on behalf of the children (Butler & Roediger, 2008). These are reflected in better memory encoding, which is crucial to an improved learning outcome in an interactive multimedia setting. These results suggest that the adoption of established educational practices is a good strategy for designing electronic storybooks with embedded interactive features to promote learning.

Individual differences in working memory capacity and attentional performance did not affect recall performance, confirming our second hypothesis. This finding supports our suggestion that feedback-type interactions have the potential to promote learning irrespective of individual differences. This particular type of interactive feature forwards information through a question and expects an attempted answer from the child, which is followed by personalized corrective feedback. This minimizes the need for sharing attention and task switching, which might reduce the risk of cognitive load (Ayres & Sweller, 2014; R. E. Mayer & Moreno, 2003). Consequently, AUC-type interactions are suitable for a broader audience, as they are cognitively less demanding for children. These results can guide teachers and designers in building a digital environment that is beneficial for all students.

We also controlled for children's verbal skills, and we did not find any correlation in this respect. This demonstrates that verbal skills do not play a role in how children process information through storybooks or the extent to which they can report the knowledge they have gained through them. The effect of the book format was also independent of demographic variables. Although the sex of the children was associated with learning outcomes, this was only a general effect. Overall, boys scored higher for all three book formats, indicating that sex did not influence how well children performed after using an electronic storybook. Considering these results, electronic storybooks (and AUC feedback-type interactions in particular) seem to be advantageous regardless of variables such as sex, maternal education, weekly screen time, or device ownership.

Although our findings have high practical relevance, we should consider a few limitations of the current study. First, we did not measure the time spent with the storybooks across the three different book formats. Consequently, we do not know how much time the children spent using the electronic storybook and whether this affected our results. In the future, it would be crucial to measure the time spent with the applications, as electronic storybooks also have the potential to promote learning through self-paced learning (Tullis & Benjamin, 2011). Our study was also conducted in a laboratory setting, as only the child and the experimenter were present in a quiet room dedicated to the experiment. While this is a good model for studying at home, to learn more about the effectiveness of electronic storybooks in the classroom, future studies should replicate this study in a more common context (e.g., during a class). Future studies should also focus on the long-term effects of using electronic storybooks. We have limited knowledge of whether improved learning outcomes remain observable after the repetitive use of these apps or whether our results are simply a consequence of the novelty effect (Rodrigues et al., 2022). Children might become accustomed to the involvement of electronic storybooks, which would make these apps less appealing and less attentive to grabbing after a while. Longitudinal studies are also needed to explore the long-term benefits of using electronic storybooks, which we have not addressed in the present study. Finally, our sample is not representative, as all the children were typically developing, which makes it difficult to draw general conclusions and recommendations. Future studies should include a specific sample of children with learning difficulties to understand how useful this feature could be for them. We might be able to utilize these tools to support the academic performance of these students. Also, all the participants were Hungarians which further limits the generalizability of our results. However, having a diverse sample in terms of socio-economic status as measured by maternal education is a strength of the study. Additionally, the participants were drawn from a diverse range of educational institutions across Hungary including rural and urban areas as well.

4.5. Conclusion

Despite these limitations, our results highlight that well-designed electronic storybooks with embedded AUC feedback-type interactive features and multimedia elements (animations and background music) are beneficial for young children aged between 8 and 10 years. They also improve learning outcomes even for those with less mature sustained and selective attention and working memory capacity. Teachers are sometimes not prepared to choose appropriate apps as an aid in the classroom (Vega & Robb, 2019). This is further complicated by the fact that educational apps such as electronic storybooks do not always deliver the expected outcome (Vaala & Lapierre, 2014). In addition, according to recent studies (Bali, Matuz-Budai, et al., 2023; Wiley et al., 2014), the efficiency of information processing through electronic storybooks is highly dependent on individual differences among children. It can be challenging to address individual needs when building a digital educational setting. Based on our results, it can be assumed that implementing well-established pedagogical techniques as interactive features in electronic storybooks is promising. In the present study, we tested the impact of immediate AUC-type feedback on learning through an electronic storybook; however, further studies should address other techniques and other types of interactive features. Systematic testing of interactive features is crucial for forming clear recommendations on how to use them effectively without increasing cognitive load. Using simple multimedia elements and one AUC feedback-type interaction per page promotes comprehension and learning, regardless of individual differences in sustained and selective attention and working memory capacity.

5. The Impact of Visual Cues on Reducing Cognitive Load in Interactive Storybooks for Children

5.1. Introduction

5.1.1. Advantages of multimedia and interactive elements

Electronic storybook applications are excellent appliances to promote learning in and outside of the classroom. These applications deliver information with the help of multimedia elements (such as narration, illustrations, animations, etc.) and interactive features (e.g., games, activities, etc.) (Takacs et al., 2015). Multimedia elements have the potential to deliver information via multiple sensory modalities (Varga, 2014), which makes them particularly applicable for creating an educational environment for effective multimedia learning. The cognitive theory of multimedia learning (Mayer, 2014) posits that learning is more efficient when information is delivered in multiple sensory modalities; e.g., when information is simultaneously explained verbally and visually by a narrated animation (see Mayer & Moreno, 1998). Multimedia elements have been the subject of numerous studies which have revealed that these elements have the potential to guide attention and facilitate the comprehension of abstract words, phrases, and complex emotions (Altun, 2018; Herrlinger et al., 2017; Li et al., 2023; Mayer & Anderson, 1992; Takacs & Bus, 2016). They also induce a higher level of engagement and lead to active learning (Mayer, 2002). Electronic storybooks can easily deliver these advantages, as they can be combined with a wide variety of multimedia elements.

Interactive features in electronic storybooks can further enhance the benefits of multimedia elements. Interactive features are available in many forms, therefore defining them is challenging (Kucirkova, 2017). Some consider self-paced instructional design interactive (H. Li et al., 2023), while others use embedded dictionaries or games (Takacs et al., 2015). What they have in common is that they are controlled by the user and aim to involve children in content-congruent activities (Varga, 2014). In the present study interactive features are considered content-congruent animated figures that become active when children interact with the touchscreen. These specific types of interactive features exert their benefits through playful learning (Hainey et al., 2016; Jusslin et al., 2022; Kangas et al., 2017; Shin et al., 2012) and eliciting content-congruent physical activities, which knowingly improve comprehension and retention (Mavilidi et al., 2016, 2017, 2018; Petrigna et al., 2022; Stapp et al., 2021). Interactive features are also more engaging

(Richter & Courage, 2017), and using a device elicits higher levels of motivation and interest (Higgins et al., 2019). On the contrary, there are some pitfalls of using interactive features which can result in decreased learning outcome, especially in a diverse population with varying attentional skills.

5.1.2. Pitfalls of using interactive elements

Learning with multimedia and interactivity is a complex process that involves detecting, processing, and integrating information from multiple sources simultaneously (R. E. Mayer, 2002). Since we have only a limited amount of cognitive capacity to manage all these parallel processes, the design of electronic storybooks should aim to keep the cognitive load as low as possible to avoid cognitive overload (Ayres & Sweller, 2014). Precise timing is key for successful multimedia learning and reducing the cognitive load (Liu et al., 2022). Synchronization decreases the risk of splitting attention and helps to connect and integrate the perceived pieces of information. This principle is known as the *contiguity principle* and heavily relies on Baddeley's theory of working memory (1992). The idea is that when the textual and pictorial representations are simultaneously presented there is no need to hold one piece of information in working memory until the other appears. This strategy is expected to reduce the risk of cognitive overload (Mayer & Moreno, 2003). Information is considered synchronized (both in time and content), if an animation begins to move, or a child activates an interactive feature when the corresponding information is spoken.

While for automatic multimedia elements the contiguity is feasible, for interactive features it can easily be violated. Multimedia elements are automatic, consequently, with the right timing, the corresponding visual and textual information is presented simultaneously. Interactive features, however, are controlled by the user, therefore, children may use them in a way that is not synchronized with the verbal information. This could mean that children may activate interactive features earlier or even later than the corresponding information is provided. This may explain the controversy around interactive elements. On the one hand, there are studies that found that interactive features enhance general knowledge acquisition and story comprehension (Bali, Csibi, et al., 2023; Bali, Matuz-Budai, et al., 2023; Son et al., 2020; Xu et al., 2021; Zipke, 2017). On the other hand, there are studies suggesting that these features are distracting and, thus, hinder learning (Parish-Morris et al., 2013; Reich et al., 2016; Takacs et al., 2015). If the synchronization between the verbal information and the corresponding interactive feature is violated it may interfere with the integration of information from different modalities. This can increase the risk of dividing attention between the content of the interactive feature and the verbal information leading to higher levels of extraneous cognitive load (R. E. Mayer & Moreno, 2003; Moreno & Mayer, 1999; Sweller & Chandler, 1994). Overall, the questions surrounding the use of interactive elements are likely to arise from issues of definition, the diversity of them, and, most importantly, the lack of examination of individual differences among users.

5.1.3. The role of attentional skills

Children with immature executive attention may struggle with distractions and additional cognitive load caused by interactive elements. The maturation of the executive attention network is still ongoing during elementary school years (V. A. Anderson et al., 2001; Best et al., 2009; Zelazo & Müller, 2010). Consequently, it can be challenging for children at this age to focus their attention on relevant content when faced with multiple sources of information. According to the *congruency principle* (Mayer & Moreno, 2003), meaningful learning only occurs if children engage with interactive features at the same time as they listen to the corresponding narration. Immature executive attention, however, favours the bottom-up rather than top-down processes (Petersen & Posner, 2012a). As a result, children are more likely to be drawn to interactive features rather than focusing on the primary learning goals, as they find them more interesting and entertaining. This can disrupt the alignment between interactive features and spoken text, leading to divided attention and higher cognitive load (Bali, Matuz-Budai, et al., 2023). Furthermore, these features provide immediate rewards, making children more inclined to use them for enjoyment rather than learning, making these children more prone to hedonic use of interactive features (Makransky et al., 2021). This may result in inappropriate processing (and incorrect recall) due to disorganization and lack of integration of information.

In some cases, the location of interactive features is indicated by visual cues, however, in many electronic storybooks, they remain hidden, which can further increase the temporal distance between the spoken text and interactive features. As children must scan the screen for them (instead of paying attention to the content), hidden interactive features can further decrease the processing capacity (Albus et al., 2021). Signaling interactive features with visual cues might be an effective solution to free up some cognitive capacity while children are using electronic storybook applications. In multimedia learning, signalling is used to highlight key points and indicate the causal chain of information delivered (Mayer, 2014). Signals could be labels, spotlights, arrows, colours, or pointing gestures highlighting relevant words, pictures, or animations. For verbal information, even intonation and pauses can serve as signals (Van Gog, 2014). These signals highlight key terms and relevant information in the learning material making it easier for students to select and organize information (Schneider et al., 2018). In regard of interactive features, signalling presumably makes it easier to achieve temporal congruence between the spoken text and interactive features. In result, it decreases cognitive load and promotes successful learning because signals can potentially direct attention and minimize searching behaviour (Albus et al., 2021). This is supported by an eye-tracking study, which found that participants spent more time fixating on the relevant parts of the screen when signals were used (Jamet, 2014). This suggests that information selection and maintaining attentional focus was easier when signals was present. This leads to better learning performance by facilitating the integration of the spoken text and corresponding interactive features. These advantages may be even more pronounced for those with attentional difficulties, as they already have a tougher time managing interactivity (Bali, Matuz-Budai, et al., 2023). Signaling is widely studied in the context of multimedia elements (Alpizar et al., 2020; Ozcelik et al., 2010; Schneider et al., 2018), however, little is known about whether signaling can reduce cognitive load and improve learning when interactive features are used. Furthermore, earlier studies did not investigate how signaling affects processing information for those with attentional difficulties.

5.1.4. Goal of the study

In the present study, we aimed to investigate whether visual signals such as pointing gestures to indicate interactive features in electronic storybooks can reduce cognitive load without compromising interactivity. While interactivity in electronic storybooks has many advantages, it must be carefully designed, as it can potentially increase cognitive load, especially for individuals with attention difficulties. Presumably signaling interactive features on the screen can be beneficial as they can direct attention and foster the integration of spoken text and interactive features. This, in turn, reduces the risk of interactive elements violating the congruency principle. We hypothesized that interactivity in electronic storybooks would improve children's learning outcomes compared to using only animated figures and static illustrations. The degree of this improvement is likely to vary due to individual differences in attentional mechanisms. We hypothesized that children with less mature attentional mechanisms may encounter difficulties when interactive features are not signalled because they are more likely to be distracted, leading to higher levels of cognitive load. Conversely, signalling interactive elements help to orient attention and organise information more efficiently, thus signalling will eliminate the impact of individual differences.

5.2. Methods

5.2.1. Sample

We recruited a total of 130 Hungarian children (69 girls) between the ages of 8 and 11 (M = 9.36, SD = 0.704) through elementary schools. All students were typically developing, with no neurological or other disorders, according to their teachers and parents. Participation was voluntary and they received no compensation for their participation. We excluded 11 children as they were identified as outliers based on their recall performance scores (short Q&A). Outliers were excluded if the recall performance scores on the short Q&A were greater than ±2 absolute deviations from the median (approximately 8.5% of all the collected data). The children were randomly assigned to four groups: a signaled interactive application group (N = 29), a non-signaled interactive application group (N = 28), a video group (N = 34), and a picture group (as a control) (N = 28). The groups were matched for all the study variables (including inattention, hyperactivity-impulsivity, and verbal skills) and age. The gender distribution across groups was unbalanced, therefore, we controlled for this variable later in the analyses. For the descriptive data and exact statistical values, see Table 4.1.

The study was approved by the Hungarian United Ethical Review Committee for Research in Psychology (reference no. 2023-06) and was carried out following the Declaration of Helsinki. Parents and teachers were informed about the details of the study. Permission of the parents was requested through an informed consent form. All the children verbally agreed to participate.

Table 4.1. Descriptive data regarding age and cognitive variables (inattention, hyperactivity/impulsivity, and verbal skills) separated by groups. The results of the statistical analyses performed to test group differences are also reported.

		Group	N		Statistics
Sex		Picture	28	(20 girls)	$x^2(3)=13.0$, p=.004
		Video	34	(20 girls)	
		Signaled interactive app	28	(7 girls)	
		Non-signaled interactive app	29	(16 girls)	
		Group	**Mean**	**SD**	**Statistics**
Age					
(years)		Picture	9.39	0.737	F(3,115)=0.208, p=.891
		Video	9.29	0.676	
		Signaled interactive app	9.32	0.67	
		Non-signaled interactive app	9.41	0.682	
ADHD					
Rating					
Scale-IV	Inattention	Picture	5.68	6.06	F(3,115)=0.252, p=.860
		Video	5.47	5.8	
		Signaled interactive app	6.75	6.23	
		Non-signaled interactive app	6.24	7.04	
	H/I	Picture	3.21	3.77	F(3,115)=0.097, p=.962
		Video	3.85	5.57	
		Signaled interactive app	3.86	5.05	
		Non-signaled interactive app	3.55	6.36	
Verbal					
fluency		Picture	36.3	9.51	F(3,115)=0.561, p= .642
		Video	35.5	9.23	
		Signaled interactive app	38	10	
		Non-signaled interactive app	38.1	9.03	

5.2.2. Study materials

5.2.2.1. The Storybook

For the storybook exposure we created a 16-slide interactive presentation in Microsoft PowerPoint. The topic of the presentation was the outer space which we found as age-appropriate and interesting yet unfamiliar for the target population. The slides depicted information from the accompanying narration. To create the presentation, we used content-congruent static pictures, two at maximum per slide. We made the presentation interactive by using the trigger function in Microsoft PowerPoint. First, we embedded a static picture and then animated it. With the trigger function we specified that we want the animation to start on click or on touch if they are used with a touchscreen device. The interactive features created in this way depicted activities related to the storybook and could be repeated in any number. The storybook application was presented to the children on a touchscreen device. The accompanying narration was recorded and added to the presentation. The narration was played automatically while children used the application. The content of the storybook based on science books for children and was written by one of the authors.

In the *interactive application groups*, the children could freely use the application, while they listened to the narration. The narration was automatically activated when children moved on to the next slide. In the *signaled interactive application group,* a small hand icon indicated the location of the interactive features, while in the *non-signaled interactive application group* children could search for them on the screen without any additional help. For the *video group*, we made a video by recording the interactive storybook to exclude the interactive features and keep the multimedia elements, including the narration. During the record we activated the interactive features, therefore, in the video version children saw automatic animations instead of interactions. In the video group, we presented this video to the children. The *picture group* was identical to the video condition with that one exception that children saw static illustrations instead of animations. We used the same audio record of the narration for all the different versions. The storybook exposure lasted approximately 10 minutes in all four groups.

5.2.2.2. Recall performance

In accordance with earlier studies (see Furenes et al., 2021; Richter & Courage, 2017), we asked the children to answer 16 questions (henceforth named *short Q&A*) related to the plot of the storybook (e.g., "*What is at the center of our galaxy?*", "*What are stars made of?*") to measure recall performance. Answers were rated on a three-point scale between 0 and 2 points by two independent scorers. Wrong answers were assigned 0 points, correct but incomplete answers were assigned 1 point, and correct answers were assigned 2 points. The children could achieve a maximum of 32 points by answering all 16 questions correctly. The number of achieved points ranged from 2 to 22 (M = 10.9; SD = 4.87). A total of 10 independent raters scored the responses, and each response was scored by at least two raters. Agreement between raters was tested with interclass correlation (ICC) in R (version 2023.09.1+494 for macOS) using the 'irr' package (Gamer et al., 2022). We used a two-way mixed-effects model with consistency of the ratings (Koo & Li, 2016). The mean ICC value was .968 (p <.001), indicating high correspondence between the raters. Because of the high correspondence, we averaged the scores given by the raters to determine the final recall performance scores for each child.

5.2.3. Assessments

5.2.3.1. ADHD Rating Scale-IV

The homeroom teacher (who spends most of the school day with the children) of each child was asked to complete the ADHD Rating Scale-IV (Perczel Forintos et al., 2005). We asked teachers, not parents, to evaluate the children because it was important for comparability that children in the same class be assessed by the same adult. In addition, teacher ratings are more reliable and better predictors of a child's attentional performance than parental ratings are (Tripp et al., 2006). The 18-item questionnaire measures inattention, hyperactivity, and impulsivity between the ages of 5 and 18 years (McGoey et al., 2007) on two subscales: inattention and hyperactivity/impulsivity. Each item is rated on a 4-point Likert-type scale ranging from 0 (never or rarely) to 3 (very often), according to which the number best describes the behavior of the child over the past six months. The questionnaire has excellent psychometric properties; in this study, McDonald's ω was .955 for the inattention subscale and .942 for the hyperactivity/impulsivity subscale.

5.2.3.2. Verbal skills

To ensure that the experimental groups are matched for verbal skills, we used the semantic fluency task (Sehyr et al., 2018; Socher et al., 2019). Children were asked to generate as many exemplars of a given category as they could under a predetermined time limit (one minute for each category). We used three categories, namely, 'animals', 'fruits', and 'clothing'. The task lasted three minutes, one minute per category. As an indicator of vocabulary, we calculated the overall number of correct responses across the three categories. Subordinate and superordinate responses were considered correct, while variations in the same item (e.g., plural forms, colour variations) were not counted. The total number of correct responses for the three categories ranged between 14 and 71.

5.2.4. Procedure

The study was conducted in a quiet, spare room at the schools of the children. The children participated individually, and only the experimenter was present during the storybook exposure and the data collection. The experimenter established rapport through a small conversation with the child and then explained what would happen during the task. The child was informed that participation was voluntary and that there were no negative consequences of withdrawal from the study. Participation required the verbal consent of the child. Children were also asked if they were familiar with the presented topic. Children who could talk coherently about the topic in two or three sentences were excluded from the data analyses. This criterion did not concern any child.

We used a between-subjects design, meaning that the children were randomly assigned to one of the four experimental groups (signaled interactive app, non-signaled interactive app, video, picture). Members of the interactive application groups were introduced to the story by an interactive storybook application on an electronic device such a smartphone or a tablet. In these groups, the children could freely explore the application while the story was presented by the read-aloud function. In the video group, the children held their device in their hands and watched the storybook without interaction. The picture group was identical to the video group except that the story was accompanied by static illustrations instead of animations. Immediately after the exposure, the children answered the short Q&A including 16 questions. The answers of the children were recorded for later analysis. After the short Q&A, we assessed participants' verbal skills. One session lasted approximately 30 minutes. Only those children who were able to complete this 30-minute session without interruption were included in the study.

5.2.5. Data analysis

Statistical analyses were performed using the JAMOVI Statistics Program (Version 2.3.28.0 for MacOS). We tested our predictions using a random intercept linear mixed model (LMM) with two between-subject factors being the format of the electronic storybook and the sex of the children. Achieved scores on the retention test were included as dependent variables. The scores on the Inattention and Hyperactivity/Impulsivity subscales of the ADHD Rating Scale-IV were entered as continuous predictors. The random factor was the school of the participants. Follow-up Bonferroni corrected pairwise comparisons were adjusted for multiple comparisons using the Satterthwaite approximation for degrees of freedom. Simple effects regarding significant interactions were also

estimated. The dataset that includes computed study variables is available on the Open Science Framework:
https://osf.io/8cxbf/?view_only=76de00b6427b428bbbf62dc6633e71df

5.3. Results

Our fist hypothesis was that interactivity would enhance learning outcomes. The distributions of the scores achieved on the short Q&A are reported in Figure 4.1. For the exact statistical values, see Table 4.2. As expected, we found a significant main effect of the book format. Bonferroni-corrected pairwise comparisons revealed that members of both the signaled (M = 11.33, *95%CI* = 8.42, 14.2) and non-signaled interactive application group (M = 12.28, *95%CI* = 9.46, 15.1) performed significantly better than did those in the picture group (M = 8, *95%CI* = 5.08, 10.9). The recall performance of the video group (M = 10.28, *95%CI* = 7.48, 13.1) differed neither from that of the picture group nor from that of the interactive application groups. The signaled and non-signaled interactive application books did not differ from each other. We found no effect of gender on the recall performance.

However, we also hypothesised that the improvement in children's performance would be influenced by individual differences in attentional mechanisms. Regarding the effect of inattention, we found both a significant main effect and a significant interaction with book format. Children with higher levels of inattention generally showed worse recall performance, but the significant interaction revealed that this effect is not entirely independent of book format. Compared to the picture group, in the video and the non-signaled interactive app group, attentional mechanisms showed a negative association with recall performance. Children with higher levels of inattention achieved lower scores on the short Q&A in these two groups. As expected, performance in the signaled interactive app group was unaffected. Hyperactivity/impulsivity did not affect recall, as we did not find a main effect or interaction. This is in line with our hypothesis insofar as we expected that signalling will be particularly helpful to children with higher levels of inattention.

Table 4.2. Detailed statistical results of the linear mixed model with pairwise comparisons regarding book format and the main effects and interactions regarding Inattention, Hyperactivity/impulsivity, and sex of the children. Significant interactions are broken down

by book format. For significant interactions simple effects are also reported. Significant main effects and interactions are italicized.

Main effect of book format		**F**	**df**	**p**
		5.01	*3, 97.3*	*0.003*
Pairwise comparisons		**t**	**df**	**p**
Picture -Video		-2.05	98.1	0.259
Picture-Signaled		*-2.73*	*97.8*	*0.045*
Picture-Non-signaled		*-3.73*	*98.4*	*0.002*
Video-Signaled		-0.94	97.2	1
Video-Non-signaled		-1.96	97.3	0.318
Signaled-Non-signaled		-0.839	97.3	1
Main effects		**F**	**df**	**p**
Inattention		*8.9*	*1, 98.3*	*0.004*
Hyperactivity/impulsivity		2.17	1, 99.1	0.144
Sex		2.53	1, 98.2	0.115
Interactions		**F**	**df**	**p**
*Inattention*Book format*		*3.34*	*3, 98.3*	*0.022*
Hyperactivity/impulsivity*Book format		1.96	3, 97.8	0.125
Sex*Book format		1.68	3, 98	0.176
	b	**t**	**df**	**p**
*Video-Picture*Inattention*	*-0.65*	*-2.38*	*97.66*	*0.02*
Signaled-Picture*Inattention	-0.01	-0.02	98.66	0.981
*Non-signaled-Picture*Inattention*	*-0.57*	*-2.05*	*98.55*	*0.043*
Simple effects of inattention	**b**	**t**	**df**	**p**
Picture	0.018	0.089	98.9	0.929
Video	*-0.64*	*-3.2*	*98.1*	*0.002*
Signaled	0.011	0.06	98.3	0.952
Non-signaled	*-0.55*	*-2.78*	*99*	*0.007*

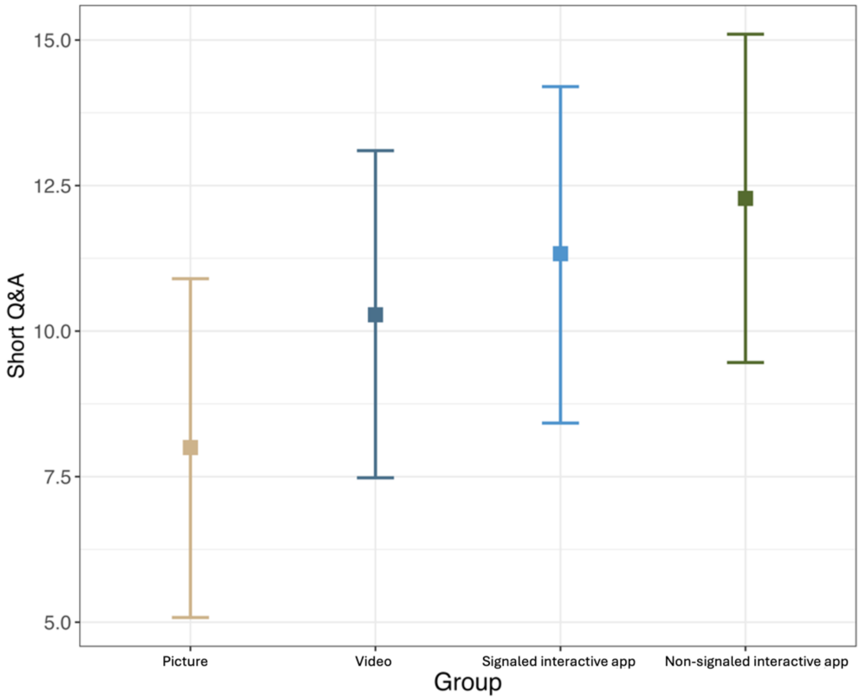

Figure 4.1. – The students' learning outcomes, represented by the mean scores on the retention test (Short Q&A) separated by groups (book format). The squares represent the mean scores in each group, while error bars indicate the 95% confidence interval.

5.4. Discussion

Electronic storybooks with embedded multimedia elements and interactivity are promising tools for improving learning outcomes. They leverage the potential of multimedia learning and the benefits of content-congruent activities through the touch screen (Takacs et al., 2015). While electronic storybooks expand multimedia learning with interactivity which further improves comprehension and retention, interactivity also might be a source of extraneous cognitive load. This is most likely to be a problem for those children who struggle with maintaining attentional focus in the presence of distractors (Bali, Matuz-Budai, et al., 2023). In the present study, our goal was to test whether visual cues, such as pointing gestures, can assist children in maintaining focus and organizing information when an electronic storybook contains interactivity. Since children typically learn better with multimedia elements and interactivity when the cognitive load is low (Ayres & Sweller, 2014; Sweller & Chandler, 1994), we hypothesized that using visual cues could help decrease the risk of cognitive overload and making learning more effective.

Our results support the idea that interactive features in general, enhance memory encoding and retention (Bali, Csibi, et al., 2023; Bali, Matuz-Budai, et al., 2023; Son et al., 2020; Zipke, 2017). Children remembered the story better when interactivity was involved compared to the version where only static illustrations were included. In contrast to interactive features, recall performance in the video group did not differ significantly from the group with narrated illustrations. Therefore, it seems plausible that adding interactivity has a more pronounced effect on learning compared to the passive reception of embedded animations. These results highlight the advantages of incorporating playfulness (Hainey et al., 2016) and content-congruent activities (Mavilidi et al., 2016, 2017) as opposed to passive learning. It is important to note that both signaled and unmarked interactive elements could achieve the same positive result suggesting that interactive features do not necessarily increase cognitive load and interfere with processing. However, when we consider the individual differences in attentional mechanisms, this result becomes more nuanced.

In line with our hypotheses, and previous literature (e.g., Bali, Matuz-Budai, et al., 2023) our results suggest that signaling is particularly helpful for children with attentional difficulties. When interactive features were unmarked, children with higher levels of inattention scored lower on the retention test. In contrast, we found no such association for those in the signaled group. Presumably, this is because in the absence of visual cues searching behavior takes up more cognitive capacity and distracts attention potentially by violating the contiguity principle (Albus et al., 2021). Consequently, the likelihood of temporal co-occurrence may decrease as the likelihood of children using interactive features non-synchronously with the corresponding narration increases (Ge et al., 2022; Moreno & Mayer, 1999). Children searching for interactive features on the screen may struggle to effectively organize information and integrate content delivered through multiple sensory modalities. These processes, however, are fundamental for effective multimedia learning (Mayer, 2002; Mayer & Moreno, 2003). Efficient attentional processes are likely to compensate for the distracting effect of non-signaled interactive elements. This is evidenced by the fact that we found no correlation between attention and learning outcomes when visual cues were used to indicate interactivity on screen.

Interestingly, children with higher levels of inattention also scored lower on the retention task in the video group indicating difficulties with processing even when animated figures were automatically displayed and synchronized with the narration. Multi-sensory integration can be an issue for those with attentional difficulties (Talsma et al., 2010). Thus, even if temporal contiguity is otherwise achieved, performance may still be impaired (Barutchu et al., 2019; Panagiotidi et al., 2017) as children fail to integrate the information coming from different modalities. In the signaled interactive app group, the performance of the children was independent of inattention, suggesting that children with attentional difficulties could successfully integrate visual and verbal information in that condition. This implies that active engagement and promoting information organization may be key elements of multimodal integration. The results also show that the true effect of interactive elements is often hidden when individual differences are not considered, which partly explains the varying results on interactive elements in previous studies. No similar results were found for hyperactivity and impulsivity, which was expected based on earlier literature (Bali, Matuz-Budai, et al., 2023).

Overall, our results show that interactivity, when used correctly, may offer additional value compared to static illustration and even to multimedia elements. In comparison to the achieved scores when static illustrations were presented, interactive animated figures lead to more significant improvements in performance than multimedia elements. Considering the current developmental level of attentional mechanisms, we concluded that those who do not have attentional difficulties perform similarly in a multimedia and interactive environment regardless of using visual cues. For them using non-signaled interactive features will still improve comprehension and learning. However, when it comes to diverse groups of children or helping those with learning difficulties (e.g., children diagnosed with ADHD) signaled interactive features could be the best option for maximum efficiency. In the current study, we defined interactivity as the inclusion of content-congruent animated figures that can be activated by touching the screen, with a maximum of two figures per page. These parameters should be considered when putting our results into practical use.

While the results are compelling, it is important to acknowledge some limitations of the study. First, we defined interactivity as using animated figures activated through the touch screen. As a result, our findings may not apply to other types of interactive features. This is important to note because drawing a general conclusion might be misleading due to the great variety of interactive elements (Kucirkova, 2017). This makes it necessary to take the specific type of interactivity under consideration when establishing recommendations. As we only used a limited amount of interactivity – two interactive features per pages. Therefore, the results may not be applicable to more than this number of features. Second, the study was conducted in a laboratory setting, with only the child and the experimenter present in a quiet room, indicating that electronic storybook applications may be suitable for self-directed learning at home but providing limited insight into their usability in the classroom. Future studies are needed to replicate these results during classroom learning. Finally, although we aimed to involve a diverse range of educational institutions across Hungary (including rural and urban areas), our sample only consisted of typically developing children, limiting the generalizability of our results. To gain a better understanding of their needs, future studies should include children with learning difficulties. Further, future studies should implement eye-tracking data to accurately track visual attention while children learn with the help of electronic storybooks to better understand the role of visual cues.

In summary, when used appropriately, interactive animated figures enhance learning for students aged 8 to 11. When incorporating them, teachers should consider the current developmental stage of the target group's attentional mechanisms. To maximize effectiveness, we recommend that visual cues, such as pointing gestures, be used to indicate the exact location of interactive features on the screen. Signaling directs visual attention and helps organize information, while interactivity facilitates multisensory integration for students with learning difficulties. These findings should be of great help not only to teachers, but also to developers and parents. The results also underscore the individual needs of students in the digital learning environment provided for them. This underscores the importance of tailoring digital tools to students' specific needs, a step that our findings can help facilitate.

6. Multimedia elements improve the learning outcomes of university students for information presented both verbally and visually

6.1. Introduction

In the contemporary era, higher education is significantly influenced by digitalization, presenting further challenges for educators and academics. This is evidenced by the increasing popularity and scientific interest in blended learning, e-learning, or multimedia learning approaches (Bizami et al., 2023). In the classroom, digital presentations (a series of slides that include text, images, video, and other multimedia elements to convey information) are often used as the preferred mode of delivery (James et al., 2006). Both teachers and students consider these digital presentations useful, informative, and captivating (Ravi & Waswani, 2020; Tang & Austin, 2009). Further, digital presentations have a great potential to enhance learning by utilizing the principles of multimedia learning. The *cognitive theory of multimedia learning* (CTML) (R. E. Mayer, 2002) posits that combining verbal and visual information enhances learning efficacy. Therefore, more efficient learning is expected from using digital presentations with multimedia elements (such as figures, videos, animations, and graphs). However, despite the expected benefits, there are mixed results regarding their effectiveness (Baker et al., 2018), meaning that the added value of these tools remains unclear. These mixed results pose a further challenge for educators and academics, who may already lack the requisite knowledge and confidence to utilize this method of delivery (Burke & James, 2008; Gordani & Khajavi, 2020; Seth et al., 2010; Sharp et al., 2017). This is especially true for students not learning in their native language whose need regarding the advantageous educational techniques are relatively unexplored (Macaro et al., 2018). Consequently, in this study, we aim to test the effectiveness of digital presentations with multimedia elements in order to provide specific suggestions on how to successfully promote learning, with a focus on international students. We believe that these suggestions can help teachers and academics to benefit more from the use of multimedia.

Digital presentations have the potential to facilitate learning by making it easy to incorporate multimedia elements into classroom learning. Multimedia elements can illustrate and complement the information provided in the classroom, leading to better learning and understanding of abstract concepts (Kulasekara et al., 2011; Langer et al., 2021). Another advantage of multimedia learning is that it is an active form of learning that requires a higher level of cognitive engagement from students (R. E. Mayer, 2002). Consequently, it facilitates deeper comprehension and more efficient learning (Bujak et al., 2013; Jägerskog et al., 2019; R. E. Mayer & Moreno, 2002). This is particularly true for explanative multimedia elements, which are designed to demonstrate a process or illustrate how something works (R. E. Mayer et al., 1995). Additionally, multimedia elements play an important role in orienting attention and information selection (Bali & Zsido, 2024; Takacs & Bus, 2016). It can also be argued that multimedia elements may grab and hold students' attention (Richter & Courage, 2017). These elements are often interesting and entertaining, which can lead to more focused attention and, thus, improved learning (Hidi, 1990; Renninger et al., 2014). This is especially crucial today because the immersed technological environment can lead to habituation to higher levels of environmental stimulation. As a result, more traditional face-to-face delivery modes may become less interesting and engaging to students (Nikkelen et al., 2014). The various ways of utilizing multimedia clearly show the multifaceted applications of these elements in the promotion of learning.

Despite its well-documented effectiveness, there are certain limitations associated with multimedia learning. If not used thoughtfully, multimedia elements can be a source of unnecessary cognitive load (Sweller, 2012; Wiley et al., 2014). Such extraneous cognitive load often occurs when the multimedia elements are not related to the content or synchronized with the verbal information, which is called the congruency principle (R. E. Mayer & Moreno, 2003; Moreno & Mayer, 1999). Another fundamental principle of multimedia learning is that humans have a limited capacity to process information simultaneously. Therefore, presenting too many elements on the screen (regardless of whether they are related to the content) can cause cognitive overload and reduce the quality of information processing (Ayres & Sweller, 2014; R. E. Mayer, 2002). While some constraints are relatively easy to address (e.g., synchronizing or the use of content-related elements), less is known about when the amount of multimedia elements becomes overwhelming. Previous research has focused primarily on the disruptive effects of seductive (i.e., unrelated to the learning material) multimedia elements (Harp & Mayer, 1998; Sanchez & Wiley, 2006; Sundararajan & Adesope, 2020). However, recent studies have shown that even content-related elements can become distracting and interfere with learning when presented in large numbers (Bali, Matuz-Budai, et al., 2023; Makransky et al., 2021; Parong & Mayer, 2018; Plass & Kalyuga, 2019). Students learning through their second language may be even more affected as they have an inherently higher cognitive load (Roussel et al., 2017). Despite this, there is a lack of data on how to define excessive multimedia use, making it difficult to adapt to this constraint. Therefore, our goal here is to provide well-defined and tangible recommendations regarding the optimal number of content-related multimedia elements.

Individual differences in cognitive processes are likely to contribute to the threshold at which cognitive overload from multimedia elements occurs. Foreign language proficiency is emerging as a new individual factor influencing the success of multimedia learning as the number of international courses and international students is increasing (Rienties et al., 2012; Singh et al., 2022). On the one hand, multimedia elements can certainly be useful for international students (Stiller & Schworm, 2019). On the other hand, they are at a higher risk of cognitive overload, as the use of a second language in itself requires more cognitive effort compared to the use of the native language, which is largely automatic (Roussel et al., 2017). This may reduce the effectiveness of multimedia learning and should be considered when designing multimedia learning materials. For second language learners, processing multiple multimedia elements simultaneously may be more demanding due to the already higher cognitive load, although it can be assumed that the level of foreign language proficiency may reduce this effect (Cloate, 2016). Recent studies have already emphasized that multimedia learning principles may differ for students learning in their second language (Kozan et al., 2015; Lee & Mayer, 2018), however, this area is relatively unexplored (Macaro et al., 2018). Given the higher risk of cognitive overload, the instructional design of a digital presentation with multimedia should be approached differently for international students. Therefore, in our study, we focused on international students in higher education and the instructional design that meets their needs.

In addition to foreign language proficiency cognitive mechanisms such as working memory capacity and attentional mechanisms may also contribute to successful multimedia learning. Multimedia learning is a cognitively complex process and can be challenging even when the instructional design of digital presentations follows the principles of multimedia learning (Mayer, 2002). Digital presentations require students to simultaneously process and integrate verbal and multiple visual information, but they have limited cognitive capacity to do so (Desimone & Duncan, 1995; Engle et al., 1999; Kane et al., 2007). Therefore, students with more limited WM capacity may have difficulties with processing all the information simultaneously, leading to early onset of cognitive overload and poorer comprehension of verbal and visual information (Sanchez & Wiley, 2006). In addition, when students exhibit higher distractibility and short attention spans, their information processing may become more fragmented, as some elements may capture their attention more than others (Colflesh et al., 2007). This can hinder simultaneous information processing and prevent meaningful learning by reducing the level of integration achieved between the verbal and visual information presented. The importance of individual differences in multimedia learning is further underscored by the fact that those with better working memory capacity or higher levels of self-control are more resistant to distraction when multimedia is presented (Makransky et al., 2021; Sanchez & Wiley, 2006; Wiley et al., 2014). Although this has primarily been tested in the context of seductive details, content-related multimedia elements can also increase the risk of cognitive overload when presented in greater numbers (Makransky et al., 2021; Parong & Mayer, 2018). Previous studies clearly indicate that better WM capacity reduces the disruptive effect of seductive details; however, little is known about the role of WM capacity and attentional mechanisms when only content-related elements are presented. The mixed results (Baker et al., 2018; James et al., 2006) call for further investigation as individual differences may partly explain them. Discovering the connection between effective multimedia learning and individual differences in core cognitive functions can help create digital presentations that fit better the needs of the audience.

The objective of this study is to provide more effective guidance on the optimal amount of content-relevant multimedia elements to incorporate into digital presentations used in the classroom. We assume that recommendations regarding the optimal amount may vary based on individual differences in WM capacity and attentional processes. Consequently, the present study sought to examine the impact of varying amounts of explanative multimedia elements on the recall performance of university students. We hypothesized that an increasing number of visual items will lead to a gradual improvement in recall performance, although this improvement is expected to vary depending on individual differences in cognitive processes. The contributing effect of individual differences on successful learning with multimedia is still neglected in the literature (J. Li et al., 2019), despite that, understanding them would be crucial in order to tailor digital presentations to the needs of students. Therefore, we aimed to test the effects of WM capacity, sustained attention, and foreign language proficiency on the learning outcomes. We hypothesized that for students with less efficient attentional processes and more limited WM capacity, recall performance will decline when more visual elements are presented on the screen. Presumably the same results will occur for foreign language proficiency as the cognitive load is inherently higher for those learning in their second language. Therefore, we hypothesize that, students with lower levels of English proficiency will recall less information from the presented topic as the number of multimedia elements increases.

6.2. Experiment 1

6.2.1. Methods

6.2.1.1. Sample

We recruited a total of 41 undergraduate psychology students (27 women, 4 preferred not to answer) studying in the English program between the ages of 19 and 41 (M = 22.3, SD = 4.68). Participants studied in an English program, therefore during the application process, they were screened for language proficiency and had at least a B2-level English language certificate. All the participants were healthy adults, and none of them reported having a psychiatric disorder. Participation was voluntary and they did not receive compensation for their participation. Data collection was carried out during university seminars. The study was approved by the Hungarian United Ethical Review Committee for Research in Psychology (reference nr. 2023-104) and was carried out following the Declaration of Helsinki. We obtained informed written and verbal consent from all participants.

6.2.1.2. Instruments

6.2.1.2.1. Presentations

During data collection, we introduced a short multimedia presentation to the participants. To choose the topic of this presentation we consulted the seminar teachers, to find a topic that fits the syllabus, but that the students do not yet have extensive knowledge of. As a result, we created presentations featuring Cloninger's psychobiological theory (Cloninger, 1987; Cloninger et al., 1998; Serretti et al., 2006). The presentation was accompanied by visual multimedia elements such as figures, static pictures, and GIFs. All the used multimedia elements (figures, GIFs, static pictures) were relevant to the topic and visualized certain parts of the subject material. We created the multimedia material accordance with the principles (Lee & Mayer, 2018; Mayer & Moreno, 2003; Moreno & Mayer, 1999) of multimedia learning to eliminate any potential confounding effects on cognitive load unrelated to the number of displayed elements. We prepared a PowerPoint presentation consisting of 16 slides. The number of multimedia elements that could appear on a slide varied between 0 to 3, resulting in 4 conditions. That is, the final presentation had four slides for each condition. The number of multimedia elements varied randomly across the slides. We visited three seminars; therefore, we created three different presentations with the same narration featuring the same text and the same visuals. The only difference between the presentations was the order in which the number of multimedia elements varied across the slides.

6.2.1.2.2. Retention test

To measure the learning outcome, we asked participants to answer multiple-choice questions related to the presented topic. We handed out the retention test immediately after the presentation. The test contained two questions referring to each slide, which resulted in a total of 32 questions. The questions were divided into four sets (eight questions per set). Each set is assigned one condition out of four, which were: control condition with no multimedia elements, Multimedia1 condition with one featured multimedia element on the slide, Multimedia2 condition with two elements, and Multimedia3 with three elements. For instance, we had a set of 8 questions referring to the slides featuring 0 multimedia elements, a different set of 8 questions referring to the slides with 1 multimedia element, and so on. Participants received one point for each correct answer and 0 for an incorrect answer; they could achieve a maximum of 32 points (i.e., 8 points per condition) by answering all of them correctly.

6.2.1.2.3. Attentional skill

We asked the participants to complete the d2 Test of Attention (Brickenkamp & Zillmer, 1998) to measure their sustained and selective attentional skills. The d2 is a paper-and-pencil cancellation task that requires high concentration and resistance to fatigue. It consists of a test sheet that portrays overall 658 “p” and “d” letters across 14 lines, each with 47 letters. The letters are surrounded by one to four dashes arranged below or above the figures. Participants had to find and cancel as many targets as they could within 20 seconds per line. The time was measured by the experimenter. After hearing the stop signal, participants had to stop and draw a straight line at the last attended figure of the given line, then move on to the next line immediately. Overall, the task lasted about five minutes. To evaluate the performance of the participants the total number of attended figures (N) and the total number of errors (E) (canceled nontarget figures and omissions) were counted. We used these values to calculate the percent of errors (E%) using the following equation ((E/N*100)). Higher scores indicate worse performance.

6.2.1.2.4. Working memory capacity

We used the backward version of The Digit Span Task () to measure working memory capacity. Participants were shown 15 sequences of digits one after another on the screen in the classroom. They had to observe each sequence carefully and then write them down on a blank paper in reverse order. The number of digits increased by one after every two sequences. Participants saw the first pair of sequences for two seconds; the presentation time was then increased by half a second per digit. Before the task participants were shown one sequence as a trial. The answers were evaluated until the participant had made at least two consecutive errors. The length of the last correctly recalled sequence was used as an indicator of working memory capacity. Higher scores indicate greater WM capacity. Participants could achieve a total of nine points.

6.2.1.2.5. English proficiency

Since English was not the native language of our participants, we screened for their English proficiency using a C1-level comprehension test from a TELC (The European Language Certificates) mock language examination (). We asked the participants to read a short text and fill in the missing sentences. They received one point for each correct answer; thus they could achieve a maximum of six points.

6.2.1.3. Procedure

The experiment took place during personality psychology seminars for undergraduate psychology students in the English BA program after a prior agreement with the teachers and students. First, the students who attended the seminar received an informed consent form. The experimenter emphasized that participation is voluntary and there are no negative consequences of withdrawal from the study. Participation required the written consent of the students. If the students agreed to participate, we handed out the test battery and asked the students to complete the first page consisting of the demographic questions. Afterward, the first author presented the slides on the 55-inch televisions placed in the classrooms. Immediately after the presentation, we asked the students to fill in the retention test according to their best knowledge. When participants finished the retention test, they completed the backward digit-span task, the d2 test of attention, and the English proficiency test. The whole experiment lasted about 1-hour.

6.2.1.4. Data analysis

Statistical analyses were performed using the 'lme4' (Bates et al., 2015) and 'emmeans' packages in R (version 2023.09.1+494). All variables were normally distributed, as the absolute values of Skewness and Kurtosis were less than 2.

First, we sought to test the effect of the number of multimedia elements on the student's performance on the retention test. For this, we performed a linear mixed model (lmm), with one within-subject factor being the number of multimedia elements (0 to 3). Achieved scores on the retention test were included as dependent variables. The random factor was the participants' code. Follow-up Tukey corrected pairwise comparisons were adjusted for multiple comparisons using the 'emmeans' package in R with the 'lmerTest' extension using the Satterthwaite approximation for degrees of freedom.

Second, we performed an additional lmm to test whether individual differences in WM capacity, attentional performance, and English language proficiency influenced the retention test scores. Therefore, we extended our original model with the main effects and interactions between the within-subject factor (number of multimedia elements) and the backward digit-span scores (WM-capacity), E% scores (sustained attention), and the achieved points on the TELC comprehension test (language). Statistical results will be presented in a table to make the description of the results easier to follow.

The dataset that includes computed study variables is available on the Open Science Framework: https://osf.io/a7vh8/?view_only=736f6bcaa72d408fb3ace7ccee1d4aee

6.2.2. Results and Discussion

The objective of Experiment 1 was to test whether the number of multimedia elements presented in a digital presentation would improve the learning outcomes of university students. Statistical results are presented in Table X; see Figure 6.1 for mean scores. We hypothesized that as the number of multimedia elements increased, students would remember the presented learning material better. In line with our hypothesis, the analysis revealed a significant main effect regarding the number of multimedia elements. Although the post-hoc analysis only showed a significant difference between the conditions presenting one and three elements, this suggests that the increased number of multimedia elements does indeed gradually improve recall performance (see Figure 6.1). See supplementary Table 6.1 for the detailed descriptive data.

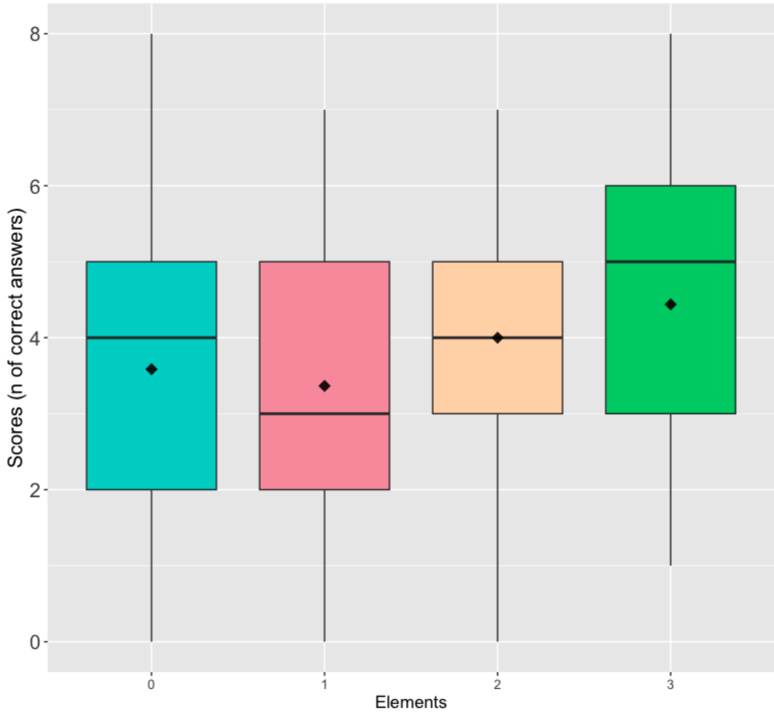

Figure 6.1. - Performance on the retention task (number of total points obtained) in the four conditions (0, 1, 2, or 3 presented elements) visualized as boxplots. The black diamonds indicate the mean scores.

Regarding individual differences, we tested the effect of sustained attention, WM capacity, and English proficiency on learning efficiency. See Table 1 for the detailed statistical results. We hypothesized that students with less efficient attentional processes and more limited working memory capacity would show reduced learning efficiency when more visual elements were presented on the screen. In the analysis, we also controlled for the English proficiency of the students, as the learning material was not delivered in their native language. We did not find a significant main effect of these variables; however, the analyses revealed interactions between learning performance and sustained attention, and between learning performance and English proficiency. We found no main effect or interaction for WM capacity. The results indicate that students with lower levels of sustained attention and lower levels of English proficiency had lower quality information processing and recalled less information correctly from the learning material.

Table 6.1. Detailed statistical results for the linear mixed models with pairwise comparisons regarding the number of multimedia elements and the interactions between conditions and attention (E%), English proficiency (language), and WM-capacity (backward digit-span scores). Significant interactions are broken down by condition. Significant main effects and interactions are italicized.

			df	**F**	**p**
n of elements			*120*	*3.47*	*0.018*
	Pairwise comparisons	Estimate	df	t	p
	Control - Multimedia1	0.22	120	0.61	0.929
	Control - Multimedia2	-0.415	120	-1.152	0.658
	Control - Multimedia3	-0.854	120	-2.372	0.088
	Multimedia1 - Multimedia2	-0.634	120	-1.762	0.297
	Multimedia1 - Multimedia3	*-1.073*	*120*	*-2.982*	*0.018*
	Multimedia2 - Multimedia3	-0.439	120	-1.22	0.616
			df	**F**	**p**
E%			30	1.35	0.255
Language			30	0.33	0.572
WM-capacity			30	1.86	0.183
n of elements*E%			*90*	*2.88*	*0.04*
n of elements*Language			*90*	*4.78*	*0.004*
n of elements*WM-capacity			90	2.08	0.109
		Estimate	**df**	**t**	**p**
	Multimedia1-Control*E%	*-0.225*	*90*	*-2.931*	*0.004*
	Multimedia2-Control*E%	-0.097	90	-1.263	0.21
	Multimedia3-Control*E%	-0.108	90	-1.414	0.161
	Multimedia1-Control*Language	0.082	90	0.341	0.734
	Multimedia2-Control*Language	0.354	90	1.469	0.145
	Multimedia3-Control*Language	*0.826*	*90*	*3.43*	*<.001*

Although we have compelling results, there is an important limitation of our study that should be noted. In the retention test, we used a mixture of questions about visually displayed (text-and-picture information) and non-displayed information (text-only information) introduced in the digital presentations. By increasing the number of elements, we could potentially ask more questions about the content that was reinforced both verbally and visually during the presentation. The picture superiority effect suggests that individuals remember pictures better than words (Paivio & Csapo, 1973; Stenberg, 2006; Winograd et al., 1982) because pictures have a perceptual advantage due to their distinctive features (Mintzer & Snodgrass, 1999). Hence, our participants may have been inclined towards processing visual information over spoken words, resulting better memory encoding of pictorial information. If this assumption is right, multimedia effect could be explained by the perceptual advantage of pictorial information. However, it is unclear from our results whether multimedia elements support this fragmented learning of the displayed information or facilitate a comprehensive understanding of the topic, as proposed by the CTLM (Mayer, 2014). In addition, it cannot be concluded that multimedia elements reduced the global encoding of the presented information for those with poorer English skills and less effective sustained attention. It is also a possibility that students may not have had the cognitive capacity to process text-only information while their cognitive resources were devoted to detecting and integrating pictorial information. Therefore, experiment 2 was designed to address these questions.

6.3. Experiment 2

A slide in a digital presentation typically visually displays some of the information but not all the content of the accompanying spoken information presented (James et al., 2006). This raises the question of whether students remember text-only information as well as text-and-picture information presented with the same slide. The CTLM suggests that the combination of text and images in an educational context can facilitate meaningful learning through increased cognitive engagement, which is a consequence of active learning (Mayer, 2002). On this basis, we would expect multimedia elements to support global comprehension. However, it is also possible that the visual elements highlight certain content from the subject material and primarily support a fragmented learning rather than global comprehension (Stenberg, 2006). If multimedia elements support global comprehension, we would expect students to show better recall performance for both text-and-picture and text-only information. Conversely, if multimedia elements work by highlighting specific information and capturing attention through their distinctive features, only the learning of pictorial information would be enhanced. Regarding individual differences, visualization may also play an important role. Students with attentional difficulties might show impaired learning performance only for text-only information during the short lecture.

Compared to Experiment 1, the retention test in Experiment 2 included an equal number of questions about text-and-picture and text-only information. With this modification, in addition to the number of elements, we added the visualization of the information as a second within-subject factor. Compared to Experiment 1, we reduced the number of tested conditions regarding the number of multimedia elements and tested only one and three multimedia elements. This was motivated by the fact that it allows us to test learning effectiveness in a lower and higher load situation. Furthermore, the results of Experiment 1 suggest that three elements can induce significant improvements in learning compared to one element.

6.3.1. Method

6.3.1.1. Sample

The sample consisted of 29 undergraduate psychology students (21 women) studying in the English program between the ages of 19 and 23 (M = 20.4, SD = 1.42). Sampling was identical to Experiment 1. All the participants were healthy adults, and none of them reported having a psychiatric disorder. Participation was voluntary and the students did not receive compensation for their participation. The study was approved by the Hungarian United Ethical Review Committee for Research in Psychology (reference nr. 2023-104) and was carried out following the Declaration of Helsinki. We obtained informed written and verbal consent from all participants.

6.3.1.2. Instruments

6.3.1.2.1. Presentations

In Experiment 2 we used slightly modified versions of the same presentations that we used in Experiment 1. The slides featured the same topic and were accompanied by the same narration, text, and multimedia elements. The presentations differed only in the number of multimedia elements. In Experiment 2 the number of multimedia elements that could appear on a slide varied between 1 and 3 pieces, resulting in 2 conditions regarding the number of multimedia elements. We had eight slides with one and another eight slides with three multimedia elements. The number of multimedia elements varied randomly across the slides. We visited two seminars; therefore, we created two different presentations with the same narration featuring the same text and the same visuals. The only difference between the presentations was the order in which the number of multimedia elements varied across the slides.

6.3.1.2.2. Retention test

Similarly to Experiment 1, we asked participants to answer multiple-choice questions related to the presented topic. We handed out the retention test immediately after the presentation. The test contained two questions referring to each slide, which resulted in a total of 32 questions. The questions can be divided into 4 (2x2) conditions (eight questions per each) along two dimensions. One is the number of multimedia elements (1 or 3) on the slide to which the question refers, and the other is whether the question asks for information visualized with a multimedia element or not (visualized or non-visualized information). The information is visualized when the slide contains multimedia elements referring to it and non-visualized when the students only receive the information in the form of written text and narration without any kind of illustration.

Participants received one point for each correct answer and 0 for an incorrect answer; they could achieve a maximum of 32 points (eight points per condition) by answering all of them correctly.

6.3.1.3. Procedure

The procedure was identical to Experiment 1.

6.3.1.4. Data analysis

Statistical analyses were performed using the ‘lme4’ (Bates et al., 2015) and ‘emmeans’ packages in R (version 2023.09.1+494). All variables were normally distributed, the absolute value of Skewness and Kurtosis were less than 2. The above 25% failure rate on D2 data was excluded (approximately .07% of all the collected data). All variables were normally distributed, the absolute value of Skewness and Kurtosis were less than 2.

First, we sought to test the effect of the number of multimedia elements and visualization on the student's performance on the retention test. For this, we performed a lmm, where the within-subject factors were the number of multimedia elements (1 or 3) and the visualization of the conveyed information (text-and-picture or text-only). Achieved scores on the retention test were included as dependent variables.

Second, we performed an additional lmm to test whether individual differences in WM-capacity, attentional performance, and English language proficiency influenced the retention test scores. We tested the main effects and interactions between the within-subject factors (number of multimedia elements and visualization) and the backward digit-span scores (WM capacity), E% scores (sustained attention), and the achieved points on the TELC comprehension test (language). Statistical results will be presented in a table to make the description of the results easier to follow.

The dataset that includes computed study variables is available on the Open Science Framework: https://osf.io/a7vh8/?view_only=736f6bcaa72d408fb3ace7ccee1d4aee

6.3.2. Results and Discussion

The aim of Experiment 2 was to test how the visualization of information affects the processing of text-only information when students learn from a digital presentation with visual multimedia. The analyses showed no main effect of the number of elements; however, we found a significant effect of visualization (see Figure 6.2, see supplementary Table 6.2 for the descriptive statistics). This confirms the assumption that visual multimedia elements in digital presentations primarily support the acquisition of text-and-picture information during a short lecture. These results also highlight that for memory encoding visual representation can be more important than the number of elements presented on the screen. We did not find any interaction between the number of elements and visualization. This suggests that up to three visual multimedia elements do not interfere with the processing of text-only information, or at least not more than a single presented element. This is supported by the fact that students correctly recalled approximately the same amount of information from text-only information whether one or three multimedia elements were presented.

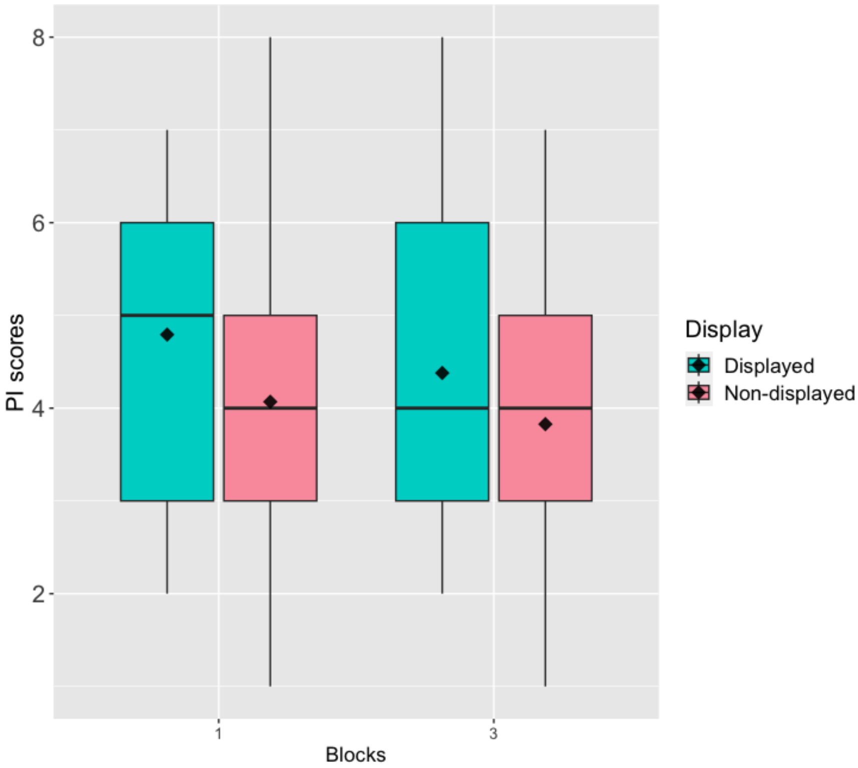

Figure 6.2. - Performance on the retention task (PI scores = number of total points obtained) for the visualized and non-visualized information, separated by the number of elements (1 or 3). The black diamonds indicate the mean scores.

Regarding individual differences the analysis revealed a main effect of sustained attention, however we found no other significant main effect or interactions. The exact statistical results are shown in Table 6.2. Since no significant interaction with visualization was found for sustained attention and English proficiency, it can be assumed that there is a global decrease in learning efficacy associated with poorer sustained attention and language proficiency, when multimedia elements are presented. This is further evidenced by the fact that students with poorer sustained attention generally performed worse on the retention test. Thus, the observed effect of these variables in Experiment 1 (a decrease in Q&A scores when multimedia elements are included) is not limited to text-only information.

Table 2. – Detailed statistical results for the linear mixed models with main effect and interaction between within-subject factors. Interactions between conditions and attention (E%), English proficiency (language), and WM-capacity (backward digit-span scores) are also reported. Significant main effects and interactions are italicized.

	df	F	p
n of elements	72	1.72	0.115
Visualization	*72*	*6.54*	*0.007*
n of elements*Visualization	72	0.12	0.885
	df	**F**	**p**
E%	*23*	*3.47*	*0.041*
Language	23	0.00	0.994
WM-capacity	23	1.25	0.274
n of elements*E%	72	0.15	0.694
n of elements*Language	72	1.91	0.170
n of elements*WM-capacity	72	0.87	0.354
Visualization*E%	72	1.57	0.213
Visualization*Language	72	1.31	0.256
Visualization*WM-capacity	72	0.17	0.678

6.5. Discussion

Nowadays, digitalization is a major challenge for educators. Our study aimed to investigate the impact of visual multimedia elements used in digital presentations on information processing and learning. Specifically, we sought to test whether increasing the number of multimedia elements up to three would improve the learning outcomes of university students. Our results suggest that content-related explanative multimedia elements of up to three do not cause cognitive overload for the average university student. In fact, the observed learning outcomes were highest with three elements. However, the number of multimedia elements seems to be less relevant when considering the visualization of the recalled information. Our results show that students primarily remember content that is presented both visually and verbally, and that this improvement in learning is independent of the number of visually presented elements. These results are in line with previous studies (Gordani & Khajavi, 2020; Lee & Mayer, 2018; Mayer, 2002) and confirm that the inclusion of explanative multimedia elements (in this case static illustrations) facilitates learning. However, the improvement in recall performance is not due to global comprehension and processing. Instead, more fragmented learning predominates, which might be explained by the fact that the visualization can highlight some specific content and capture attention (Mitzner et al., 2019).

In addition to the number of elements, we sought to test the role of individual differences in sustained attention and WM capacity on the learning outcomes of university students after the multimedia presentation. We also controlled for the students' language proficiency, as the learning material was not presented in their native language. We expected that cognitive overload would occur earlier for those with lower levels of sustained attention or WM capacity. In line with our hypothesis, our results indicate that students with lower levels of sustained attention show a lower quality of information processing and recall less of the presented information correctly. This effect occurred both for information presented verbally only and for information presented verbally and visually, showing that multimedia elements interfere with global comprehension and processing when students have shorter attention spans. This not only emphasizes the significance of examining individual differences (Li et al., 2019) but also demonstrates that explanative content-related multimedia elements can negatively impact learning outcomes when attentional processes are less efficient.

Students' learning efficiency was globally impaired, suggesting that parallel processing increases cognitive load even with a relatively small number of elements. Previous studies have found this disruptive effect of multimedia elements primarily in the context of seductive (i.e., entertaining but unrelated to content) details (Harp & Mayer, 1998; Sanchez & Wiley, 2006; Wiley et al., 2014). However, our results suggest that processing content-related multimedia elements is just as demanding as seductive details for students with shorter attention spans. A similar effect was observed for foreign language proficiency, indicating that it may be an important factor in determining the most appropriate instructional design for non-native language learners. As previously demonstrated (Lee & Mayer, 2018), different multimedia principles may apply to students who are learning in their second language. Our findings also suggest that these students may warrant further interest in future research. It appears that cognitive load occurs earlier with lower language proficiency, which affects students' learning effectiveness in a multimedia environment. In our study a decrease in learning success was observed despite the fact that the presentations included written text in addition to the spoken information. Based on the modality effect (Ginns, 2005; Knoop-Van Campen et al., 2018; Moreno & Mayer, 1999; Tabbers et al., 2004) providing written text and spoken information simultaneously would increase cognitive load, but the opposite was observed for students learning in their second language (Kozan et al., 2015; Lee & Mayer, 2018). Regarding WM capacity, we did not find a significant effect. This is somewhat surprising, as previous research in multimedia learning has mainly emphasized the role of WM capacity in the context of individual differences while the possible contribution of sustained attention was not investigated (Anmarkrud et al., 2019; Doolittle & Mariano, 2008; Kozan et al., 2015; Sanchez & Wiley, 2006; Wiley et al., 2014). Thus, in the future, it may be worthwhile to include attentional processes in the study of multimedia learning, as it appears that attentional processes may contribute more to the prevention of cognitive load.

Some limitations of the study should also be noted. We measured recall performance immediately after the digital presentation; thus, we do not know how the number of multimedia elements affects recall in the long term. Additionally, the digital presentation was relatively short (15 min) compared to an actual university lecture, raising questions about the extent to which the results can be generalized to a longer and hence more cognitively demanding lecture or seminar. Our measure of learning outcomes was a retention test and did not include transfer questions. Therefore, we can only generalize our results to the acquisition of fragmented knowledge rather than deeper understanding. To better understand the connection between multimedia information processing and attentional performance, it may be worthwhile to incorporate eye-tracking in the future. Mapping eye movements would help us to better understand the attentional mechanisms that contribute to successful learning with multimedia elements. Despite these limitations, the advantage of the study is that the data were collected during actual seminar classes presenting theoretical material related to the curriculum. This increases both the ecological validity and the generalizability of our findings. Furthermore, we used a within-subject design, which allowed us to test improvements in the actual performance of the participants. Also, instead of the media comparison approach that currently dominates the field (Buchner & Kerres, 2023), we followed the value-added approach and tested different versions of the same digital presentation with nuanced modifications. This allows us to make more precise suggestions about the optimal instructional design of this multimedia delivery mode (Baker et al., 2018).

In conclusion, visual multimedia elements in digital presentations can effectively highlight key terms in the presented information. Although the average university student can process up to three visual elements without experiencing cognitive overload, multimedia elements should be used with caution. This is because processing and integrating these elements is more challenging for students with lower levels of sustained attention. This indicates that even content-related explanative multimedia elements may reduce learning effectiveness due to individual differences in attentional mechanisms. Possibly because these elements distract attention and consume a significant amount of cognitive capacity, disrupting the global comprehension of the presented information and affecting the acquisition of both text-and-picture and text-only information. Future studies should further investigate the impact of attentional mechanisms on multimedia learning and consider these factors not only in the context of seductive details. We believe that these results can guide educators in creating an instructional design that is consistent with the principles of multimedia learning while addressing the individual needs of their students.

7. The Impact of Pictures on High School Students' Learning: How Many Pictures Are Too Many?

7.1. Introduction

Students are surrounded by an increasing amount of visual information as they learn. Textbooks are rich in illustrations, figures, graphs, etc (Hochpöchler et al., 2013), however, digital technology further enriches the educational environment with visual content. Educators can supplement classroom learning with interactive applications, digital presentations, augmented reality, or even virtual reality (Barrow et al., 2019; Parong & Mayer, 2018; Savoy et al., 2009; Takacs et al., 2015). Visual aids not only make learning more entertaining (Choi, 2018) but also improve learning efficiency and promote deeper comprehension (Bujak et al., 2013; Carney & Levin, 2002; Jägerskog et al., 2019; Levie & Lentz, 1982). This is known as the multimedia-effect in literature and is explained by the theory of multimedia learning (CTML) (Mayer, 2014). According to the CTML adding visual information to words (whether it is spoken or written) makes the subject material cognitively more engaging, because processing the visual and verbal information altogether requires detecting, integrating, and organizing. This higher cognitive engagement, in turn, leads to better understanding and encoding of the information (Mayer, 2002). Pictures also improve learning and comprehension by depicting abstract concepts – this is particularly important in STEM education – (Çeken & Taşkın, 2022; Mutlu-Bayraktar et al., 2019) or eliciting situational interest in students (Endres et al., 2020). Consequently, it is presumed that accompanying text with visual information can effectively serve educational purposes and students will benefit from learning with the help of pictures.

Although adding pictures to text has proven benefits, it can also be a source of extraneous cognitive load. Humans have limited cognitive capacity for processing information, therefore parallel processing of pictures and text can be challenging for many (Sweller & Chandler, 1994). When the instructional design of the multimedia material is overwhelming, it may exceed the available cognitive capacity of the students and cognitive overload will occur (Mayer & Moreno, 2003). This interferes with the emergence of benefits of using visual information (Bali, Matuz-Budai, et al., 2023; Parong & Mayer, 2018). The easiest way to minimize cognitive load is to use content-congruent explanative pictures (designed to demonstrate a process) (Mayer et al., 1995; Sundararajan & Adesope, 2020) and ensure the temporal synchronization of visual and textual content (Ge et al., 2022; Liu et al., 2022; Mayer & Anderson, 1992). During instructor-based/system-based classroom learning (which is the focus of this study), the risk of cognitive overload is further decreased when pictorial information is accompanied by spoken instead of written text. This is known as the modality principle and assumes that spoken text and pictures are processed through different sensory modalities which frees up cognitive capacity (Ginns, 2005; Moreno & Mayer, 1999; Paivio, 1990).

The amount of information (both textual and visual) that students are expected to attend, organize, and integrate simultaneously should also be considered when designing teaching materials with pictures. Since students can only hold a limited amount of information in their working memory (Cowan, 2008), having too many pictures on the screen at once can be distracting and lead to cognitive overload (Ayres & Sweller, 2014). This excessive multimedia use can hinder the quality of information processing even when only content-congruent visuals are included (Bali, Matuz-Budai, et al., 2023; Makransky et al., 2021; Parong & Mayer, 2018). This calls for the need to define what we mean by excessive multimedia use for content-congruent stimuli. Previous research has focused primarily on the impact of decorative, non-content-congruent pictures (Harp & Mayer, 1998; Mutlu-Bayraktar et al., 2019; Sanchez & Wiley, 2006; Sundararajan & Adesope, 2020), therefore, less is known about how the increase in the number of content-congruent pictures affects information processing and learning. To reduce extraneous load when adding pictures to spoken text, it is crucial to determine the amount of multimedia elements on the screen that can be considered intrusive.

The increased workload might not equally affect the processing of information aided with pictures and information presented only verbally. It is possible that pictures primarily take away processing capacity from information that is spoken but not visually supported. The impact of pictures in most studies has been predominantly assessed by tests measuring the overall performance of the students. Thus, it is difficult to determine whether recall performance differs for text-only and text-and-picture information. The limited research (Brookshire et al., 2002; Herrlinger et al., 2017; Levie & Lentz, 1982), which differentiated between these two types of information, found that pictures did not improve the retention of text-only information. This indicates that pictures are primarily beneficial for spoken information that is also visually aided while they do not affect the encoding of text-only information. Earlier studies, however, did not explore how recall of text-only information changes when the number of pictures simultaneously presented increases. Pictures have distinctive features and therefore, have a perceptual advantage over spoken information

(Mintzer & Snodgrass, 1999). According to the *picture superiority effect theory* this leads to better learning of pictures than words (Paivio & Csapo, 1973; Stenberg, 2006; Winograd et al., 1982). Consequently, it can be assumed that text-and-picture information has an advantage over text-only information during perception, potentially leading to split attention and higher workload (Brünken & Leutner, 2001). That is, students may give more attention to text-and-picture information at the expense of text-only information. If we follow the assumption that perceptual system favours pictures over text-only information, it is plausible that the processing of text-only information becomes less efficient as the number of pictures increases, while processing text-and-picture information remains intact. This may be due to that pictures may act as distraction when students process text-only information.

In addition to the amount and visuality of information to be processed, the occurrence of cognitive overload may also be a function of individual variables, such as students' attention and average screen media activity. Students, who are easily distracted, have shorter attention spans, and lower levels of cognitive control may struggle with parallel information processing (Makransky et al., 2021; Wiley et al., 2014). Their attention might be captured by single elements when parallel information is present (Colflesh et al., 2007), increasing the likelihood of divided attention. This may interfere with their ability to integrate and organize information presented in multiple sensory modalities (Ayres & Sweller, 2014). The amount of screen media activity is negatively associated with the efficiency of cognitive control functions (Meri et al., 2023; Ophir et al., 2009) and may result in altered attentional or information processing strategies (Konok et al., 2021; Nikkelen et al., 2014), thus might have a negative impact in an educational context. Overall, it can be assumed that children with attentional difficulties (and higher amount of screen-time) may experience cognitive overload even when less information is presented on the screen. Therefore, it is crucial to control for attentional mechanisms and screen time activity when examining risk factors for cognitive overload during picture-aided learning.

Overall, while the use of pictures can enhance learning, specific recommendations are needed to avoid cognitive overload, including guidance on the optimal number of content-congruent pictures. Therefore, our aim in the present study was to systematically test how the quality of information processing changes as the number of pictures on the screen increases. We also distinguished between learning outcomes for text-and-picture information and for text-only information. *Regarding text-and-picture information*, we hypothesized that when spoken text is accompanied by one or two pictures, students' recall performance will improve compared to the schematic background condition without additional pictures. We further hypothesized that this improvement will be independent of the number of pictures, because each picture conveys different information, and because the pictures are congruent in content and synchronized with the narration. Therefore, it is unlikely that the two pictures impose a significant extraneous load that diverts cognitive resources from other concurrently displayed content. *Regarding text only information*, we hypothesize that students' recall performance will gradually decrease as the number of pictures increases, because the pictures impose a significant extraneous load and interfere with the processing of text-only information. As the number of pictures increases, the interference will be greater due to the perceptual advantage of processing pictures.

We tested these hypotheses during instructor-based classroom learning, using a narrated digital presentation with pictures. Further, our experimental design will follow the value-added research approach rather than media comparison to provide precise recommendations on how to use pictures in a way that is beneficial to students. The value-added research approach does not compare different instructional technologies, but rather tests the same technology and manipulates an attribute within it (Buchner & Kerres, 2023). For this reason, it provides better insights for instructors, yet media comparison is typically used in research (Baker et al., 2018).

7.2. Methods

7.2.1. Sample

We recruited a total of 260 Hungarian high school students (133 girls) between the ages of 14 and 18 (M = 16, SD = 0.874). All students were typically developing, with no neurological or other disorders, according to their teachers and parents. Participation was voluntary and they received no compensation for their participation.

The study was approved by the Hungarian United Ethical Review Committee for Research in Psychology out following the Declaration of Helsinki. Parents and teachers were informed about the details of the study. Permission of the parents was requested through an informed consent form. All the students agreed to participate both in a verbal and a written form.

7.2.2. Instruments

7.2.2.1. Presentations

We created a 12-slide presentation using Microsoft PowerPoint. We used Norse mythology as the theme of our presentation, with the myth of Thor's journey to the land of the giants. We chose this story because it was age-appropriate for the target population and presumably unfamiliar to the students since it was not part of the curriculum. This was confirmed by the fact that later in the questionnaire none of the students reported a high level of expertise in Norse mythology, and none were familiar with the story.

The slides of the presentation featured content-relevant visual multimedia elements that illustrated the story. The pictures were simple and depicted actual scenes from the spoken text. In addition, all slides had a general background image that was neutral to the story. The number of multimedia elements that could appear on a slide varied from 0 to 2 (not including the neutral background), resulting in three conditions. The number of multimedia elements varied randomly across the slides. During the presentation, students heard a spoken text that complemented the pictorial content on the slides. Thus, some information was present in both visual and auditory formats (text-and-picture information), while others were present only in auditory format (text-only information). In the two-element text-and-picture condition, we had an A and a B version. In the A version, the retention test included a question about both visual information, while in the B version, the retention test included questions about one of the visual elements. The scores obtained for the A and B versions were combined. The retention test included questions about text-only and text-and-picture information as well. With this distinction, we had a total of five conditions: slides with one multimedia element conveying text-and-picture and text-only information, slides with two multimedia elements conveying text-and-picture and text-only information, and an additional control condition with no multimedia elements (conveying only text-only information). The conditions, with examples, are shown in Figure 1. We had four versions of the same presentation, each of them a mix of three of the conditions shown in Figure 1. By using multiple versions, we ensured that the different conditions were not exclusively associated with a single part of the story but varied across participants. Students were introduced to one of the four versions and, thus, randomly participated in three of the five conditions. The spoken text was pre-recorded and added to the presentation to ensure that all participants had the same audio experience, regardless of which version they had seen. The presentation lasted approximately 15 minutes. For the order of the conditions per each version of presentation see Supplementary Table 7.1.

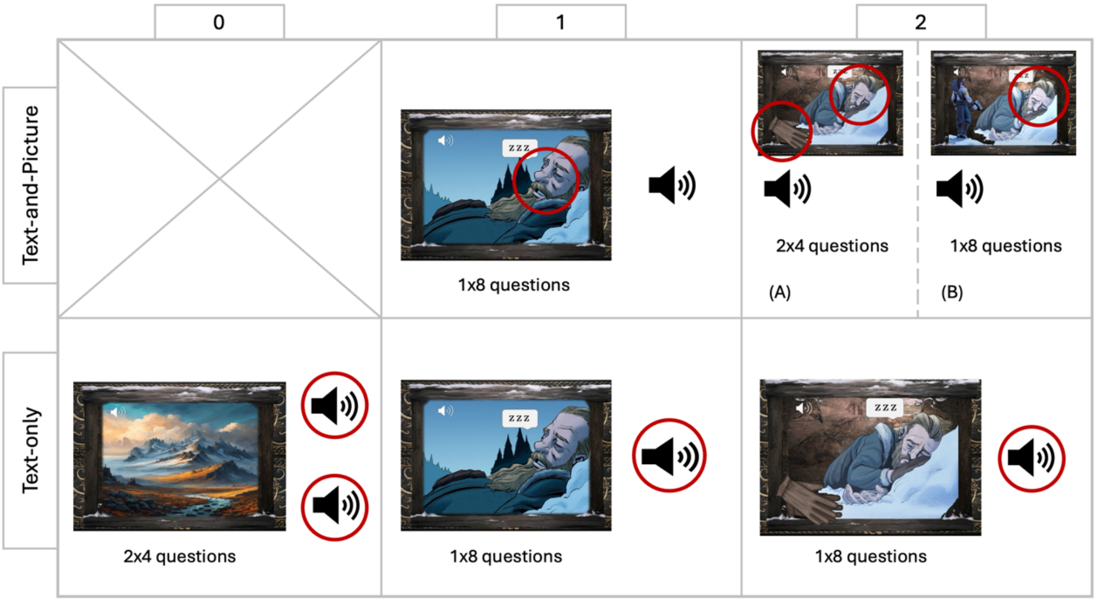

Figure 7.1. – Examples for each condition. From left to right, conditions 0, 1, or 2 are shown. The upper panel shows the text-and-picture, and the lower panel shows the text-only conditions. The pictures represent the visual information, while the speaker icons represent the text-only information. The red circles indicate the format of the information we asked in the retention test in that particular condition. In the two-element text-and-picture condition, we had an A and B version. In the A version, the retention test included a question for both visual information, while in the B version, the retention test included questions about one of the visual elements. The obtained scores for the A and B versions were merged. The figure also shows the distribution of questions in the retention test for each condition. The images are of the actual stimuli used in the study and show how the same slide looked in the four different versions.

7.2.2.2. Retention test

We measured participants' learning efficiency with open-ended questions about the story presented. Participants answered the questions immediately after the presentation. The retention test contained two questions for each slide and 8 questions per condition, for a total of 24 questions. Some of the questions asked for information that was visually displayed (text-and-picture information), while others asked for information that was only auditory presented (text-only information). Responses to the retention test were scored on a three-point scale between 0 and 2. Wrong answers scored 0, correct but incomplete answers scored 1, and correct answers scored 2. Students could earn a maximum of 48 points by answering all questions correctly and 16 points per condition. The total score ranged from 1 to 40 points (M = 20.09; SD = 9.01). All responses were scored by independent raters. A total of five independent raters scored the responses, and each response was scored by two raters. Agreement between raters was tested with interclass correlation (ICC) in R (version 2023.09.1+494 for macOS) using the 'irr' package (Gamer et al., 2022). We used a two-way mixed-effects model with consistency of the ratings (Koo & Li, 2016). We chose this model because we were interested in assessing the consistency of ratings given by multiple raters. ICC values ranged from 0.7 to 1. The overall mean ICC across the 24 questions was 0.91, with a 95% confidence interval ranging from 0.89 to 0.93, indicating good inter-rater consistency among raters. All ICC values were statistically significant ($p < .001$). See Supplementary Table 7.2 for the exact statistical values per question.

7.2.2.3. Attention

We used the 6-items short-version of the Adult ADHD Self-Report Scale (ASRS) to measure participants' difficulties in attentional mechanisms and hyperactivity (Kessler et al., 2005; Lundin et al., 2019). Participants rated how often the statements on the scale were true for them in the previous 6 months on a five-point Likert-type scales (never to very often). Higher scores indicated more attentional difficulties and higher levels of hyperactivity. Although the scale was designed for adults, it has been shown to reliably measures adolescents (Green et al., 2019). In this study the McDonald's ω was .59. Scores ranged from 8 to 27.

7.2.2.4. Screen-media use

We used the Screen media activity scale (Paulus et al., 2019) to measure participants' screen time on an average day. The original scale consists of 8 items; however, we added an additional item to measure the frequency of using any form of streaming services. Participants rated the items on seven-point Likert-type scales (none to 4 hours or more) according to how much time they spent on each screen media activity included in the questionnaire (e.g., browsing the Internet, using social media, etc.). Higher scores indicate higher average daily screen time. In this study, the McDonald's ω was .59. Scores ranged from 15 to 40.

7.2.3. Procedure

Data collection took place at the participating schools. Prior to the study, the experimenter emphasized that participation was voluntary and that there were no negative consequences for withdrawing from the study. First, students were asked to fill out an informed consent form. Then they completed the demographic questions and the two questionnaires. Students were also screened for prior knowledge of Norse mythology. Students were asked to indicate on a 10-point Likert-type scale how well they knew Norse mythology and whether they were familiar with the myth of Thor's journey to the land of the giants. If they answered yes, they were asked to briefly explain the plot of the myth. None of the participants answered in the affirmative. Then, one of the authors played the presentation on a digital blackboard smart TV. Immediately after the presentation, we asked the students to fill out the retention test according to the best of their knowledge. The students completed the questionnaires and the retention test via an online form in the classroom. The whole experiment took about 45 minutes.

7.2.4. Data analysis

Statistical analyses were performed using R (version 2023.09.1+494 for macOS) (R Core Team, 2020). All variables were normally distributed, as the absolute values of skewness and kurtosis were less than 2. None of the students reported a high level of expertise in Norse mythology, and none were familiar with the story, so we did not exclude students based on their prior knowledge. However, we excluded 2 participants (0.7% of the data collected) because they did not meet the inclusion criterion of answering at least one question correctly on the retention test.

We tested the effect of the number of multimedia elements on learning outcomes using linear mixed models (LMM) with random intercept. We had two LMMs to analyze the recall performance separately for text-and-picture and text-only information. First, we tested the contributors to students' learning outcomes for text-and-picture information. To do this, we performed an LMM in which one factor was the number of multimedia elements presented on each slide (0, 1, or 2). Scores obtained on the retention test were included as the dependent variable. We also controlled for students' attention difficulties and

hyperactivity and screen time. To do this, we used total scores on the ASRS and SM questionnaires. The random factor was the participants' ID. Follow-up Tukey corrected pairwise comparisons were adjusted for multiple comparisons using the Kenward-Roger approximation for degrees of freedom. Next, we conducted the same LMM to test the contributors to students' learning outcomes related to text-only information. For descriptive data see Supplementary Table 7.3. The dataset containing the computed study variables is available on the Open Science Framework:
https://osf.io/2jm6y/?view_only=92e4e75d2bba4f56b421acf1fcc805db

7.3. Results

We examined retention scores for text-and-picture information to test our prediction that when pictures are presented, students will perform better on the retention test. Exact statistical results are presented in Table 7.1. Regarding the learning outcomes of text-and-picture information, we found a significant main effect of the number of multimedia elements. Compared to the slides with no multimedia elements, students recalled significantly more information when visual information was present on the slides. This improvement was the same for conditions with one and two multimedia elements. Students' attentional mechanisms and use of screen media did not affect their learning outcomes, as we found no significant main effects or interactions for these individual variables.

Table 7.1. – Detailed statistical results for the linear mixed model testing the effect of number of multimedia elements on students' learning outcomes for text-and-picture information. Significant main effects and interactions are italicized.

			df	**f**	**p**
Number of elements			*322.1*	*8.18*	*<.001*
	Pairwise comparisons	**b**	**df**	**t**	**p**
	0 - 1	*-1.038*	*291*	*-3.673*	*<.001*
	0 - 2	*-0.915*	*339*	*-3.312*	*0.002*
	1 - 2	0.122	339	0.441	0.898
			df	**f**	**p**
SM score			286.19	3.6	0.059
ASRS score			284.72	0.74	0.389

Elements*SM score		319.53	1.98	0.14
Elements*ASRS score		327.14	2.71	0.068
Random Effect				
σ^2	4.47			
τ_{00} ID	8.08			
ICC	0.64			
$_N$ ID	253			
Observations	516			
Marginal R^2 / Conditional R^2	0.040 / 0.658			

We next examined retention scores for text-only information to test our hypotheses claiming for text-only information, that recall performance will gradually decrease as the number of pictures increases. Figure 7.2. presents the descriptive statistics for these comparisons; statistical results are presented in Table 7.2. We found a significant main effect of the number of multimedia elements, but the pattern of students' performance was different from the analysis of the text-and-picture information. For the text-only information, students performed similarly when the slides contained zero or one multimedia element, whereas their performance on the retention test decreased significantly when the slides contained two multimedia elements. This partially confirmed our second hypothesis. Students' attentional mechanisms and screen media time did not affect their learning outcomes, as we found no significant main effects or interactions with these variables.

Table 7.2. – Detailed statistical results for the linear mixed model testing the effect of number of multimedia elements on students' learning outcomes for text-only information. Significant main effects and interactions are italicized.

			df	**f**	**p**
Number of elements			*212.48*	*16.58*	*<.001*
	Pairwise comparisons	**b**	**df**	**t**	**p**
	0 - 1	0.125	221	0.413	0.91
	0 - 2	*1.789*	*224*	*5.7*	*<.001*
	1 - 2	*1.664*	*336*	*4.453*	*<.001*

		df	f	p
SM score		245.12	0.94	0.334
ASRS score		256.1	0.04	0.841
Elements*SM score		214.5	0.01	0.989
Elements*ASRS score		219.71	1.78	0.171
Random Effect				
σ^2	4.55			
τ_{00} ID	7.01			
ICC	0.61			
N ID	253			
Observations	398			
Marginal R^2 / Conditional R^2	0.061 / 0.630			

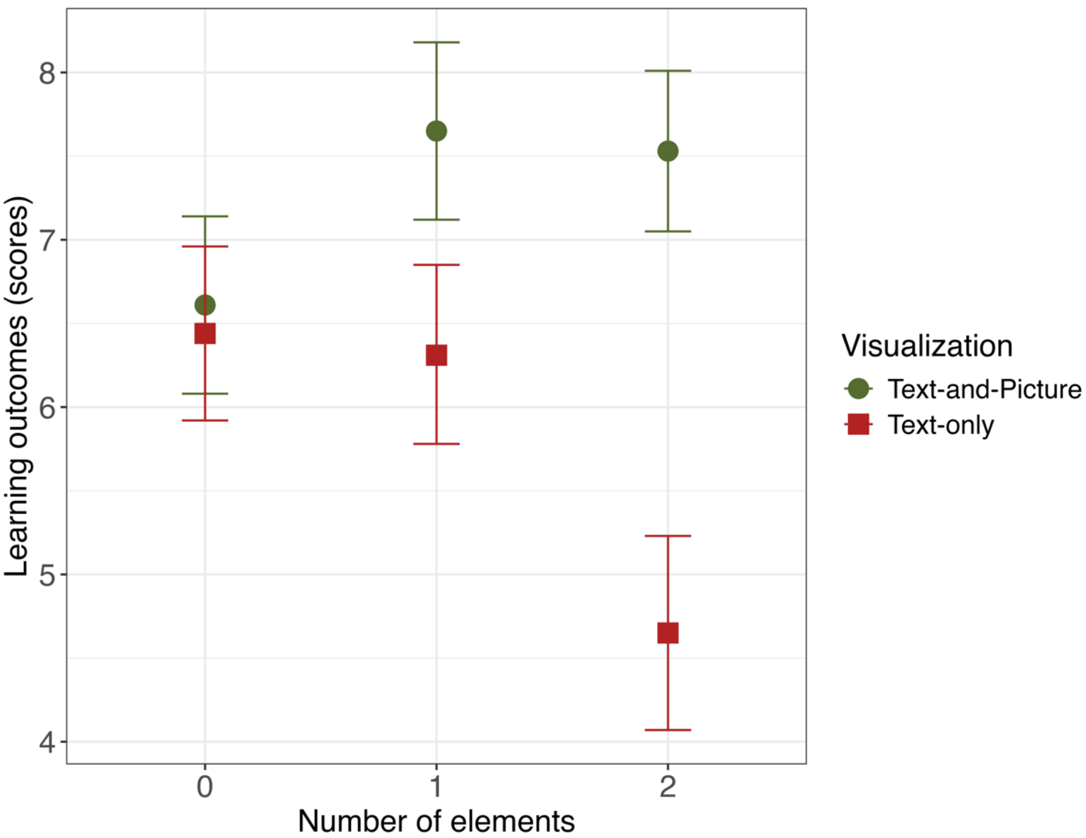

Figure 7.2. – The students' learning outcomes, represented by the mean scores on the retention test, separated by the performed LMM models. Green color shows the results of

the first analysis and red color shows the results of the second analysis. The green circles show the mean scores of the text-and-picture information, while red squares show the mean scores of the text-only information, separated by the number of multimedia elements. Error bars indicate the 95% confidence interval.

7.4. Discussion

Accompanying spoken text in system-based learning with explanatory, content-congruent pictures is beneficial for students. The use of multimedia content, such as pictures, helps students engage in active learning, leading to better comprehension and encoding (Mayer, 2002). At the same time, however, they might increase the risk of cognitive overload (Ayres & Sweller, 2014; Sweller & Chandler, 1994). Therefore, precise recommendations are needed to incorporate pictures in a way that is truly beneficial for students. This includes guidance on the optimal number of content-congruent pictures presented simultaneously on the screen. The number of pictures should be tailored to students' limited cognitive capacity (Sweller, 2010), however, there are no specific recommendations on how many pictures will constitute an increased workload. Thus, in this study, we aimed to systematically test the effect of the number of pictures (increasing from 0 to 2) on the learning efficiency of high school students. We also argued that the increased extraneous load due to the increasing number of pictures will mainly affect the processing of text-only information.

We found a beneficial effect of including pictures in a narrated presentation for text-and-picture information. This is in line with our first hypothesis and earlier studies (Carney & Levin, 2002; Çeken & Taşkın, 2022; Jägerskog et al., 2019). Compared to the condition in which students saw only a neutral background, students gave more accurate answers and recalled more information when pictures were included. As expected, the observed effect was consistent regardless of the number of pictures. This suggests that students can effectively process text-and-picture information with up to two pictures presented, leading to better learning outcomes. However, the improved performance was only observed for text-and-picture information, suggesting that pictures do not promote better learning of text-only information. Compared to the neutral background only condition, participants' performance was the same as when they saw only one picture and were asked about text-only information. However, compared to these two conditions, students scored lower on the retention test for text-only information when they were exposed to two pictures. These results, together with the findings of previous studies (Brookshire et al., 2002; Herrlinger et al., 2017; Levie & Lentz, 1982) suggest that one picture does not lead to significantly increased workload. Conversely, two pictures already represent a load that negatively affects the processing of text-only information. This confirms our hypothesis that pictures have a perceptual advantage (Mintzer & Snodgrass, 1999) and consume cognitive resources from text-only information. Taken together, our results suggest that the optimal number of pictures on the screen at one time, is one when the audience consists of high school students engaged in teacher- or system-based classroom learning and when the pictures are used in conjunction with spoken text.

These results should make practitioners aware that for best performance, digital presentations should contain no more than one picture per slide. The use of one picture is beneficial because it enhances the recall of visually presented information without impairing the processing of text-only information that is spoken but not visually displayed. For maximum efficiency, the included picture should be content-congruent (Mayer & Moreno, 2003) and used to highlight key terms or concepts. Presenting two pictures will still improve the retention of text-and-picture information, but the cognitive cost will be higher, resulting in less efficient learning overall. In this case, perception is shifted towards spoken information with pictures, reducing the efficiency of processing text-only information. This is likely due to increased cognitive load, as the higher number of pictures distracts and divides attention (Ayres & Sweller, 2014). In addition, compared to text-only information, the distinctive features of the pictures are likely to trigger bottom-up processing (Mintzer & Snodgrass, 1999), which is automatic and therefore more difficult to inhibit. As a result, pictures might have an advantage in competing for limited cognitive capacity (Desimone & Duncan, 1995). Taken together, these findings suggest that one picture should be included at once mainly to support spoken information, especially when the information is highly important or a key to better comprehension.

Although our study provides novel results with great practical applicability, some limitations of the study should be considered. First, we used short (approx. 15 min) digital presentations that are not comparable in length to an actual classroom lesson. Classroom lessons are not only longer, but presumably more cognitively demanding. Second, we used a retention test without transfer questions. Compared to a retention test, transfer questions measure deeper understanding and might provide a more accurate insight into what students have learned. Therefore, it would be important to include such questions in future studies. Third, we argued that students' performance will decrease for text-only information when two pictures are presented, because pictures distract attention by having a perceptual advantage during perception. Although this hypothesis is theoretically supported, further eye-tracking studies are needed to gain a better understanding of the perceptual processes involved in learning with pictures. Finally, we would like to reiterate that our findings are primarily applicable to system-based classroom learning using narrated digital presentations without any use of written text. This is important because different recommendations may apply for self-paced learning or when the digital presentation includes written text.

In conclusion, pictures in digital presentations enhance the learning of text-and-picture information. When used appropriately, they can effectively highlight and teach key terms and concepts. However, for maximum efficiency, it is not advisable to include more than one picture per slide, as even two pictures seem to reduce the learning efficiency of text-only information. We believe that the findings of the present study are truly helpful in creating digital presentations with pictures in a way that is beneficial for students. Following the value-added research approach (Baker et al., 2018; Buchner & Kerres, 2023), the results are highly generalizable because the hypotheses were tested during actual classroom learning rather than in a lab-based study. This provided the opportunity to make concrete recommendations for the optimal design of digital presentations. We hope that our results will be useful for practitioners (educators, instructors, or designers) who often still find the use of digital presentations challenging (James et al., 2006; Sharp et al., 2017).

8. Final Conclusions

The use of digital technologies with multimedia elements and interactive features to enhance learning has become increasingly popular in schools and families (Hockenson, 2020; Wylie, 2023). While these tools can have benefits, they pose new challenges for teachers and parents (Vaala & Lapierre, 2014; Vega & Robb, 2019). With numerous applications and options available (Curry, 2023), it can be difficult to navigate and establish a digital educational environment that truly supports learning. While the principles of CTML offer valuable guidance (Mayer & Moreno, 2003), they do not address all the emerging issues. Multimedia learning is a complex process, requiring simultaneous information processing, which increases the risk of higher cognitive load (Ayres & Sweller, 2014; Mayer, 2002). To manage this, it is recommended to limit the amount of multimedia elements or interactive features to match the capacity constraints of the target audience (Sweller & Chandler, 1994). However, this recommendation does not specify the exact number of multimedia elements and interactive features that should be considered demanding. Another issue with interactive elements is not only their quantity can be a concern, but they also pose a higher risk of violating the principle of temporal contiguity (Ginns, 2005). This can lead to a split of attention and a further increase in cognitive load. An often overlooked, yet important factor in the occurrence of higher cognitive load is the attentional mechanisms of the learners. Multimodal integration, the essence of multimedia learning is more challenging when the learner experiences attentional difficulties (Barutchu et al., 2019). Consequently, it is reasonable to assume that it is necessary to tailor the digital learning environment not only to the age but also to the individual needs of the audience. This requires an understanding of the influence of individual differences in attention on information processing when multimedia elements and interactive features are involved.

To address these issues, we primarily focused on the main contributors of cognitive load in multimedia learning, namely the quantity of multimedia elements and interactive features and its interaction with individual differences in attentional mechanisms. In the first part of the dissertation, we focused on younger age groups (pre-schoolers and elementary school students), and investigated interactivity besides multimedia elements, while in the second part we studied older age groups concentrating on the quantity of multimedia elements. The role of attentional processes was addressed throughout the whole series of studies. See Table 8.1 for an overview of the main results.

Table 8.1. – An overview of the results of experiments presented in the dissertation

Study nr.	Experiment nr.	Sample	Main findings
Study I.	Narrative Review	-	No precise recommendation is available for the optimal number of multimedia elements. Individual differences in core cognitive functions should be considered, however the literature lacks data on this aspect.
Study II.	Experiment 1.	Pre-schoolers	An interactive electronic storybook facilitated learning, and this improvement was observed in the long-term.
	Experiment 2.		Children with attentional difficulties scored lower on the retention test when multimedia elements or interactive features were included.
Study III.	Experiment 1.	Elementary school students	Compared to animations and static illustrations, answer-until-correct feedback type interactive features facilitated learning regardless of individual differences.
Study IV.	Experiment 1.	Elementary school students	Signaling interactive features with visual cues decreased cognitive load in children with attentional difficulties.
Study V.	Experiment 1.	University students	Up to three elements static pictures improved learning. Attentional difficulties and language barriers were associated with lower scores on the retention test.
	Experiment 2.		Students better remember to text-and-picture information. Attentional difficulties associated with a global decrease in achieved scores on the retention test.
Study VI.	Experiment 1.	High school students	Pictures enhance the learning of text-and-picture information. Compared to the control condition, two pictures decreased the learning of text-only information. No

association was found with attentional difficulties.

In Study II, we focused on pre-schoolers aged between 5 to 6 years old. First, in experiment 1, we aimed to test the long-term efficacy of multimedia devices, specifically interactive electronic storybooks, as their long-term impact on learning is often overlooked (Furenes et al., 2021). We found that the differences in recall performance between the interactive app group and the print group remained consistent over time. From this, we concluded that further studies should focus on the phase of memory encoding because those who encode information more effectively during the storybook exposure will benefit in the long term from the use of multimedia elements and interactivity. Consequently, in experiment 2, we omitted the follow-up measurements. Instead, we focused on exploring in more detail what contributes to efficient encoding, namely individual differences in book format, attentional mechanisms, and working memory processes. Here, we found that multimedia elements and interactivity facilitated learning, however, the improvement in recall performance was not independent of the function of attentional processes. Children with attentional difficulties scored lower on the retention test for multimedia elements and interactive features, supporting our thesis that attentional mechanisms are important determinants of efficient multimedia learning.

In Studies III and IV, we replicated Study II with slight modifications on elementary school students aged between 8 and 11 years. Study III reduced the number of multimedia and interactive features to one per page (with one exception on the first page) and tested one specific type of interactive feature (answer-until-correct feedback type). Focusing on one specific type of interactivity was identified as an important factor due to definitional problems and the variety of interactive features (Kucirkova, 2017). These modifications of the experimental design were implemented to investigate how to reduce the impact of individual differences. Our results suggest that using one interactive feature based on a well-established pedagogical technique (AUC feedback type) is an efficient way to reduce cognitive load, as scores on the retention test were independent of attentional mechanisms, working memory capacity, and verbal skills. The results of Study III raised interest in whether the relationship between attentional mechanisms and performance would change if the number of interactive elements were increased. Therefore, in Study IV, we increased the maximum number of interactive features to 2. Since in the previous three experiments working memory capacity showed no association with recall performance, we decided not to explore this factor further to minimize the workload on the children during data collection. In this experiment, we sought to address another issue with interactivity: the challenge of temporal synchronization and information organization. Consequently, for some participants we signaled the location of interactive features with visual cues, expecting that the signals will decrease searching behavior and guide attention. The results showed that, processing two elements per page led to reduced efficiency for students with attentional difficulties. This pattern was observed for both multimedia and non-signaled interactive features. However, as expected, the impact of individual differences lessened when interactive features were signaled, showing that it is an effective technique to ease the workload of children with higher levels of inattention. While Study III and Study IV complement each other, it is worth noting that the results are not entirely comparable due to the use of different interactive features.

In Study V, we sought to test the effect of the number of multimedia elements on the learning efficiency of university students. We considered this important as our previous studies have shown that the number of elements is an important influencing factor. In experiment 1, we increased the number of multimedia elements from 0 to 3 and observed a gradual improvement in recall performance as the number of multimedia elements increased. As we expected, this improvement was a function of individual differences in sustained attention. Participants experiencing difficulties focusing and maintaining attention demonstrated less efficient learning when multimedia elements were presented. Additionally, foreign language proficiency emerged as a significant factor influencing effective learning.

Experiment 2 was conducted to address a limitation identified in Experiment 1. Like previous studies (e.g., Lee & Mayer, 2018; Sanchez & Wiley, 2006), we assessed learning outcomes as a comprehensive construct that combined learning efficiency for both text-and-picture and text-only information, making it challenging to interpret the results. It was unclear whether the perceptual advantage of pictures contributed to the improved recall performance, as participants may have demonstrated better performance because there were potentially more questions in the test related to information highlighted with pictures. Furthermore, it was uncertain whether the increased cognitive load due to the growing number of pictures resulted in a general decrease in learning or only impacted the processing of text-only information for individuals with attentional difficulties. Experiment 2 indicated that pictures primarily enhanced the memory encoding of text-and-picture information while learning efficiency decreased for both text-and-picture and text-only information among those with attentional difficulties, suggesting a general decline in learning efficiency.

In Study VI, we adopted the experimental design of Study V and based on the results of Experiment 2 we distinguished between text-only and text-and-picture information. Our aim was to test the efficiency of multimedia learning among high school students aged 14 to 18 years, as limited knowledge is available regarding this population. In the digital presentation, the number of pictures varied from 0 to 2 to shorten the length of the experiment; otherwise, data collection would be too demanding and could potentially mask the results of multimedia learning. Similarly to the previous study, we found that pictures facilitated the learning of text-and-picture information. While one picture did not affect the learning of text-only information, presenting two pictures simultaneously significantly decreased the memory encoding of text-only information. The learning outcome of the students was independent of individual differences in attentional mechanisms, which contradicts the findings of Study V. This might be explained by the fact that in Study V students participated using their second language, which increased the elements interactivity of the subject material for them, potentially contributing to a higher workload. Therefore, it is more likely that attentional mechanisms played a more pronounced role in students learning in their second language. However, again, the results are not entirely comparable due to the differences in the targeted age groups. In the future, we aim to address this limitation by conducting further studies.

The main objective of the dissertation was to provide recommendations on how multimedia elements and interactivity can contribute to creating a digital educational environment tailored to the specific needs of learners. In summary, it was demonstrated that interactive and multimedia features in electronic storybook applications are beneficial for learning. However, it is recommended to limit their quantity, and indicate the location of interactive features clearly. These recommendations are intended to mitigate the influence of individual differences in attention. Regarding multimedia elements, it is also suggested to limit their quantity, as having more than one content-congruent multimedia element can impede the learning of text-only information. Therefore, for maximum effectiveness, it is advised to use one multimedia element to emphasize key terms or concepts.

9. New theses of the dissertation

1. **Learning efficiency with interactive features depends on individual differences in attentional mechanisms.**
   While interactive features can enhance learning for preschoolers and elementary school students, the level of improvement in memory encoding is influenced by sustained and selective attention. To mitigate cognitive load and benefit from interactivity, it may be effective to limit the number of interactive features to one per page or to clearly indicate their location. These considerations apply to a maximum of two content-relevant interactive animated figures and answer-until-correct feedback type interactive features.

2. **General knowledge acquisition is associated with individual differences in attention when young children (preschoolers and elementary school students) encounter animated figures.**
   When electronic storybooks contained more than one animated figure per page children with attentional difficulties scored lower on the retention test, similar to the results observed in the case of non-signaled interactive features. Signaling decreased this association for interactivity, most likely because visual cues guided attention. However, the same guidance is expected from automatic movements (such as animations). One potential explanation for the negative association is that multimodal integration is difficult for children with higher levels of inattention. Therefore, it is possible that actively engaging with the animated figures through interactivity may be an important factor in helping children connect the visual information to the spoken text.

3. **Content-congruent pictures primarily support the learning of text-end-picture information and interfere with the processing of text-only information.**
   For high schoolers and university students, pictures improved recall performance for text-and-picture information. Based on our findings including one picture most likely would not affect the processing of text-only information, while presenting two pictures simultaneously would hinder the memory encoding of text-only information. This effect was independent of individual differences in attention. In

university students, a general decline in recall performance was associated with attentional difficulties, which could be linked to the fact that they were participating in their second language.

Supplementary materials

Supplementary Table 6.1. – Detailed descriptive statistics for Study V, Experiment 1.

Task			Mean	SD
Retention test	Time1	Control	3.59	1.84
		Multimedia1	3.37	1.79
		Multimedia2	4	1.72
		Multimedia3	4.44	1.91
		Total	3.85	1.85
	Time2 (N=17)	Control	3.06	1.48
		Multimedia1	3.18	1.19
		Multimedia2	4.18	1.7
		Multimedia3	4.24	1.3
		Total	3.66	1.5
Cognitive Tasks				
Attentional skill (D2)		E%	7.5	4.98
English proficiency		Language	3.63	1.7
Digit Span Task (Backward)		WM-capacity	6.76	1.26

Supplementary Table 6.2. – Detailed descriptive statistics for Study V, Experiment 2.

Task				Mean	SD
Retention task	Time1	n of elements	Multimedia1	4.43	1.62
			Multimedia3	4.1	1.75
		Visualization	Visualized	4.59	1.79
			Non-visualized	3.95	1.54
			Total	4.27	1.69
	Time2 (N = 14)	n of elements	Multimedia1	3.68	1.25
			Multimedia3	3.32	1.47
		Visualization	Visualized	3.21	1.52
			Non-visualized	3.79	1.13
			Total	3.5	1.36
Cognitive tasks					
Attentional skill (D2)			E%	7.72	5.05
English proficiency			Language	3.85	1.62
Digit Span Task (Backward)			WM-capacity	6.74	1.22

Supplementary Table 7.1 – Order of the conditions for each version of the presentation (Study VI.)

Slide	Ver1	Ver2	Ver3	Ver4
1st	D1/ND1	D1/ND1	D2(B)/ND2	D2(B)/ND2
2nd	D1/ND1	D1/ND1	D2(B)/ND2	D2(B)/ND2
3rd	D1/ND1	D2(A)	ND0	D2(B)/ND2
4th	ND0	D1/ND1	D2(B)/ND2	D2(A)
5th	ND0	D1/ND1	D2(B)/ND2	D2(A)
6th	D1/ND1	D2(A)	ND0	D2(B)/ND2
7th	ND0	D1/ND1	D2(B)/ND2	D2(A)
8th	D1/ND1	D2(A)	ND0	D2(B)/ND2
9th	D1/ND1	D2(A)	ND0	D2(B)/ND2
10th	D1/ND1	D1/ND1	D2(B)/ND2	D2(B)/ND2
11th	ND0	D1/ND1	D2(B)/ND2	D2(A)
12th	D1/ND1	D1/ND1	D2(B)/ND2	D2(B)/ND2

Supplementary Table 7.2. – Exact statistical results of the Interclass correlation. (Study VI.)

Question number	ICC	lower 95%CI	upper 95%CI	p
1	0.97	0.96	0.98	<.001
2	0.94	0.92	0.95	<.001
3	0.91	0.89	0.93	<.001
4	0.94	0.93	0.96	<.001
5	1.00	0.99	1.00	<.001
6	0.98	0.97	0.98	<.001
7	0.95	0.93	0.96	<.001
8	0.70	0.61	0.76	<.001
9	0.89	0.86	0.92	<.001
10	0.91	0.89	0.93	<.001
11	0.95	0.94	0.96	<.001
12	0.99	0.99	0.99	<.001
13	0.92	0.90	0.94	<.001
14	0.94	0.93	0.96	<.001
15	0.90	0.88	0.93	<.001
16	0.91	0.89	0.93	<.001
17	0.81	0.75	0.85	<.001
18	0.90	0.88	0.92	<.001
19	0.72	0.65	0.78	<.001
20	0.81	0.76	0.85	<.001
21	0.90	0.87	0.92	<.001
22	0.99	0.99	1.00	<.001
23	0.98	0.97	0.98	<.001
24	0.98	0.98	0.99	<.001

Supplementary Table 7.3. – Descriptive statistics for all variables in Study VI. Means, 95%CI, Minimum, Maximum values are reported for Screen media use (SM score), Attention (ASRS score), and recall performance. Regarding recall performance values are reported separately for each condition. For the questionnaires data reliability (McDonald's ω) is also reported.

	SM score	ASRS score		Text-and-picture			Text-only		
				0	**1**	**2**	**0**	**1**	**2**
Mean	26.2	16.5		6.61	7.65	7.53	6.44	6.31	4.65
95%CI lower	25.9	16.3		6.08	7.12	8.18	5.92	5.78	4.07
95%CI upper	26.4	16.7		7.14	8.18	8	6.96	6.85	5.23
Min	15	8		0	0	0	0	0	0.5
Max	40	27		15	15.5	15	15	15.5	12
McDonald's ω	0.585	0.586	N of observations	141	140	239	141	140	120

References

Albus, P., Vogt, A., & Seufert, T. (2021). Signaling in virtual reality influences learning outcome and cognitive load. *Computers & Education*, *166*, 104154. https://doi.org/10.1016/j.compedu.2021.104154

Alloway, T. P., & Alloway, R. G. (2013). Working memory across the lifespan: A cross-sectional approach. *Journal of Cognitive Psychology*, *25*(1), 84–93. https://doi.org/10.1080/20445911.2012.748027

Alpizar, D., Olusola, ·, Adesope, O., Wong, R. M., & Adesope, O. O. (2020). *A meta-analysis of signaling principle in multimedia learning environments*. *68*, 2095–2119. https://doi.org/10.1007/s11423-020-09748-7

Altun, D. (2018). The Efficacy of Multimedia Stories in Preschoolers' Explicit and Implicit Story Comprehension. *Early Childhood Education Journal*, *46*(6), 629–642. https://doi.org/10.1007/s10643-018-0916-8

Altun, D. (2021). Twice Upon a Mind: Preschoolers' Narrative Processing of Electronic and Printed Stories. *Early Childhood Education Journal*, *49*, 349–359. https://doi.org/10.1007/s10643-020-01079-9

Altun, D. (2022). The effects of e-stories on preschoolers' narrative comprehension, retelling and reading attitudes among poor and good comprehenders: *Https://Doi.Org/10.1177/14687984221079010*. https://doi.org/10.1177/14687984221079010

Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. In *Child Neuropsychology* (Vol. 8, Issue 2, pp. 71–82). https://doi.org/10.1076/chin.8.2.71.8724

Anderson, V. A., Anderson, P., Northam, E., Jacobs, R., & Catroppa, C. (2001). Development of executive functions through late childhood and adolescence in an Australian sample. *Developmental Neuropsychology*, *20*(1), 385–406. https://doi.org/10.1207/S15326942DN2001_5

Anmarkrud, Ø., Andresen, A., & Bråten, I. (2019). Cognitive Load and Working Memory in Multimedia Learning: Conceptual and Measurement Issues. *Educational Psychologist*, *54*(2), 61–83. https://doi.org/10.1080/00461520.2018.1554484

Awh, E., Vogel, E. K., & Oh, S. H. (2006). Interactions between attention and working memory. *Neuroscience*, *139*(1), 201–208. https://doi.org/10.1016/j.neuroscience.2005.08.023

Ayres, P., & Sweller, J. (2014). The split-attention principle in multimedia learning. In *The Cambridge Handbook of Multimedia Learning, Second Edition* (pp. 206–226). https://doi.org/10.1017/CBO9781139547369.011

Baddeley, A. (1992). Working Memory. *Science*, *255*(5044), 556–559. https://doi.org/10.1126/SCIENCE.1736359

Baker, J. P., Goodboy, A. K., Bowman, N. D., & Wright, A. A. (2018). Does teaching with PowerPoint increase students' learning? A meta-analysis. *Computers and Education*, *126*, 376–387. https://doi.org/10.1016/J.COMPEDU.2018.08.003

Bali, C., Csibi, K. Z., Arato, N., & Zsido, A. N. (2023). *Feedback-type interactive features in applications for elementary school students enhance learning regardless of cognitive differences [Manuscript submitted for publication]. Department of Cognitive and Evolutionary Psychology, University of Pécs*.

Bali, C., Matuz-Budai, T., Arato, N., Labadi, B., & Zsido, A. N. (2023a). Executive attention modulates the facilitating effect of electronic storybooks on information encoding in preschoolers. *Heliyon*, *9*(1). https://doi.org/10.1016/j.heliyon.2023.e12899

Bali, C., & Zsido, A. N. (2023). *Investigating the factors influencing multimedia learning among university students [in preparation]. Department of Cognitive and Evolutionary Psychology, University of Pécs*.

Barroso, C., Ganley, C. M., McGraw, A. L., Geer, E. A., Hart, S. A., & Daucourt, M. C. (2021). A Meta-Analysis of the Relation Between Math Anxiety and Math Achievement. *Psychological Bulletin*, *147*(2), 134–168. https://doi.org/10.1037/bul0000307

Barrow, J., Forker, C., Sands, A., O'Hare, D., & Hurst, W. (2019). *Augmented reality for enhancing life science education*. https://aura.abdn.ac.uk/bitstream/handle/2164/16663/Augmented_Reality_for_Enhancing_Life_Science_Education_Camera_Ready.pdf?sequence=1

Barutchu, A., Toohey, S., Shivdasani, M. N., Fifer, J. M., Crewther, S. G., Grayden, D. B., & Paolini, A. G. (2019). Multisensory perception and attention in school-age children. *Journal of Experimental Child Psychology*, *180*, 141–155. https://doi.org/10.1016/J.JECP.2018.11.021

Bates, D., Mächler, M., Bolker, B. M., & Walker, S. C. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/JSS.V067.I01

Berkowitz, T., Schaeffer, M. W., Maloney, E. A., Peterson, L., Gregor, C., Levine, S. C., & Beilock, S. L. (2015). Math at home adds up to achievement in school. *Science*, *350*(6257), 196–198. https://doi.org/10.1126/science.aac7427

Best, J. R., Miller, P. H., & Jones, L. L. (2009). Executive functions after age 5: Changes and correlates. In *Developmental Review* (Vol. 29, Issue 3, pp. 180–200). https://doi.org/10.1016/j.dr.2009.05.002

Bizami, N. A., Tasir, Z., & Kew, S. N. (2023). Innovative pedagogical principles and technological tools capabilities for immersive blended learning: a systematic literature review. *Education and Information Technologies*, *28*(2), 1373–1425. https://doi.org/10.1007/S10639-022-11243-W/METRICS

Brookshire, J., Scharff, L. F. V., & Moses, L. E. (2002). The influence of illustrations on children's book preferences and comprehension. *Reading Psychology*, *23*(4), 323–339. https://doi.org/10.1080/713775287

Brünken, R., & Leutner, D. (2001). Aufmerksamkeitsverteilung oder Aufmerksamkeitsfokussierung? Empirische Ergebnisse zur" Split-Attention-Hypothese" beim Lernen mit Multimedia. *Unterrichtswissenschaft* , *29*. https://www.pedocs.de/frontdoor.php?source_opus=7720

Buchner, J., & Kerres, M. (2023). Media comparison studies dominate comparative research on augmented reality in education. *Computers & Education*, *195*, 104711. https://doi.org/10.1016/J.COMPEDU.2022.104711

Buetti, S., & Lleras, A. (2016). Distractibility is a function of engagement, not task difficulty: Evidence from a new oculomotor capture paradigm. *Journal of Experimental Psychology: General*, *145*(10), 1382–1405. https://doi.org/10.1037/xge0000213

Bujak, K. R., Radu, I., Catrambone, R., MacIntyre, B., Zheng, R., & Golubski, G. (2013). A psychological perspective on augmented reality in the mathematics classroom. *Computers and Education*, *68*, 536–544. https://doi.org/10.1016/j.compedu.2013.02.017

Burke, L. A., & James, K. E. (2008). POWERPOINT-BASED LECTURES IN BUSINESS EDUCATION: AN EMPIRICAL INVESTIGATION OF STUDENT-PERCEIVED

NOVELTY AND EFFECTIVENESS. *Business Communication Quarterly*, *71*(3), 277–296. https://doi.org/10.1177/1080569908317151

Butler, A. C., & Roediger, H. L. (2008). Feedback enhances the positive effects and reduces the negative effects of multiple-choice testing. *Memory and Cognition*, *36*(3), 604–616. https://doi.org/10.3758/MC.36.3.604

Carney, R. N., & Levin, J. R. (2002). Pictorial Illustrations Still Improve Students' Learning From Text. *Educational Psychology Review*, *14*(1).

Çeken, B., & Taşkın, N. (2022). Multimedia learning principles in different learning environments: a systematic review. *Smart Learning Environments*, *9*(1), 1–22. https://doi.org/10.1186/S40561-022-00200-2/TABLES/10

Çetin, H., & Türkan, A. (2022). The Effect of Augmented Reality based applications on achievement and attitude towards science course in distance education process. *Education and Information Technologies*, *27*(2), 1397–1415. https://doi.org/10.1007/S10639-021-10625-W/TABLES/4

Chaharsooghi, E. T., Mohammadi, A. Z., & Hoshyar, M. (2011). The effect of miniature learning on concentration of learning disability children. *Procedia - Social and Behavioral Sciences*, *30*, 2617–2620. https://doi.org/10.1016/j.sbspro.2011.10.512

Champely, S., Ekstrom, C., Dalgaard, P., Gill, J., Weibelzahl, S., Anandkumar, A., Ford, C., Volcic, R., & Rosario, H. De. (2017). *pwr: Basic functions for power analysis*. https://nyuscholars.nyu.edu/en/publications/pwr-basic-functions-for-power-analysis

Chang, F. T.-Y., & Li, M.-N. F. (2019). A Relative Effectiveness Assessment of an Immediate Feedback Assessment Technique Employed on Computers and Scratch Cards: A Meta-Analysis. *International Journal of Educational Technology*, *6*(1), 12–29. https://eric.ed.gov/?id=EJ1215440

Chen, I.-J., & Chang, C.-C. (2017). Cognitive Load Theory: An Empirical Study of Anxiety and Task Performance in Language Learning. *Electronic Journal of Research in Education Psychology*, *7*(18), 729–746. https://doi.org/10.25115/ejrep.v7i18.1369

Chen, Y. C. (2019). Effect of Mobile Augmented Reality on Learning Performance, Motivation, and Math Anxiety in a Math Course. *Journal of Educational Computing Research*, *57*(7), 1695–1722. https://doi.org/10.1177/0735633119854036

Choi, G. Y. (2018). Learning through digital storytelling: exploring entertainment techniques in lecture video. *Educational Media International*, *55*(1), 49–63. https://doi.org/10.1080/09523987.2018.1439710

Christakis, D. A., Zimmerman, F. J., DiGiuseppe, D. L., & McCarty, C. A. (2004). Early Television Exposure and Subsequent Attentional Problems in Children. *Pediatrics*, *113*(4 I), 708–713. https://doi.org/10.1542/peds.113.4.708

Cloate, R. (2016). The relationship between international students' English test scores and their academic achievements. *Journal of Pedagogic Development*, *6*(6). https://uobrep.openrepository.com/handle/10547/611800

Cloninger, C. R. (1987). A Systematic Method for Clinical Description and Classification of Personality Variants. *Archives of General Psychiatry*, *44*(6), 573. https://doi.org/10.1001/archpsyc.1987.01800180093014

Cloninger, C. R., Bayon, C., & Svrakic, D. M. (1998). Measurement of temperament and character in mood disorders: a model of fundamental states as personality types. *Journal of Affective Disorders*, *51*(1), 21–32. https://doi.org/10.1016/S0165-0327(98)00153-0

Colflesh, G. J. H., Conway, A. R. A., & Colflesh, G. J. H. (2007). Individual differences in working memory capacity and divided attention in dichotic listening. *Psychonomic Bulletin & Review*, *14*(4), 699–703.

Cowan, N. (2008). Chapter 20 What are the differences between long-term, short-term, and working memory? In *Progress in Brain Research* (Vol. 169, pp. 323–338). https://doi.org/10.1016/S0079-6123(07)00020-9

Cowan, N. (2010). The magical mystery four: How is working memory capacity limited, and why? *Current Directions in Psychological Science*, *19*(1), 51–57. https://doi.org/10.1177/0963721409359277

Curry, D. (2023). *App Store Data (2023)*. Business of Apps. https://www.businessofapps.com/data/app-stores/

Danaei, D., Jamali, H. R., Mansourian, Y., & Rastegarpour, H. (2020). Comparing reading comprehension between children reading augmented reality and print storybooks. *Computers and Education*, *153*, 103900. https://doi.org/10.1016/j.compedu.2020.103900

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. In *Annual Review of Neuroscience* (Vol. 18, pp. 193–222). Annual Reviews Inc. https://doi.org/10.1146/annurev.ne.18.030195.001205

Diamond, A. (2013). Executive functions. In *Annual Review of Psychology* (Vol. 64, pp. 135–168). Annual Reviews Inc. https://doi.org/10.1146/annurev-psych-113011-143750

Doolittle, P., & Mariano, G. (2008). Working memory capacity and mobile multimedia learning environments: Individual differences in learning while mobile. *Journal of Educational Multimedia and …*, *17*(4), 511–530. http://www.editlib.org/p/26079

Dowker, A., Sarkar, A., & Looi, C. Y. (2016). Mathematics anxiety: What have we learned in 60 years? *Frontiers in Psychology*, *7*(APR). https://doi.org/10.3389/FPSYG.2016.00508/FULL

Endres, T., Weyreter, S., Renkl, A., & Eitel, A. (2020). When and why does emotional design foster learning? Evidence for situational interest as a mediator of increased persistence. *Journal of Computer Assisted Learning*, *36*(4), 514–525. https://doi.org/10.1111/JCAL.12418

Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual Differences in Working Memory Capacity and What They Tell Us About Controlled Attention, General Fluid Intelligence, and Functions of the Prefrontal Cortex. *Models of Working Memory*, 102–134. https://doi.org/10.1017/CBO9781139174909.007

Ernst, B., & Steinhauser, M. (2012). Feedback-related brain activity predicts learning from feedback in multiple-choice testing. *Cognitive, Affective and Behavioral Neuroscience*, *12*(2), 323–336. https://doi.org/10.3758/s13415-012-0087-9

Etta, R. A., & Kirkorian, H. L. (2019). Children's learning from interactive eBooks: Simple irrelevant features are not necessarily worse than relevant ones. *Frontiers in Psychology*, *9*(JAN), 2733. https://doi.org/10.3389/fpsyg.2018.02733

Evans, C., Jordan, A., Issues, J. H.-J. of F., & 2011, undefined. (2011). Only two hours? A qualitative study of the challenges parents perceive in restricting child television time. *Journals.Sagepub.ComCA Evans, AB Jordan, J HornerJournal of Family Issues, 2011•journals.Sagepub.Com*, *32*(9), 1223–1244. https://doi.org/10.1177/0192513X11400558

Fabio, R. A., & Antonietti, A. (2012). Effects of hypermedia instruction on declarative, conditional and procedural knowledge in ADHD students. *Research in Developmental Disabilities*, *33*(6), 2028–2039. https://doi.org/10.1016/j.ridd.2012.04.018

Fabio, R. A., Caprì, T., Iannizzotto, G., Nucita, A., & Mohammadhasani, N. (2019). Interactive avatar boosts the performances of children with attention deficit hyperactivity disorder in dynamic measures of intelligence. *Cyberpsychology, Behavior, and Social Networking*, *22*(9), 588–596. https://doi.org/10.1089/cyber.2018.0711

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Fenstermacher, S. K., Barr, R., Salerno, K., Garcia, A., Shwery, C. E., Calvert, S. L., & Linebarger, D. L. (2010). Infant-directed media: An analysis of product information and claims. *Infant and Child Development*, *19*(6), 557–556. https://doi.org/10.1002/icd.718

Fry, A. F., & Hale, S. (2000). Relationships among processing speed, working memory, and fluid intelligence in children. *Biological Psychology*, *54*(1–3), 1–34. https://doi.org/10.1016/S0301-0511(00)00051-X

Furenes, M. I., Kucirkova, N., & Bus, A. G. (2021). A Comparison of Children's Reading on Paper Versus Screen: A Meta-Analysis. *Review of Educational Research*, *91*(4), 483–517. https://doi.org/10.3102/0034654321998074

Gamer, M., Lemon, L., & Singh, P. (2022). *Title Various Coefficients of Interrater Reliability and Agreement*. https://www.r-project.org

Garon, N., Bryson, S. E., & Smith, I. M. (2008). *Executive Function in Preschoolers: A Review Using an Integrative Framework*. https://doi.org/10.1037/0033-2909.134.1.31

Gathercole, S. E., & Alloway, T. P. (2009). Working Memory and Learning: A Practical Guide for Teachers. *Support for Learning*, *24*(1), 50–51.

Gazella, J., & Stockman, I. J. (2003). Children's story retelling under different modality and task conditions: Implications for standardizing language sampling procedures. *American Journal of Speech-Language Pathology*, *12*(1), 61–72. https://doi.org/10.1044/1058-0360(2003/053)

Ge, S., Hai Leng, C., & Baharudin, S. M. (2022). The effect of multimedia and temporal contiguity principles on students' attitude and retention in learning Japanese language. *International Journal of Chinese Education*, *11*(2). https://doi.org/10.1177/2212585X221099964/ASSET/IMAGES/LARGE/10.1177_2212585X221099964-FIG3.JPEG

Gentile, D. A., Swing, E. L., Lim, C. G., & Khoo, A. (2012). Video game playing, attention problems, and impulsiveness: Evidence of bidirectional causality. *Psychology of Popular Media Culture*, *1*(1), 62–70. https://doi.org/10.1037/a0026969

Georgiou, Y., & Ioannou, A. (2021). Developing, Enacting and Evaluating a Learning Experience Design for Technology-Enhanced Embodied Learning in Math Classrooms. *TechTrends*, *65*(1), 38–50. https://doi.org/10.1007/s11528-020-00543-y

Georgiou, Y., Ioannou, A., & Kosmas, P. (2021). Comparing a digital and a non-digital embodied learning intervention in geometry: can technology facilitate? *Technology, Pedagogy and Education*, *30*(2), 345–363. https://doi.org/10.1080/1475939X.2021.1874501

Ginns, P. (2005). Meta-analysis of the modality effect. *Learning and Instruction*, *15*(4), 313–331. https://doi.org/10.1016/j.learninstruc.2005.07.001

Girelli, M., & Luck, S. J. (1997). Are the same attentional mechanisms used to detect visual search targets defined, by color, orientation, and motion? *Journal of Cognitive Neuroscience*, *9*(2), 238–253. https://doi.org/10.1162/jocn.1997.9.2.238

Gordani, Y., & Khajavi, Y. (2020). The impacts of multi-modal PowerPoint presentation on the EFL students' content knowledge attainment and retention over time. *Education and Information Technologies*, *25*(1), 403–417. https://doi.org/10.1007/s10639-019-09979-z

Green, J. G., DeYoung, G., Wogan, M. E., Wolf, E. J., Lane, K. L., & Adler, L. A. (2019). Evidence for the reliability and preliminary validity of the Adult ADHD Self-Report Scale v1.1 (ASRS v1.1) Screener in an adolescent community sample. *International Journal of Methods in Psychiatric Research*, *28*(1), e1751. https://doi.org/10.1002/MPR.1751

Hainey, T., Connolly, T. M., Boyle, E. A., Wilson, A., & Razak, A. (2016). A systematic literature review of games-based learning empirical evidence in primary education. *Computers & Education*, *102*, 202–223. https://doi.org/10.1016/J.COMPEDU.2016.09.001

Harp, S. F., & Mayer, R. E. (1998). How Seductive Details Do Their Damage: A Theory of Cognitive Interest in Science Learning. *Journal of Educational Psychology*, *90*(3), 414–434. https://doi.org/10.1037/0022-0663.90.3.414

Herrlinger, S., Höffler, T. N., Opfermann, M., & Leutner, D. (2017). When Do Pictures Help Learning from Expository Text? Multimedia and Modality Effects in Primary Schools. *Research in Science Education*, *47*(3), 685–704. https://doi.org/10.1007/S11165-016-9525-Y/FIGURES/3

Hidi, S. (1990). Interest and Its Contribution as a Mental Resource for Learning. *Review of Educational Research*, *60*(4), 549–571. https://doi.org/10.3102/00346543060004549

Higgins, K., Huscroft-D'Angelo, J., & Crawford, L. (2019). Effects of Technology in Mathematics on Achievement, Motivation, and Attitude: A Meta-Analysis. *Journal of*

Educational Computing Research, *57*(2), 283–319. https://doi.org/10.1177/0735633117748416

Hochpöchler, U., Schnotz, W., Rasch, T., Ullrich, M., Horz, H., McElvany, N., & Baumert, J. (2013). Dynamics of mental model construction from text and graphics. *European Journal of Psychology of Education*, *28*(4), 1105–1126. https://doi.org/10.1007/S10212-012-0156-Z/FIGURES/4

Hockenson, L. (2020). Sensor Tower's 2020 Education Report: COVID-19's Profound Impact on App-Based Learning. In *Sensor Tower*.

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. In *Trends in Cognitive Sciences* (Vol. 16, Issue 3, pp. 174–180). https://doi.org/10.1016/j.tics.2012.01.006

Huber, B., Tarasuik, J., Antoniou, M. N., Garrett, C., Bowe, S. J., & Kaufman, J. (2016). Young children's transfer of learning from a touchscreen device. *Computers in Human Behavior*, *56*, 56–64. https://doi.org/10.1016/j.chb.2015.11.010

Jägerskog, A. S., Jönsson, F. U., Selander, S., & Jonsson, B. (2019). Multimedia learning trumps retrieval practice in psychology teaching. *Scandinavian Journal of Psychology*, *60*(3), 222–230. https://doi.org/10.1111/sjop.12527

James, K. E., Burke, L. A., & Hutchins, H. M. (2006). Powerful or Pointless? Faculty Versus Student Perceptions of PowerPoint Use in Business Education. *Http://Dx.Doi.Org/10.1177/1080569906294634*, *69*(4), 374–396. https://doi.org/10.1177/1080569906294634

Jamet, E. (2014). An eye-tracking study of cueing effects in multimedia learning. *Computers in Human Behavior*, *32*, 47–53. https://doi.org/10.1016/J.CHB.2013.11.013

Janacsek, K., Tánczos, T., Mészáros, T., & Németh, D. (2009). A munkamemória új magyar nyelvuʹ neuropszicholó giai méroʹeljárása: a hallási mondatterjedelem teszt (HMT). *Magyar Pszichologiai Szemle*, *64*(2), 385–406. https://doi.org/10.1556/MPSzle.64.2009.2.5

Jones, L. B., Rothbart, M. K., & Posner, M. I. (2003). Development of executive attention in preschool children. *Developmental Science*, *6*(5), 498–504. https://doi.org/10.1111/1467-7687.00307

Jusslin, S., Korpinen, K., Lilja, N., Martin, R., Lehtinen-Schnabel, J., & Anttila, E. (2022). Embodied learning and teaching approaches in language education: A mixed studies review. *Educational Research Review*, *37*, 100480. https://doi.org/10.1016/J.EDUREV.2022.100480

Kabali, H. K., Irigoyen, M. M., Nunez-Davis, R., Budacki, J. G., Mohanty, S. H., Leister, K. P., & Bonner, R. L. (2015). Exposure and Use of Mobile Media Devices by Young Children. *Pediatrics*, *136*(6), 1044–1050. https://doi.org/10.1542/PEDS.2015-2151

Kállai, J., Páll, T., Topa, K., & Zsidó, A. N. (2023). Physically real and virtual reality exposed line bisection response patterns: visuospatial attention allocation in virtual reality. *Frontiers in Psychology*, *14*. https://doi.org/10.3389/fpsyg.2023.1176379

Kane, M., Conway, A. R., Hambrick, D. Z., & Engle, R. W. (2007). Variation in working memory capacity as variation in executive attention and control. *Variation in Working Memory*, *1*, 21–48. https://www.google.com/books?hl=hu&lr=&id=6DhnDAAAQBAJ&oi=fnd&pg=PA21&dq=Variation+in+Working+Memory+Capacity+as+Variation+in+Executive+Attention+and+Control&ots=4wtQoZ1dql&sig=BaARzNvu_5RzRCeVzwvbXiFeVww

Kangas, M., Siklander, P., Randolph, J., & Ruokamo, H. (2017). Teachers' engagement and students' satisfaction with a playful learning environment. *Teaching and Teacher Education*, *63*, 274–284. https://doi.org/10.1016/j.tate.2016.12.018

Kessler, R. C., Adler, L., Ames, M., Demler, O., Faraone, S., Hiripi, E., Howes, M. J., Jin, R., Secnik, K., Spencer, T., Ustun, T. B., Walters, E. E., & E. (2005). The World Health Organization adult ADHD self-report scale (ASRS): a short screening scale for use in the general population. *Psychological Medicine*, *35*(2), 245–256. https://doi.org/10.1017/S0033291704002892

Kim, M. K., McKenna, J. W., & Park, Y. (2017). The Use of Computer-Assisted Instruction to Improve the Reading Comprehension of Students With Learning Disabilities: An Evaluation of the Evidence Base According to the What Works Clearinghouse Standards. *Remedial and Special Education*, *38*(4), 233–245. https://doi.org/10.1177/0741932517693396

Knoop-Van Campen, C. A. N., Segers, | Eliane, & Ludo Verhoeven, |. (2018). *The modality and redundancy effects in multimedia learning in children with dyslexia*. https://doi.org/10.1002/dys.1585

Konok, V., Liszkai-Peres, K., Bunford, N., Ferdinandy, B., Jurányi, Z., Ujfalussy, D. J., Réti, Z., Pogány, Á., Kampis, G., & Miklósi, Á. (2021). Mobile use induces local attentional precedence and is associated with limited socio-cognitive skills in preschoolers. *Computers in Human Behavior*, *120*. https://doi.org/10.1016/j.chb.2021.106758

Koo, T. K., & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine*, *15*(2), 155–163. https://doi.org/10.1016/J.JCM.2016.02.012

Kosmas, P., & Zaphiris, P. (2023). Improving students' learning performance through Technology-Enhanced Embodied Learning: A four-year investigation in classrooms. *Education and Information Technologies*. https://doi.org/10.1007/s10639-022-11466-x

Kozan, K., Erçetin, G., & Richardson, J. C. (2015). Input modality and working memory: Effects on second language text comprehension in a multimedia learning environment. *System*, *55*, 63–73. https://doi.org/10.1016/j.system.2015.09.001

Krieger, V., & Amador-Campos, J. A. (2018). Assessment of executive function in ADHD adolescents: contribution of performance tests and rating scales. *Child Neuropsychology*, *24*(8), 1063–1087. https://doi.org/10.1080/09297049.2017.1386781

Kucirkova, N. (2017). An integrative framework for studying, designing and conceptualising interactivity in children's digital books. *British Educational Research Journal*, *43*(6), 1168–1185. https://doi.org/10.1002/berj.3317

Kucirkova, N. (2019). How could children's storybooks promote empathy? A conceptual framework based on developmental psychology and literary theory. *Frontiers in Psychology*, *10*(FEB), 121. https://doi.org/10.3389/fpsyg.2019.00121

Kulasekara, G. U., Jayatilleke, B. G., & Coomaraswamy, U. (2011). Learner perceptions on instructional design of multimedia in learning abstract concepts in science at a distance. *Open Learning*, *26*(2), 113–126. https://doi.org/10.1080/02680513.2011.567459

Langer, K., Lietze, S., & Krizek, G. Ch. (2021). Vector AR3-APP – A Good-Practice Example of Learning with Augmented Reality. *European Journal of Open, Distance and E-Learning*, *23*(2), 51–64. https://doi.org/10.2478/eurodl-2020-0010

Lee, H., & Mayer, R. E. (2018). Fostering learning from instructional video in a second language. *Applied Cognitive Psychology*, *32*(5), 648–654. https://doi.org/10.1002/acp.3436

Levie, W. H., & Lentz, R. (1982). Effects of text illustrations: A review of research. *Educational Communication & Technology*, *30*(4), 195–232. https://doi.org/10.1007/BF02765184/METRICS

Li, H., Zhang, T., Woolley, J. D., An, J., & Wang, F. (2023). Exploring factors influencing young children's learning from storybooks: Interactive and multimedia features. *Journal of Experimental Child Psychology*, *233*, 105680. https://doi.org/10.1016/J.JECP.2023.105680

Li, J., Antonenko, P. D., & Wang, J. (2019). Trends and issues in multimedia learning research in 1996–2016: A bibliometric analysis. In *Educational Research Review* (Vol. 28). https://doi.org/10.1016/j.edurev.2019.100282

Lima, M., Baeta, É., Duro, D., Tábuas-Pereira, M., Valério, D., Freitas, S., Simões, M. R., & Santana, I. (2023). Toulouse-Piéron Cancellation Test: Normative scores for the portuguese population. *Applied Neuropsychology:Adult*, *30*(2), 169–175. https://doi.org/10.1080/23279095.2021.1918694

Liu, T. C., Lin, Y. C., & Paas, F. (2022). A new application of the temporal contiguity effect in designing narrated slideshows. *Educational Technology Research and Development*, *70*(1), 59–72. https://doi.org/10.1007/S11423-021-10076-7/TABLES/2

Lundin, A., Kosidou, K., & Dalman, C. (2019). Testing the Discriminant and Convergent Validity of the World Health Organization Six-Item Adult ADHD Self-Report Scale Screener Using the Stockholm Public Health Cohort. *Journal of Attention Disorders*, *23*(10), 1170–1177. https://doi.org/10.1177/1087054717735381

Macaro, E., Curle, S., Pun, J., An, J., & Dearden, J. (2018). A systematic review of English medium instruction in higher education. *Language Teaching*, *51*(1), 36–76. https://doi.org/10.1017/S0261444817000350

Mäkinen, L., Loukusa, S., Nieminen, L., Leinonen, E., & Kunnari, S. (2014). The development of narrative productivity, syntactic complexity, referential cohesion and event content in four- to eight-year-old Finnish children. *First Language*, *34*(1), 24–42. https://doi.org/10.1177/0142723713511000

Makransky, G., Andreasen, N. K., Baceviciute, S., & Mayer, R. E. (2021). Immersive virtual reality increases liking but not learning with a science simulation and generative learning strategies promote learning in immersive virtual reality. *Journal of Educational Psychology*, *113*(4), 719–735. https://doi.org/10.1037/edu0000473

Makransky, G., & Petersen, G. B. (2021). The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of Learning in Immersive

Virtual Reality. In *Educational Psychology Review* (Vol. 33, Issue 3, pp. 937–958). Springer. https://doi.org/10.1007/s10648-020-09586-2

Martel, M., Nikolas, M., & Nigg, J. T. (2007). Executive function in adolescents with ADHD. *Journal of the American Academy of Child and Adolescent Psychiatry*, *46*(11), 1437–1444. https://doi.org/10.1097/chi.0b013e31814cf953

Mavilidi, M. F., Okely, A., Chandler, P., Louise Domazet, S., & Paas, F. (2018). Immediate and delayed effects of integrating physical activity into preschool children's learning of numeracy skills. *Journal of Experimental Child Psychology*, *166*, 502–519. https://doi.org/10.1016/j.jecp.2017.09.009

Mavilidi, M. F., Okely, A. D., Chandler, P., & Paas, F. (2016). Infusing Physical Activities Into the Classroom: Effects on Preschool Children's Geography Learning. *Mind, Brain, and Education*, *10*(4), 256–263. https://doi.org/10.1111/mbe.12131

Mavilidi, M. F., Okely, A. D., Chandler, P., & Paas, F. (2017). Effects of Integrating Physical Activities Into a Science Lesson on Preschool Children's Learning and Enjoyment. *Applied Cognitive Psychology*, *31*(3), 281–290. https://doi.org/10.1002/acp.3325

Mayer, R. (2001). Signaling as a Cognitive Guide in Multimedia Learning. *Article in Journal of Educational Psychology*. https://doi.org/10.1037/0022-0663.93.2.377

Mayer, R. E. (2002). Multimedia learning. *Psychology of Learning and Motivation - Advances in Research and Theory*, *41*, 85–139. https://doi.org/10.1016/s0079-7421(02)80005-6

Mayer, R. E. (2014). The Cambridge handbook of multimedia learning, second edition. In *The Cambridge Handbook of Multimedia Learning, Second Edition*. https://doi.org/10.1017/CBO9781139547369

Mayer, R. E., & Anderson, R. B. (1992). The instructive animation: Helping students build connections between words and pictures in multimedia learning. *Journal of Educational Psychology*, *84*(4), 444–452. https://doi.org/10.1037/0022-0663.84.4.444

Mayer, R. E., & Moreno, R. (2002). Animation as an Aid to Multimedia Learning. In *Educational Psychology Review* (Vol. 14, Issue 1).

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, *38*(1), 43–52. https://doi.org/10.1207/S15326985EP3801_6

Mayer, R. E., Sims, V., & Tajika, H. (1995). Brief Note: A Comparison of How Textbooks Teach Mathematical Problem Solving in Japan and the United States. *American Educational Research Journal*, *32*(2), 443–460. https://doi.org/10.3102/00028312032002443

Mayer, R., & Moreno, R. (1998). A split-attention effect in multimedia learning: Evidence for dual processing systems in working memory. *Journal of Educational Psychology*, *90*(2). https://psycnet.apa.org/fulltext/1998-02710-011.html

McClure, E., Vaala, S., & Spiewak Toub, T. (2017). *QuickReport: Discovering Kids' Apps: Do Family Strategies Vary by Income?* Joan Ganz Cooney Center. https://joanganzcooneycenter.org/wp-content/uploads/2017/06/jgcc_discoveringkidsapps.pdf

McGoey, K. E., DuPaul, G. J., Haley, E., & Shelton, T. L. (2007). Parent and teacher ratings of attention-deficit/hyperactivity disorder in preschool: The ADHD rating scale-IV preschool version. *Journal of Psychopathology and Behavioral Assessment*, *29*(4), 269–276. https://doi.org/10.1007/s10862-007-9048-y

Meri, R., Hutton, J., Farah, R., DiFrancesco, M., Gozman, L., & Horowitz-Kraus, T. (2023). Higher access to screens is related to decreased functional connectivity between neural networks associated with basic attention skills and cognitive control in children. *Child Neuropsychology*, *29*(4), 666–685. https://doi.org/10.1080/09297049.2022.2110577

Mertens, U., Finn, B., & Lindner, M, A. (2022). Effects of Computer-Based Feedback on Lower- and Higher-Order Learning Outcomes: A Network Meta-Analysis. *Journal of Educational Psychology*, *114*(8), 1743–1772. https://doi.org/https://doi.org/10.1037/edu0000764

Meyer, M., Zosh, J. M., McLaren, C., Robb, M., McCaffery, H., Golinkoff, R. M., Hirsh-Pasek, K., & Radesky, J. (2021). How educational are "educational" apps for young children? App store content analysis using the Four Pillars of Learning framework. *Journal of Children and Media*, *15*(4), 526–548. https://doi.org/10.1080/17482798.2021.1882516

Mintzer, M. Z., & Snodgrass, J. G. (1999). The picture superiority effect: Support for the distinctiveness model. *American Journal of Psychology*, *112*(1), 113–146. https://doi.org/10.2307/1423627

Mitzner, T. L., Savla, J., Boot, W. R., Sharit, J., Charness, N., Czaja, S. J., & Rogers, W. A. (2019). Technology Adoption by Older Adults: Findings from the PRISM Trial. *Gerontologist*, *59*(1), 34–44. https://doi.org/10.1093/geront/gny113

Montazami, A., Ann Pearson, H., Kenneth Dubé, A., Kacmaz, G., Wen, R., & Shajeen Alam, S. (2022). Why this app? How educators choose a good educational app. *Computers and Education*, *184*. https://doi.org/10.1016/j.compedu.2022.104513

Moore, T., & Zirnsak, M. (2017). Neural Mechanisms of Selective Visual Attention. In *Annual Review of Psychology* (Vol. 68, pp. 47–72). https://doi.org/10.1146/annurev-psych-122414-033400

Moreno, R., & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology*, *91*(2), 358–368. https://doi.org/10.1037/0022-0663.91.2.358

Mutlu-Bayraktar, D., Cosgun, V., & Altan, T. (2019). Cognitive load in multimedia learning environments: A systematic review. *Computers and Education*, *141*, 103618. https://doi.org/10.1016/j.compedu.2019.103618

Nagyne-Rez, I., Lanyine-Engelmayer, A., Kuncz, E., Meszaros, A., Mlinko, R., Bass, L., Rozsa, S., & Ko, N. (2008). *A WISC-IV gyermek intelligencia teszt magyar kézikönyve, Hazai tapasztalatok, vizsgálati eredmények és normák*. OS Hungary Tesztfejlesztő Kft.

Nedelescu, M., Stan, M., Ciobanu, A. M., Bălălău, C., Filippini, T., & Baconi, D. (2022). Attention deficit among preschool and school-aged children living near former metal-processing plants in Romania. *Environmental Research*, *208*. https://doi.org/10.1016/j.envres.2022.112689

Nikkelen, S. W. C. ;, Valkenburg, P. M. ;, Huizinga, M. ;, & Bushman, B. J. (2014). Media use and ADHD-related behaviors in children and adolescents: A meta-analysis. *Psycnet.Apa.OrgSWC Nikkelen, PM Valkenburg, M Huizinga, BJ BushmanDevelopmental Psychology, 2014•psycnet.Apa.Org*. https://doi.org/10.1037/a0037318

Ophir, E., Nass, C., & Wagner, A. D. (2009). Cognitive control in media multitaskers. *Proceedings of the National Academy of Sciences*, *106*(37), 15583–15587. https://doi.org/10.1073/PNAS.0903620106

Ozcelik, E., Arslan-Ari, I., & Cagiltay, K. (2010). Why does signaling enhance multimedia learning? Evidence from eye movements. *Computers in Human Behavior*, *26*(1), 110–117. https://doi.org/10.1016/J.CHB.2009.09.001

Paivio, A. (1990). *Mental representations: A dual coding approach*.

Paivio, A., & Csapo, K. (1973). Picture superiority in free recall: Imagery or dual coding? *Cognitive Psychology*, *5*(2), 176–206. https://doi.org/10.1016/0010-0285(73)90032-7

Pan, Z., Cheok, A. D., Yang, H., Zhu, J., & Shi, J. (2006). Virtual reality and mixed reality for virtual learning environments. *Computers and Graphics (Pergamon)*, *30*(1), 20–28. https://doi.org/10.1016/j.cag.2005.10.004

Panagiotidi, M., Overton, P. G., & Stafford, T. (2017). Multisensory integration and ADHD-like traits: Evidence for an abnormal temporal integration window in ADHD. *Acta Psychologica*, *181*, 10–17. https://doi.org/10.1016/J.ACTPSY.2017.10.001

Papadakis, S. (2020). Tools for evaluating educational apps for young children: a systematic review of the literature. *Interactive Technology and Smart Education*, *18*(1), 18–49. https://doi.org/10.1108/ITSE-08-2020-0127

Papadakis, S., & Kalogiannakis, M. (2017). Mobile educational applications for children: What educators and parents need to know. *International Journal of Mobile Learning and Organisation*, *11*(3), 256–277. https://doi.org/10.1504/IJMLO.2017.085338

Parish-Morris, J., Mahajan, N., Hirsh-Pasek, K., Golinkoff, R. M., & Collins, M. F. (2013). Once upon a time: Parent-child dialogue and storybook reading in the electronic era. *Mind, Brain, and Education*, *7*(3), 200–211. https://doi.org/10.1111/mbe.12028

Parong, J., & Mayer, R. E. (2018). Learning science in immersive virtual reality. *Journal of Educational Psychology*, *110*(6), 785–797. https://doi.org/10.1037/edu0000241

Parry, D. A., le Roux, D. B., & Bantjes, J. R. (2020). Testing the feasibility of a media multitasking self-regulation intervention for students: Behaviour change, attention, and self-perception. *Computers in Human Behavior*, *104*, 106182. https://doi.org/10.1016/J.CHB.2019.106182

Paulus, M. P., Squeglia, L. M., Bagot, K., Jacobus, J., Kuplicki, R., Breslin, F. J., Bodurka, J., Morris, A. S., Thompson, W. K., Bartsch, H., & Tapert, S. F. (2019). Screen media activity and brain structure in youth: Evidence for diverse structural correlation networks from the ABCD study. *NeuroImage*, *185*, 140–153. https://doi.org/10.1016/J.NEUROIMAGE.2018.10.040

Perczel-Forintos, D., Kiss, Z., & Ajtay, G. (2005). *Kérdőívek, becslőskálák a klinikai pszichológiában* (OPNI, Ed.).

Petersen, S. E., & Posner, M. I. (2012a). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience*, *35*, 73–89. https://doi.org/10.1146/annurev-neuro-062111-150525

Petersen, S. E., & Posner, M. I. (2012b). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience*, *35*, 73–89. https://doi.org/10.1146/annurev-neuro-062111-150525

Petrigna, L., Thomas, E., Brusa, J., Rizzo, F., Scardina, A., Galassi, C., Lo Verde, D., Caramazza, G., & Bellafiore, M. (2022). Does Learning Through Movement Improve Academic Performance in Primary Schoolchildren? A Systematic Review. In *Frontiers in Pediatrics* (Vol. 10, p. 841582). Frontiers Media SA. https://doi.org/10.3389/fped.2022.841582

Plass, J. L., & Kalyuga, S. (2019). Four Ways of Considering Emotion in Cognitive Load Theory. *Educational Psychology Review*, *31*(2), 339–359. https://doi.org/10.1007/S10648-019-09473-5/FIGURES/1

Posner, M., & Rothbart, M. K. (2005). *The Development of Executive Attention: Contributions to the Emergence of Self-Regulation*. https://doi.org/10.1207/s15326942dn2802_2

Quintero, M., Hasty, L., Li, T., Song, S., & Wang, Z. (2022). A multidimensional examination of math anxiety and engagement on math achievement. *British Journal of Educational Psychology*, *92*(3), 955–973. https://doi.org/10.1111/bjep.12482

R Core Team. (2020). *R: A language and environment for statistical computing*. https://www.r-project.org/

Randolph, J. J., Kangas, M., Ruokamo, H., & Hyvönen, P. (2016). Creative and playful learning on technology-enriched playgrounds: an international investigation. *Interactive Learning Environments*, *24*(3), 409–422. https://doi.org/10.1080/10494820.2013.860902

Ravi, S., & Waswani, S. (2020). Perception of Students Toward the Use of PowerPoint Presentations as a Teaching Tool. *Role of ICT in Higher Education*, 33–40. https://doi.org/10.1201/9781003130864-3

Reich, S. M., Yau, J. C., & Warschauer, M. (2016). Tablet-based ebooks for young children: What does the research say? In *Journal of Developmental and Behavioral Pediatrics* (Vol. 37, Issue 7, pp. 585–591). https://doi.org/10.1097/DBP.0000000000000335

Renninger, K. A., Hidi, S., Krapp, A., & Renninger, A. (2014). The Role of interest in Learning and Development. In K. A. Renninger, S. Hidi, A. Krapp, & A. Renninger (Eds.), *The Role of interest in Learning and Development*. Psychology Press. https://doi.org/10.4324/9781315807430

Richter, A., & Courage, M. L. (2017). Comparing electronic and paper storybooks for preschoolers: Attention, engagement, and recall. *Journal of Applied Developmental Psychology*, *48*, 92–102. https://doi.org/10.1016/j.appdev.2017.01.002

Rienties, B., Beausaert, S., Grohnert, T., Niemantsverdriet, S., & Kommers, P. (2012). Understanding academic performance of international students: The role of ethnicity, academic and social integration. *Higher Education*, *63*(6), 685–700. https://doi.org/10.1007/S10734-011-9468-1/TABLES/4

Rodrigues, L., Pereira, F. D., Toda, A. M., Palomino, P. T., Pessoa, M., Carvalho, L. S. G., Fernandes, D., Oliveira, E. H. T., Cristea, A. I., & Isotani, S. (2022). Gamification suffers from the novelty effect but benefits from the familiarization effect: Findings from a longitudinal study. *International Journal of Educational Technology in Higher Education*, *19*(1). https://doi.org/10.1186/s41239-021-00314-6

Rothbart, M. K., & Posner, M. I. (2015). The developing brain in a multitasking world. In *Developmental Review* (Vol. 35, pp. 42–63). Academic Press. https://doi.org/10.1016/j.dr.2014.12.006

Roussel, S., Joulia, D., Tricot, A., & Sweller, J. (2017). Learning subject content through a foreign language should not ignore human cognitive architecture: A cognitive load theory approach. *Learning and Instruction*, *52*, 69–79. https://doi.org/10.1016/J.LEARNINSTRUC.2017.04.007

Rueda, M. R., Fan, J., Mccandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., & Posner, M. I. (2004). Development of attentional networks in childhood. *Neuropsychologia*, *42*, 1029–1040. https://doi.org/10.1016/j.neuropsychologia.2003.12.012

Rueda, M. R., Rothbart, M. K., McCandliss, B. D., Saccomanno, L., & Posner, M. I. (2005). Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(41), 14931–14936. https://doi.org/10.1073/pnas.0506897102

Sanchez, C. A., & Wiley, J. (2006). An examination of the seductive details effect in terms of working memory capacity. *Memory & Cognition*, *34*(2), 344–355. https://doi.org/10.3758/BF03193412

Savoy, A., Proctor, R. W., & Salvendy, G. (2009). Information retention from PowerPoint™ and traditional lectures. *Computers & Education*, *52*(4), 858–867. https://doi.org/10.1016/J.COMPEDU.2008.12.005

Schmicker, M., Schwefel, M., Vellage, A. K., & Müller, N. G. (2016). Training of attentional filtering, but not of memory storage, enhances working memory efficiency by strengthening the neuronal gatekeeper network. *Journal of Cognitive Neuroscience*, *28*(4), 636–642. https://doi.org/10.1162/jocn_a_00922

Schneider, S., Beege, M., Nebel, S., & Rey, G. D. (2018). A meta-analysis of how signaling affects learning with media. *Educational Research Review*, *23*, 1–24. https://doi.org/10.1016/J.EDUREV.2017.11.001

Schweppe, J., & Rummer, R. (2014). Attention, Working Memory, and Long-Term Memory in Multimedia Learning: An Integrated Perspective Based on Process Models of Working Memory. *Educational Psychology Review*, *26*(2), 285–306. https://doi.org/10.1007/s10648-013-9242-2

Sehyr, Z. S., Giezen, M. R., & Emmorey, K. (2018). Comparing Semantic Fluency in American Sign Language and English. *The Journal of Deaf Studies and Deaf Education*, *23*(4), 399–407. https://doi.org/10.1093/DEAFED/ENY013

Serretti, A., Mandelli, L., Lorenzi, C., Landoni, S., Calati, R., Insacco, C., & Cloninger, C. R. (2006). Temperament and Character in Mood Disorders: Influence of DRD4, SERTPR, TPH and MAO-A Polymorphisms. *Neuropsychobiology*, *53*(1), 9–16. https://doi.org/10.1159/000089916

Seth, V., Upadhyaya, P., Ahmad, M., & Moghe, V. (2010). *PowerPoint or chalk and talk: Perceptions of medical students versus dental students in a medical college in India*. https://doi.org/10.2147/AMEP.S12154

Sharp, J. G., Hemmings, B., Kay, R., Murphy, B., & Elliott, S. (2017). Academic boredom among students in higher education: A mixed-methods exploration of characteristics, contributors and consequences. *Journal of Further and Higher Education*, *41*(5), 657–677. https://doi.org/10.1080/0309877X.2016.1159292

Shi, J., Weng, X., He, S., & Jiang, Y. (2010). Biological motion cues trigger reflexive attentional orienting. *Cognition*, *117*(3), 348–354. https://doi.org/10.1016/j.cognition.2010.09.001

Shin, N., Sutherland, L. M., Norris, C. A., & Soloway, E. (2012). Effects of game technology on elementary student learning in mathematics. *British Journal of Educational Technology*, *43*(4), 540–560. https://doi.org/10.1111/J.1467-8535.2011.01197.X

Shuler, C., Levine, Z., & Ree, J. (2012). iLearn II: An analysis of the education category of Apple's app store. *Joan Ganz Cooney Center*, *January*, 1–32. www.joanganzcooneycenter.org.

Singh, P., Williams, K., Jonnalagadda, R., Gogineni, A., Reddy, R. R. S., Singh, P., Williams, K., Jonnalagadda, R., Gogineni, A., & Reddy, R. R. S. (2022). International

Students: What's Missing and What Matters. *Open Journal of Social Sciences*, *10*(2), 381–397. https://doi.org/10.4236/JSS.2022.102027

Skogli, E. W., Andersen, P. N., Hovik, K. T., & Øie, M. (2017). Development of Hot and Cold Executive Function in Boys and Girls With ADHD: A 2-Year Longitudinal Study. *Journal of Attention Disorders*, *21*(4), 305–315. https://doi.org/10.1177/1087054714524984

Slusarek, M., Velling, S., Bunk, D., & Eggers, C. (2001). Motivational effects on inhibitory control in children with ADHD. *Journal of the American Academy of Child and Adolescent Psychiatry*, *40*(3), 355–363. https://doi.org/10.1097/00004583-200103000-00016

Smeets, D. J. H., & Bus, A. G. (2015). The interactive animated e-book as a word learning device for kindergartners. *Applied Psycholinguistics*, *36*(4), 899–920. https://doi.org/10.1017/S0142716413000556

Smith, Z. R., & Langberg, J. M. (2018). Review of the Evidence for Motivation Deficits in Youth with ADHD and Their Association with Functional Outcomes. In *Clinical Child and Family Psychology Review* (Vol. 21, Issue 4, pp. 500–526). Springer New York LLC. https://doi.org/10.1007/s10567-018-0268-3

Socher, M., Lyxell, B., Ellis, R., Gärskog, M., Hedström, I., & Wass, M. (2019). Pragmatic Language Skills: A Comparison of Children With Cochlear Implants and Children Without Hearing Loss. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.02243

Son, S. H. C., Butcher, K. R., & Liang, L. A. (2020). The influence of interactive features in storybook apps on children's reading comprehension and story enjoyment. *Elementary School Journal*, *120*(3), 422–454. https://doi.org/10.1086/707009

Stapp, A. C., Prior, L. F., & Smith, C. H. (2021). Moving Across Mississippi: Young Children's enjoyment and teachers' perceptions of standards-based physical activity videos. *Teaching and Teacher Education*, *107*. https://doi.org/10.1016/j.tate.2021.103472

Stenberg, G. (2006). Conceptual and perceptual factors in the picture superiority effect. *European Journal of Cognitive Psychology*, *18*(6), 813–847. https://doi.org/10.1080/09541440500412361

Stevens, T., & Mulsow, M. (2006). There is no meaningful relationship between television exposure and symptoms of attention-deficit/hyperactivity disorder. *Pediatrics*, *117*(3), 665–672. https://doi.org/10.1542/peds.2005-0863

Stiller, K. D., & Schworm, S. (2019). Game-Based Learning of the Structure and Functioning of Body Cells in a Foreign Language: Effects on Motivation, Cognitive Load, and Performance. *Frontiers in Education*, *4*, 441165. https://doi.org/10.3389/FEDUC.2019.00018/BIBTEX

Sundararajan, N., & Adesope, O. (2020). Keep it Coherent: A Meta-Analysis of the Seductive Details Effect. *Educational Psychology Review*, *32*(3), 707–734. https://doi.org/10.1007/s10648-020-09522-4

Sweller, J. (2010). Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educational Psychology Review*, *22*(2), 123–138. https://doi.org/10.1007/S10648-010-9128-5/METRICS

Sweller, J. (2012). The Redundancy Principle in Multimedia Learning. *The Cambridge Handbook of Multimedia Learning*, 159–168. https://doi.org/10.1017/CBO9780511816819.011

Sweller, J., & Chandler, P. (1994). Why Some Material Is Difficult to Learn. *Cognition and Instruction*, *12*(3), 185–233. https://doi.org/10.1207/S1532690XCI1203_1

Tabbers, H. K., Martens, R. L., & Van Merriënboer, J. J. G. (2004). Multimedia instructions and cognitive load theory: Effects of modality and cueing. *British Journal of Educational Psychology*, *74*(1), 71–81. https://doi.org/10.1348/000709904322848824

Takacs, Z. K., & Bus, A. G. (2016). Benefits of motion in animated storybooks for children's visual attention and story comprehension. An eye-tracking study. *Frontiers in Psychology*, *7*(OCT), 1591. https://doi.org/10.3389/fpsyg.2016.01591

Takacs, Z. K., Swart, E. K., & Bus, A. G. (2015). Benefits and Pitfalls of Multimedia and Interactive Features in Technology-Enhanced Storybooks: A Meta-Analysis. *Review of Educational Research*, *85*(4), 698–739. https://doi.org/10.3102/0034654314566989

Talsma, D., Senkowski, D., Soto-Faraco, S., & Woldorff, M. G. (2010). The multifaceted interplay between attention and multisensory integration. *Trends in Cognitive Sciences*, *14*(9), 400–410. https://doi.org/10.1016/J.TICS.2010.06.008

Tang, T. L. P., & Austin, M. J. (2009). Students' perceptions of teaching technologies, application of technologies, and academic performance. *Computers & Education*, *53*(4), 1241–1255. https://doi.org/10.1016/J.COMPEDU.2009.06.007

Tarasuik, J., Hansen, M. B., Wang, F., Xie, H., Wang, Y., Hao, Y., & An, J. (2016). Using Touchscreen Tablets to Help Young Children Learn to Tell Time. *Front. Psychol*, *7*, 1800. https://doi.org/10.3389/fpsyg.2016.01800

Tärning, B. (2018). Review of feedback in digital applications - Does the feedback they provide support learning? *Journal of Information Technology Education: Research*, *17*, 247–283. https://doi.org/10.28945/4104

Tripp, G., Schaughency, E. A., & Clarke, B. (2006). Parent and teacher rating scales in the evaluation of attention-deficit hyperactivity disorder: Contribution to diagnosis and differential diagnosis in clinically referred children. *Journal of Developmental and Behavioral Pediatrics*, *27*(3), 209–218. https://doi.org/10.1097/00004703-200606000-00006

Tullis, J. G., & Benjamin, A. S. (2011). On the effectiveness of self-paced learning. *Journal of Memory and Language*, *64*(2), 109–118. https://doi.org/10.1016/j.jml.2010.11.002

Vaala, S. E., & Lapierre, M. A. (2014). Marketing genius: The impact of educational claims and cues on parents' reactions to infant/toddler DVDs. *Journal of Consumer Affairs*, *48*(2), 323–350. https://doi.org/10.1111/joca.12023

Van Gog, T. (2014). The signaling (or cueing) principle in multimedia learning . In R. , E. Mayer (Ed.), *The cambridge handbook ofmultimedia learning* (2nd ed., pp. 263–278). Cambridge University Press.

Varga, E. (2014). Az interaktív mesekönyv kommunikációs stratégiái. In A. Dombi & M. Dombi (Eds.), *Pedagógikum és kommunikáció* (pp. 209–225). Universitas Kiadó.

Vega, V., & Michael Robb. (2019). *The common sense census: Inside the 21st-century classroom*. Common Sense Media. https://www.commonsensemedia.org/sites/default/files/research/report/2019-educator-census-inside-the-21st-century-classroom_1.pdf

Wang, F., Gao, C., Kaufman, J., Tong, Y., & Chen, J. (2021). Watching versus touching: The effectiveness of a touchscreen app to teach children to tell time. *Computers and Education*, *160*, 104021. https://doi.org/10.1016/j.compedu.2020.104021

Wang, F., Xie, H., Wang, Y., Hao, Y., & An, J. (2016). Using touchscreen tablets to help young children learn to tell time. *Frontiers in Psychology*, *7*(NOV), 1800. https://doi.org/10.3389/fpsyg.2016.01800

Wang, J., Stebbins, A., & Ferdig, R. E. (2022). Examining the effects of students' self-efficacy and prior knowledge on learning and visual behavior in a physics game. *Computers and Education*, *178*, 104405. https://doi.org/10.1016/j.compedu.2021.104405

Wiley, J., Sanchez, C. A., & Jaeger, A. J. (2014). The individual differences in working memory capacity principle in multimedia learning. In *The Cambridge Handbook of*

Multimedia Learning, Second Edition (pp. 598–620). Cambridge University Press. https://doi.org/10.1017/CBO9781139547369.029

Winograd, E., Smith, A. D., & Simon, E. W. (1982). Aging and the Picture Superiority Effect in Recall. *Journal of Gerontology*, *37*(1), 70–75. https://doi.org/10.1093/GERONJ/37.1.70

Wylie, L. (2023). *Education App Revenue and Usage Statistics (2023)*. Business of Apps. https://www.businessofapps.com/data/education-app-market/

Xie, H., Peng, J., Qin, M., Huang, X., Tian, F., & Zhou, Z. (2018). Can touchscreen devices be used to facilitate young children's learning? A meta-analysis of touchscreen learning effect. In *Frontiers in Psychology* (Vol. 9, Issue DEC, p. 381928). Frontiers Media S.A. https://doi.org/10.3389/fpsyg.2018.02580

Xu, Y., Yau, J. C., & Reich, S. M. (2021). Press, swipe and read: Do interactive features facilitate engagement and learning with e-Books? *Journal of Computer Assisted Learning*, *37*(1), 212–225. https://doi.org/10.1111/JCAL.12480

Yuen, S. C.-Y., Yaoyuneyong, G., & Johnson, E. (2011). Augmented Reality: An Overview and Five Directions for AR in Education. *Journal of Educational Technology Development and Exchange*, *4*(1), 119–140. https://doi.org/10.18785/jetde.0401.10

Zelazo, P. D., & Müller, U. (2010). Executive Function in Typical and Atypical Development. In *The Wiley-Blackwell Handbook of Childhood Cognitive Development, Second edition* (pp. 574–603). https://doi.org/10.1002/9781444325485.ch22

Zipke, M. (2017). Preschoolers explore interactive storybook apps: The effect on word recognition and story comprehension. *Education and Information Technologies*, *22*(4), 1695–1712. https://doi.org/10.1007/s10639-016-9513-x

List of own publications

Publications in the topic of the dissertation

Papers and Book chapters

Bali, C., Matuz-Budai, T., Arato, N., Labadi, B., & Zsido, A. N. (2023). Executive attention modulates the facilitating effect of electronic storybooks on information encoding in preschoolers. *Heliyon*, e12899.

Bali, C., Zsido, A.N. (2024). Optimizing Learning Outcomes of Educational Applications Enhanced with Multimedia and Interactive Features: A Review. In: Papadakis, S., Kalogiannakis, M. (eds) *Education, Development and Intervention. Integrated Science*, vol 23. Springer, Cham. https://doi.org/10.1007/978-3-031-60713-4_11

Bali C., Zsidó A. N. (2022) IKT eszközök hatása a figyelmi folyamatokra. In: Zsidó A. N.; Lábadi, B. (eds.) *Figyelem a gyakorlatban*. Akadémiai Kiadó.

Conference abstracts

Bali, C., & Zsido, A. N. (2023) A multimédia-tanulást befolyásoló tényezők vizsgálata felsőoktatásban tanuló hallgatók bevonásával. In *Találkozás a változásban - Változások a találkozásban* (p. 339).

Tasdelen, B., Hamed, R., **Bali C.**, & Zsido A. N. (2022) The Influence of Attentional Performance and Working Memory Capacity on Recall Performance in University Students on a Multimedia Learning Setting. In *XI. Interdiszciplináris Doktorandusz Konferencia 2022. november 25-26 = 11th Interdisciplinary Doctoral Conference 25-26th of November 2022* (p. 102).

Bali, C., & Zsidó, N. A. (2021). Az interaktív multimédiás eszközök felidézési teljesítményre gyakorolt hatásának vizsgálata a figyelmi folyamatok működésének tükrében. In *Út a reziliens jövő felé. A Magyar Pszichológiai Társaság XXIX. Országos Tudományos Nagygyűlése* (pp. 165–165).

Bali, C., Stecina, D. T., & Zsidó, A. N. (2020). Óvodás gyermekek felidézési teljesítményének vizsgálata multimédiás eszközök használata során. In *IX. INTERDISZCIPLINÁRIS DOKTORANDUSZ KONFERENCIA 2020 ABSZTRAKTKÖTET* (pp. 182–182).

Bali, C., Takáts, A., Farkas, H. K., Takács, K., Balogh, V., Gáspár, G., & Zsidó, A. N. (2024). Multimédiás elemek ismeretszerzésben betöltött szerepe. In *XVIII. Magatartástudományi Konferencia* (p. 59).

Bali, C., Takáts, A., Fehér, Z., Dombai, N., Eszter Kiss, D., Várkonyi, G., … N. Zsidó, A. (2024). Marked interactions improve learning outcomes of primary school children despite individual differences in executive attention. In *TeaP 2024 Regensburg - 66th Conference of Experimental Psychologists* (p. 48).

Bali, C., Takáts, A., Fehér, Zs., Dombai, N., E. Kiss, D., Várkonyi, G., … N. Zsidó, A. (2024). Multimedia elements and marked interactions enhance learning in primary school children. In *BCCCD 2024. Budapest CEU Conference on Cognitive Development* (pp. 71–72).

Bali, C., Csibi K. Zs., Kis V., Gerely B., Lábadi B., & Zsidó A. N. (2023). Multimedia and interactive features facilitate knowledge acquisition in primary school children regardless of individual differences in cognitive skills. In *BCCCD Budapest CEU Conference on Cognitive Development - 2023 Program and Abstracts* (pp. 50–51).

Bali, C., Beatrix, L., & Zsidó, A. N. (2022). Individual differences in attentional performance of pre-schoolers influence how well they remember the content of electronic storybooks. In *TeaP 2022 : Abstracts of the 64th Conference of Experimental Psychologists* (pp. 324–324).

Bali, C., Csibi, K. Z., Kis, V., Gerely, B., & Zsidó, A. N. (2022). Multimedia elements and and interactive features improve recall performance of primary school children. In *XXV. Tavaszi Szél Konferencia 2022. Absztraktkötet* (pp. 585–585).

Bali C., Lábadi B., & Zsidó A. N. (2021). Multimedia elements in electronic storybooks improve recall performance in children. In *BCCCD21 Book of Abstracts* (pp. 125–125).

Publications Outside of the Topic of the Dissertation

Papers and Book chapters

Bali, C., Feher, Z., Arato, N. et al. The mediating role of ICT learning confidence and technostress between executive functions and digital skills. *Scientific Reports* 14, 12343 (2024). https://doi.org/10.1038/s41598-024-63120-w

Basler J., **Bali C.**, Fehér A., Kiss B. L., & Zsidó A. N. (2024). A Liebowitz Szociális Szorongás Kérdőív magyar nyelvű validálása, faktorstruktúráinak összehasonlítása és tételeinek modern tesztelméleti elemzése. *Magyar Pszichológiai Szemle*, 79(1), 73-100. https://doi.org/10.1556/0016.2023.00054

Kiss B. L., **Bali C.**, Basler J., Fehér A., & Zsidó A. N. (2024). A Morbid Kíváncsiság Skála magyar nyelvű változatának adaptációja. *Magyar Pszichológiai Szemle*, 79(1), 101-118. https://doi.org/10.1556/0016.2023.00050

Pakai-Stecina, D. T., Hout, M. C., **Bali, C.**, & Zsido, A. N. (2024). Can the processing of task-irrelevant threatening stimuli be inhibited? – The role of shape and valence in the saliency of threatening objects. Acta Psychologica, 243, 104150. https://doi.org/10.1016/j.actpsy.2024.104150

Zsidó, A. N., **Bali, C.**, Kocsor, F., & Hout, M. C. (2023). Task-irrelevant threatening information is harder to ignore than other valences. *Emotion*, 23(6), 1606–1617. https://doi.org/10.1037/emo0001189

Zsidó, A. N., Inhof, O., Kiss, B. L., **Bali, C.**, & March, D. S. (2024). Threatening stimuli have differential effects on movement preparation and execution—A study on snake fear. *People and Nature*, 6(3), 973-986. https://doi.org/10.1002/pan3.10500

Zsido, A. N., Inhóf, O., Arató, N., Budai, T., **Bali, C.**, & Lábadi, B. (2024). Problematic internet use may be linked to issues with verbal processing. *Psicologica* 45(1): e16117 https://doi.org/10.20350/digitalCSIC/16117

Conference abstracts

Arndt, B., Illés, A., & **Bali, C.** (2022). Preference of meaning and prototypicality: An eye-tracking study. *HORIZONS OF PSYCHOLOGY*, *31*, 578–578.

Bali, C., Fehér Zs., Várkonyi, G., Arató, N., Lábadi, B., & Zsidó, A. N. (2022). Examining the relationship between cognitive flexibility, ICT attitude, and digital competences. *HORIZONS OF PSYCHOLOGY*, *31*, 571–571.

Kiss, B. L., Zsidó, A. N., **Bali, C.**, & Birkás, B. (2022). Investigating anticipatory form of attentional biases using the cVPT paradigm for content related to BII phobia. *HORIZONS OF PSYCHOLOGY*, *31*, 583–583.

Bali, C., Kiss, B. L., Arató, N., Lábadi, B., & Zsidó, A. N. (2023). A nyitottság és a technostressz közvetítő szerepe a végrehajtó funkciók és a digitális kompetenciák elsajátítása között. In *Találkozás a változásban - Változások a találkozásban* (pp. 237–238).

Kiss, B. L., **Bali, C**., Basler, J., & Zsidó, A. N. (2023). A Morbid Kíváncsiság Skála magyar nyelvű változatának adaptációja. In *Találkozás a változásban - Változások a találkozásban* (pp. 321–321).

Zsidó, A. N., Kiss, B. L., Basler, J., & **Bali, C**. (2023). A közeli fenyegető ingerek hatása a mozgás előkészítésére és végrehajtására – passzív vagy aktív lefagyás? In *Találkozás a változásban - Változások a találkozásban* (p. 155).

Bali C., Fehér Zs., Kiss B. L., Arató, N., Lábadi B., & Zsidó A. N. (2022). The influence of executive functions on digital literacy through affective variables. In *XI. Interdiszciplináris Doktorandusz Konferencia 2022. november 25-26 = 11th Interdisciplinary Doctoral Conference 25-26th of November 2022* (pp. 104–104).

Himanshika, J., **Bali, C.,** & Labadi, B. (2022). Perspective taking: How perspective taking affects your social behaviour. In *XI. Interdiszciplináris Doktorandusz Konferencia 2022. november 25-26 = 11th Interdisciplinary Doctoral Conference 25-26th of November 2022* (p. 106).

Stecina, D. T., **Bali, C**., & Zsidó, A. N. (2022). Általános vonás detekció és a fenyegető ingerek gátlásának nehézségei = General Feature Detection and the Difficulties of Inhibiting Threatening Stimuli. In *XX. Szentágothai János Mutidiszciplináris Konferencia és Hallgatói Verseny Absztrakt kötet = XX. János Szentágothai Multidisciplinary Conference and Student Competition* (pp. 249–250).

Bali, C., Fehér, Zs., Várkonyi, G., Lábadi, B., Arató, N., & Norbert Zsidó, A. (2021). Exploring the role of cognitive factors in the usage of digital technology. In *10th Jubilee Interdisciplinary Doctoral Conference: Book of Abstracts = 10. Jubileumi Interdiszciplináris Doktorandusz Konferencia: Absztraktkötet* (pp. 151–151).

Zsido A. N., **Bali, C.** & Hout, M., C. (2023). Are threatening stimuli special? – A comparison of the ability to ignore stimuli with different emotional valences. In *TeaP 2023: Abstracts of the 65th Conference of Experimental Psychologists.* (p. 119).

Kiss B., **Bali C**., Lázár Gy., Kocsor F., Birkás B. & Zsidó A. N. (2023). Examining the anticipatory attentional biases triggered by threatening content related to medical fears. In *TeaP 2023: Abstracts of the 65th Conference of Experimental Psychologists.* (p. 1).

Basler J., Kiss B. L., **Bali C.,** Birkás B., & Zsidó A. N. (2023). Actions and consequences: participating in cyberostracism leads to avoidance of disgusted faces. In *TeaP 2023: Abstracts of the 65th Conference of Experimental Psychologists.* (p. 1).

Zsidó A. N., **Bali, C.**, Kocsor, F. & Hout, M., C. (2022). Delving deeper into the effects of emotional valence during visual search. In *Psychonomic Society 2022 Annual Meeting Abstracts* (p. 1).

Zsidó, A. N., **Bali, C.,** Stecina, T. D., & Lábadi, B. (2022). Bottom-up and top-down effects of emotionally charged task-irrelevant stimuli under various load conditions. In *TeaP 2022: Abstracts of the 64th Conference of Experimental Psychologists* (p. 1).

Ihász, V., **Bali, C.,** Basler J., Cseh, R., Stecina, T. D., & Zsidó A. N. (2020). Own-age effect on emotional face detection. In *BCCCD 2020 (Budapest CEU Conference on Cognitive Development)* (p. 146).

Ihász, V., **Bali, C.,** & Zsidó, A. N. (2019). Érzelemkifejező arcok vizuális keresése a saját életkor iránti elfogultság számításba vételével. In *Összetart a sokszínűség: A Magyar Pszichológiai Társaság XXVIII. Országos Tudományos Nagygyűlése : kivonatkötet* (pp. 255–255).

Doktori értekezés benyújtása és nyilatkozat a dolgozat eredetiségéről

Declaration of originality

Név: Bali Cintia

Születési név: Bali Cintia

Anyja neve: Sztanik Marianna

Születési hely, idő: Szeged, 1994, szeptember 1.

The Role of Individual Differences in Attention in Multimedia Learning Across Different Age Groups

című doktori értekezésemet a mai napon benyújtom a(z) Pszichológia Doktori Iskola Evolúciós és Kognitív Pszichológia Programjához

Témavezető neve: Dr. Zsidó András Norbert

Egyúttal nyilatkozom, hogy jelen eljárás során benyújtott doktori értekezésemet
- korábban más doktori iskolába (sem hazai, sem külföldi egyetemen) nem nyújtottam be,
- fokozatszerzési eljárásra jelentkezésemet két éven belül nem utasították el,
- az elmúlt két esztendőben nem volt sikertelen doktori eljárásom,
- öt éven belül doktori fokozatom visszavonására nem került sor,
- értekezésem önálló munka, más szellemi alkotását sajátomként nem mutattam be, az irodalmi hivatkozások egyértelműek és teljesek, az értekezés elkészítésénél hamis vagy hamisított adatokat nem használtam.

Dátum: 2024. 08. 30.

....

aláírás