CHARLES UNIVERSITY
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Department of Information Science and Librarianship

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DISSERTATION THESIS

MgA. Ondřej Javora

Visual Design Aspects of Advanced Digital Multimedia Learning Materials: Effects on Learning and Information Behavior in Case of Primary School Children

Aspekty visuálního designu pokročilých digitálních multimediálních výukových materiálů: vliv na učení a informační chování u dětí prvního vzdělávacího stupně

Dissertation supervisor doc. Mgr. Cyril Brom, Ph.D.

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I hereby declare that I have written this dissertation independently, using only the mentioned and duly cited sources and literature, and that the work has not been used in another university study programme or to obtain the same or another academic title.

In Prague on 27. 3. 2022 MgA. Ondřej Javora m.p.

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Dedicated to Trinitas

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Abstract

This thesis investigates the effects of selected visual design aspects of information representation in advanced digital multimedia learning materials (ADMLMs) on learning outcomes and information behavior of primary school children (8-11 years old). It consists of three experimental studies in laboratory conditions, each individually focusing on different issue, including effects of *overall visual appearance* (VA; N=53), *visual dynamicity* (VD; N=134), and *visual customizability* (VC; N=143). The general theoretical framework is based on the insights from science of learning, cognitive psychology, and information science. On one hand, the results show that the investigated visual design aspects do not have a detectable effect on the self-reported learning enjoyment and learning outcomes (i.e., comprehension tests, transfer tests). On the other hand, the results also confirm that children at this age are sensitive to these aspects, which are generally capable to impact children's evaluation of attractiveness (d_{VA}=0.86; d_{VD}=1.11), motivation towards further interaction with the learning materials (x^2_{VA} [2] = 21.269, $p < .001$; x^2_{VD} [1] = 87.04, $p < .001$) and related information behavior. The theoretical as well as practical implications are discussed. Although investigated visual design aspects of ADMLMs failed to promote learning outcomes, they did not harm them either. It is concluded, that due to ability of investigated visual design aspects to potentially positively impact children's information behavior, their usage is still overall rather beneficial.

Abstrakt

Tato disertační práce zkoumá dopad vybraných aspektů visuálního designu reprezentace informací v *pokročilých digitálních multimediálních výukových materiálech* na vzdělávací výsledky a informační chování u dětí prvního vzdělávacího stupně (8-11 let). Skládá se ze tří experimentálních studií v laboratorních podmínkách. Každá ze studií se zaměřuje na jinou problematiku, které se týkají: *celkového visuálního vzhledu* (VV; N=53), *visuální dynamičnosti* (VD; N=134), a *visuální přizpůsobitelnosti* (VP; N=143). Obecný teoretický rámec je stavěn na poznatcích z pedagogické psychologie, kognitivní psychologie a informační vědy. Výsledky studií ukazují, že zkoumané visuální aspekty nemají zjistitelný dopad na vnímané potěšení z učení a vzdělávací výsledky (tj. znalostní testy, transferové testy). Výsledky však rovněž ukazují, že děti v tomto věku jsou citlivé na zkoumané aspekty visuálního designu, které jsou obecně schopny u dětí ovlivňovat evaluaci atraktivity (d_{VV}=0.86; d_{VD}=1.11), motivaci k další interakci s výukovými materiály (x^2_{VA} [2] = 21.269, p < .001; x^2_{VD} [1] = 87.04, p < .001) a související informační chování. Teoretické i praktické implikace jsou diskutovány. Zkoumané aspekty visuálního designu sice selhaly v podpoře vzdělávacích výsledků, nicméně zároveň ani nebyly příčinou vlivů negativních. Práce dochází k závěru, že díky potenciální schopnosti zkoumaných visuálních aspektů pozitivně u dětí ovlivnit informační chování, je jejich použití celkově stále spíše prospěšné.

Key words

Advanced digital multimedia learning materials; Multimedia learning; Digital game-based learning; Information behavior; Visual design aspects; Appearance; Animation; Customizability; Children; Emotional design; Affect; Emotions; Motivation; Cognitive-affective theory of learning with media; Integrated cognitive-affective model of learning with media; Cognitive load theory

Klíčová slova

Pokročilé digitální multimediální výukové materiály; Multimediální učení; Učení pomocí digitálních her; Informační chování; Aspekty visuálního designu; Vzhled; Animace; Přizpůsobitelnost; Děti; Emoční design; Afekt; Emoce; Motivace; Kognitivně-afektivní teorie učení, Integrovaný kognitivně-afektivní model učení; Teorie kognitivního zatížení

Contents

Foreword

The empirical research in this dissertation was conducted as part of cooperation between Charles University's Faculty of Arts and the Faculty of Mathematics and Physics. It contains three studies: a Visual Appearance Study (Chapter 4), a Visual Dynamicity Study (Chapter 5), and a Visual Customizability Study (Chapter 6). All studies were funded by Charles University's PRIMUS/HUM/03 project. The Visual Customizability Study was primarily funded by a grant from the Czech Science Foundation (GAČR) as part of the project "EduGames4K: Designing educational games for kids" (No. 19-02532S). Additionally, my work has been partly supported by a student grant from Charles University's Faculty of Arts (GAUK 684218; "The Role of Narrative in Multimedia Learning Materials").

I retain the role of main author of the research presented in this thesis, including the research questions, individual studies, and interventions. The original digital learning game was developed for the purpose of this dissertation and served as a core experimental instrument (see Section 3.1). I figured as the author, developer, game designer, instructional designer, graphic designer, and animator for the game (including its variations for individual studies). All development was done in cooperation with a team of colleagues (see Table 1). In addition, I also served as an administrator for all three studies; as data collection coordinator in the case of the Visual Customizability Study and assistant and consultant in the pilot phase; and as a graphic designer of selected measures (see Section 3.2.2 and Section 3.2.6). I also participated in the data collection and data analysis for each study, including the eye-tracker data analysis in the Visual Dynamicity Study (see Chapter 5).

Table 1

Experimental digital learning game development team members and their roles

Team Member	Role
Ondřej Javora	lead game design, instructional design, lead graphic design, piloting / testing assistance and consultation
Cyril Brom	game design, instructional design, general consultation and supervision
Tomáš Kozák	lead coder, game design consultation
Radka Dvořáková	biology expert consultation and supervision
Kristina Volná	game design supervision, participant recruitment
Tereza Hannemann	piloting and testing management, consultation, game design participation
Tereza Stárková	piloting and testing assistance, consultation

Most of the measures used in all three studies (see Section 3.2) were designed, calibrated, and piloted by my colleagues: primarily, Tereza Hannemann and Tereza Stárková, under the supervision of Cyril Brom. Tereza Hannemann also served as data collection coordinator in the case of the Visual Appearance Study and Tereza Tetourová in the case of the Visual Dynamicity Study. Kristina Volná organized the recruitment of participants. All the statistical analyses and procedures were consulted, supervised, and conducted by Filip Děchtěrenko. Statistical analysis in the case of the Visual Appearance and Visual Dynamicity Study was also done in cooperation with Tereza Hannemann. The eye-tracking procedure and related data analysis was consulted with Jiří Lukavský. Filip Děchtěrenko also assisted in writing the Data analysis and Results sections in each study.

Credit also goes to research assistants who helped with the administration of individual experimental sessions, data collection and data analyses: Visual Appearance Study – Tereza Tetourová, Tereza Jandová, Martin Semrád, Petra Plintová, and Jaroslav Rác; Visual Dynamicity Study – Tereza Jandová, Martin Semrád, Petra Plintová, and Jaroslav Rác; Visual Customizability Study – Karolína Faberová, Nikola Kopáňková, Nikola Sochová, Markéta Sázavská, Lucie Jičínská, and Erin Poláková.

The research was conducted with the help of Štěpánka Sunková and the whole Development and New Media Department (decko.cz and ctart.cz) at Czech Television.

The results of individual studies have been already published in separate articles: the Visual Appearance Study – *Children like it more but don't learn more: Effects of esthetic visual design in educational games* (Javora, Hannemann, Stárková, Volná, & Brom, 2019); the Visual Dynamicity Study – *Is contextual animation needed in multimedia learning games for children? An eye-tracker study* (Javora, Hannemann, Volná, Děchtěrenko, Tetourová, Stárková, & Brom, 2021); the Visual Customizability Study – *Customization in educational computer games and its effect on learning: an Experimental study with primary school children* (Javora, Děchtěrenko, Tetourová, Volná, & Brom, 2021). I am the main author of all the published articles. The vertical line on the left side of the text is used in the body of this thesis to mark clearly directly quoted, paraphrased, or adopted parts from these published studies. The texts of each study have been substantially revised and edited to ensure consistency in terminology and better readability within the context of the present thesis. The general theoretical framework (including information behavior), discussion, and conclusions have not yet been published.

The structure, concept, and reasoning of this dissertation and all related publications were thoroughly consulted and reviewed by my supervisor Cyril Brom. English proofreading and editing were done by Brady Clough. Within the thesis I use plural pronouns (e.g., "we") in cases where I refer to direct cooperation with my colleagues mentioned above. The plural form is also used to indicate the collaborative nature of conducting the experimental studies and the research agenda in general. Despite the many collaborations described above, which made this dissertation possible, I remain the main author of this work and bear full responsibility for its content and any possible shortcomings.

PART I. – Introduction, Theoretical Foundations and Methodology

1 Introduction

In this work I investigate the effects of selected visual design aspects of information representation in *advanced multimedia learning materials* (ADMLMs) on children's *knowledge acquisition* and *information behavior*. The process of knowledge acquisition is approached as identical to learning, and it is further addressed below (see Chapter 2). Information behavior is in the context of this work mainly related to children's motivation or willingness to interact with information sources like ADMLMs (see Section 2.3). I operate using the term ADMLMs, as proposed by Brom (2017), to narrow the broad range of multimedia learning materials used in various learning environments. Mayer (2009, 2014c) defines general multimedia instruction as any presentation of material using both verbal (e.g., printed text or spoken word) and pictorial information (e.g., photos, printed pictures, videos, etc.) with the intention of learning. This includes a wide variety of formats from mere chalk talk presentations using blackboards to online learning games and simulations (Mayer, 2014c). The adjective *digital* in the case of ADMLMs is used to accent the focus solely on new media formats (i.e., computerized learning materials) and *advanced* to "leave out non-animated linear materials (basically textbooks and simple slides)" (Brom, 2017, p. 2). Therefore, ADMLMs include interactive instructional presentations, educational websites, learning games, or simulations together with borderline cases such as video clips and animations with basic interactivity.

In recent decades, information technology has caused unprecedented technological shifts and has transformed many fields: including children's formal as well as informal education and learning in general. Hand in hand with this transformative process, ADMLMs (e.g., presentations, web sites, digital learning games, etc.) began to function regularly as information sources in diverse learning environments. Their usage is expected to increase in the future due to the growing role of information technology in educational systems (cf. European Commission, 2019). The speed of this trend was most probably accelerated even more by the covid-19 pandemic and related crisis in 2020. The latter forced policy makers around the globe to mandate the switch to some form of distance learning, which mostly required usage of, and access to, information and communication technology (Arshad, 2020; Bozkurt et al., 2020).

The inevitability of this trend is also apparent in recent reports showing that children in European countries use their smartphones and internet on a daily basis (Smahel et al., 2020). Similar findings have been reported in the United States, where the youngest group of children (0 – 8 years old) already use more than two hours of screen media per day on average (Rideout & Robb, 2020). Children's top activities include watching videos, web browsing, and playing digital games (Rideout & Robb, 2019, 2020; Smahel et al., 2020). Despite the natural assumption that such activities are related primarily to entertainment, they are also inherently connected with information seeking and information exposure; especially in educational contexts (e.g., De Freitas, 2018; Jones & Cuthrell, 2011, Neumann & Herodotou, 2020, Rideout & Robb, 2019). Due to this widespread, early-age exposure to digital media, it has become popular to label youth growing up with information technology as *digital natives* (Prensky, 2001). This label presumes their natural ability, and skills, to use technology effectively. Although such presumptions have turned out to be misleading stereotypes lacking solid empirical support (Smith, Kahlke, & Judd, 2020), the ubiquity of technology in children's everyday lives cannot be denied. In short, seeking and retrieving information via information technology and new media like ADMLMs is today second nature for children in formal (e.g., school) as well as informal scenarios (e.g., leisure time) and this phenomenon deserves appropriate attention.

These trends raise a number of practical and theoretical questions connected with ADMLMs: including ones about their design and the latter's effect on users. Such questions are of central interest in this dissertation. It focuses on the visual design aspects of information representation in ADMLMs and those aspects' effects on user's (i.e., children's) learning and motivation to interact with these instructional materials. In accordance with the approach by Buchtová (2014), who previously used it (the approach) specifically in cases involving learning games and simulations, ADMLMs are seen here as *dynamic systems of information representation*. Such systems "can attribute sound and visual characteristics to specific details, portray interrelations of its subsystems and simulate its behavior in various situations" and "might facilitate understanding of complex data" (Buchtová, 2014, p. 8; see

Section 2.1 for further details). These properties are generally shared by ADMLMs: including learning games and simulations. Present work focuses on the effects of *how* information is represented (i.e., the form or surface qualities of information) rather than on *what* information is represented (i.e., information content) in ADMLMs.

This is addressed in three related studies investigating the effects of three different visual design aspects of information representation within ADMLMs: particularly effects of *visual appearance* (VA), *visual dynamicity* (VD)*,* and *visual customizability* (VC) on children's knowledge acquisition and information behavior. The first study (i.e., visual appearance) is concerned with the effects of how the given learning materials *look*. This area is related to concepts like visual complexity and unity (see Beardsley, 1981; Dickie, 1989; Kulka, 1996) and deals with the relationships of all visual elements in the given learning environment (see Chapter 4). The second study (i.e., visual dynamicity) focuses on the effects of how the visually represented information in learning materials *moves*. It is particularly connected with the topic of animation, which can be considered a visually dynamic representation of information, and its usage in ADMLMs (see Chapter 5). The last study (i.e., visual customizability) investigates the effects of how the visual design in learning materials *adjusts* to these materials' users. In other words, it focuses on ADMLMs' ability to change their look based on user preferences (see Chapter 6). Despite the specific interests of each study, they pursue common goals together. These goals can be summed up in two umbrella research questions, which this dissertation addresses

> **RQ1:** Do the investigated visual design aspects of information representation in advanced multimedia learning materials influence primary school children's learning outcomes (i.e., knowledge acquisition)?
>
> **RQ2:** Are the investigated visual design aspects of information representation in advanced multimedia learning materials capable of affecting primary school children's information behavior?

Based on the chosen theoretical framework (see Chapter 2) and specific needs of each study, additional related variables were examined as well, including perceived attractivity, learning enjoyment, and gaze patterns (see Section 3.2).

Answering these questions can shine more light on the importance and function of visual design aspects as relates to information representation in ADMLMs. For instance, these answers can be specifically useful when producing such instructional materials because investigated design aspects are predominantly connected with higher costs. Knowing when and how to use enhanced visuals allows ADMLM designers to allocate production resources better, while keeping these materials instructionally efficient and beneficial for users (i.e., learners). This is also connected with the potential effects of selected visual design aspects on children's information behavior. For instance, situations where children hesitate to interact with learning materials due to perceived unattractive visual design can result in complete avoidance or limited interaction. Subsequently, any content-related qualities, including fine-tuned instructional design, might turn out to be of secondary importance. This is because surface qualities (i.e., visual design aspects) can impact users' interaction on a fundamental level.

From a theoretical perspective, the present thesis attempts to find out whether and how these visual design aspects and their potential effects might be approached using current cognitive-affective models of learning and information behavior. The knowledge acquisition process and information behavior are at the center of all three studies. Thus, the combination of approaches from the science of learning and information science serves as a common theoretical basis for the whole work (see Chapter 2). In addition, particular individual concepts are further theoretically approached and described with the insights from related fields like cognitive psychology or aesthetics.

This thesis' conclusions are based on empirical findings from all three studies. All of them use experimental, value-added design (Mayer, 2014b; 2019) in laboratory conditions as a general research method (see Chapter 3). The participants were 330 Czech children ($N_{studyVA} = 53$, $N_{studyVD} = 134$, $N_{studyVC} = 143$) attending the 3rd or 4th grade of primary school (8 – 11 years old). All studies, yet with different manipulations, use the same digital learning game as a core research instrument (see Section 3.1 for further details). The game was developed and tested as a part of this research. The game includes learning simulation features and also self-paced instructional slides. The intervention covers topics from the domain of biology including process of photosynthesis and water transpiration in case of plants. The intervention's format (i.e., digital learning game) was chosen for its multifaceted complexity which makes it a suitable representative of ADMLMs. To a certain degree it also allows for the application of present findings and conclusions to other related formats (e.g., interactive presentations, websites, etc.). The key measures focused on knowledge acquisition and information behavior-related variables, included comprehension tests, knowledge transfer tests, and free-choice behavior (see Section 3.2).

Overall, the topic of this dissertation is thematically related and close to educational science. Yet, its main emphasis is not on education as such, for example in the sense of *teaching* someone, but rather on the process of *learning*. That is, the acts of perceiving information and acquiring knowledge. Its primary focus, which is placed on the effects of visual design aspects in information representation in ADMLMs, places it somewhere on the border between information science and educational sciences: including the science of learning and instructional design. The present work also attempts to explore further the overlaps and interwoven concepts in both fields. As was already noted by Buchtová (2014) "with rapidly changing information channels on one side and technologies infiltrating educational environments on the other side, it is apparent that both fields [i.e., information science and educational science] need to focus on similar issues" (p. 11). Overall, it follows the premise that "enabling people to become better informed (learning, becoming more knowledgeable) is, or should be, the central concern of information studies" (Buckland, 2012, p. 5).

The results and conclusions of the individual studies part of the present dissertation can be of use for various professional groups. These include practitioners in education, school policy makers, instructional designers, graphic designers as well as the general public: like children's parents, who are often in charge of activities and the amount of time children spend with new media.

2 The Common Theoretical Background

As was already mentioned in the introduction, advanced digital multimedia learning materials (ADMLMs) belong to the category of multimedia instruction (Mayer, 2009, 2014c). The general goal of ADMLMs is to present information in a such way that it enables and facilitates users' learning. As new media, ADMLMs offer plenty of means how to achieve this goal. This is reflected in the number of varied formats; ranging from learning websites to digital learning games. Despite their variability, all of them must deal with some sort of information representation. There are two theoretical questions occurring in the context of selected visual design aspects' effects on knowledge acquisition and learners' information behavior. First, the most fundamental one is the relations between *information*, *knowledge,* and *learning*. The second question is whether and how the learning process and information behavior can be influenced by the visual design aspects of learning materials according to current state of knowledge. The following sections address these issues using approaches from information science and the science of learning.

2.1 Information, Knowledge, and Learning

In the scope of information science, "information" and "knowledge" are closely interwoven concepts and, in some cases, they may be treated as being synonymous (e.g., Case & Given, 2016; Frické, 2009). One of the useful approaches for investigation of information representation in ADMLMs is Buckland's (1991) classification of information. Compared to a traditional hierarchical view (e.g., Frické, 2009, see also Case & Given, 2016; Machlup & Mansfield, 1983) Buckland's (1991) approach allows us to make a clear distinction between the key terms: *information* and *knowledge*. Thus, it serves as a general framework for the present thesis.

Buckland (1991; 2012) classifies information into three categories. The first category of *information-as-thing* attributes the term "information" to physical (tangible) objects like journals, images, sounds and so forth. Although it is predominantly applied to classical printed documents, such as books and related traditional information systems like libraries, it does not omit computer-based information systems and processing of electronic data. Hence, ADMLMs also belong to this category of information-as-thing and they are seen as complex "systems based on physical representations of knowledge" (Buckland, 1991, p. 352; cf. Buchtová, 2014). All studies in this work can be considered as *partly system-oriented*; that means they look at matters from the perspective of an information system's properties and evaluate these properties' effects on users (e.g., Choo & Auster, 1993; Dervin & Nilan, 1986; Vakkari, 1999).

The second category of *information-as-process* is "concerned with the imparting of knowledge" (Buckland, 2012, p. 3) and refers to the process of informing someone. It is close to Belkin's and Robertson's (1976) notion about information's capability to change "the knowledge state of the recipient" (Case & Given, 2016, p. 82). This category is, in the context of the present thesis, identical to *learning*.

In the third category of *information-as-knowledge*, the term "knowledge" itself is attributed to the information what was processed by the human mind and acquired while learning (Buckland, 1991, 2012). In other words, the learning process (i.e., information-as-process) leads to the users' *knowledge acquisition* (i.e., information-as-knowledge). Within this scope, the terms *acquired knowledge* and *learning outcomes* are synonymous. This framework also makes knowledge solely subjective (intangible) and "strictly a phenomenon of the human mind" (Case & Given, 2016, p. 89). In order to communicate knowledge, it must be first expressed in a physical way (i.e., expressed as information-as-thing). For instance, in the educational context, learners' intangible knowledge states are typically expressed by means of requiring them to complete a test. The filled-in test allows for such physical (tangible) communication.

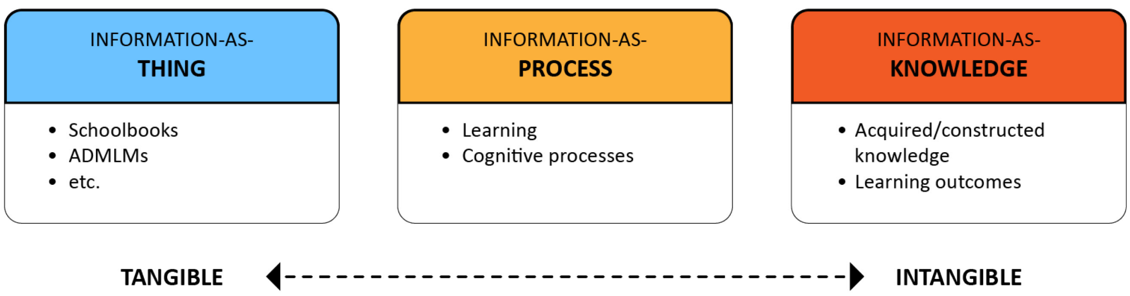

Figure 1. Categories of information in the learning context.

All three information categories listed above are of use when describing the process of learning with ADMLMs (see Figure 1). This is because information represented in them (i.e., information-as-thing) is mentally processed during learning (i.e., information-as-process) and results in acquired knowledge (i.e., information-as-knowledge). Against this background, the first research question can be posed as follows: can (intangible) acquired knowledge be affected by selected visual design aspects of (tangible) information representation in ADMLMs? The second research question is analogous: that is whether selected visual design aspects of (tangible) information representation in ADMLMs can influence users' interaction with these materials and change their information behavior?

The key category in this context is information-as-process because it includes users' interaction with ADMLMs, during which the mental processing of the information presented takes place, that is the learning itself. The process of learning is further addressed by the science of learning, which is concerned with the central, general question of 'how do people learn' and seeks to create a "theory of learning based on scientific evidence" (Mayer, 2009, p. 59). To meet this goal, the science of learning draws insights from multiple disciplines: including cognitive science, cognitive psychology, or education sciences (see Meltzoff, Kuhl, Movellan, & Sejnowski, 2009; Mayer, 2009; 2014c; Schnotz, 2014). Both the science of learning as well as information science presuppose the mental processing of represented information for learning to occur. Thus, contrary to information science, the "processing of information" included in learning is, within the present context, primarily related to human cognition and not to the processing of various tangible information sources by the information system (cf. Buckland, 1991).

Learning itself is defined as a change in a learner's knowledge caused by experience in a learning environment (Mayer, 2009). Such an environment is, in the present case, provided and represented by ADMLMs. One of the main goals of learning is *retention*; that is the learners' ability to remember the presented information. Despite its crucial role, a mere focus on retention leads to *rote learning*, resulting solely in the remembering of isolated bits of information as factual knowledge (Anderson et al., 2001). Within this simplistic view of learning as the mere addition of information to the human mind (Buckland, 2012; Dervin & Nilan, 1986), the "information is seen as a commodity that can be moved from one place to another" (Mayer, 2009, p. 16). In contrast, *meaningful learning* is "a change in what we knew rather than simple addition" (Buckland, 2012, p. 3). Apart from retention, the goal of meaningful learning is *transfer*; that is the ability to use acquired knowledge in novel situations (Mayer & Wittrock, 1996; Anderson et al., 2001; Mayer, 2014c). It goes beyond mere remembering (e.g., by understanding or applying the knowledge) and results in more organized, complex conceptual knowledge: including schemas and mental models (Anderson et al., 2001).

Meaningful learning is consistent with the *knowledge construction* view. This view stems from *cognitive constructivism*, which is based on the premise that knowledge is "actively constructed by the learners… which build on what they already know" (Wallace, 2008, p. 61). It presupposes that acquired knowledge is actively constructed within the learner's cognitive system and thus it "cannot be delivered in exactly the same form from one mind to another" (Mayer, 2009, p. 17). According to this view, learners aim to make sense of information presented in the learning environment (e.g., ADMLMs) and build from it a coherent mental representation (Anderson et al., 2001, Mayer, 2009). More robust mental representation (i.e., knowledge) allows better transfer.

Overall, this dissertation thesis builds on the presumption that ADMLMs' users are not passive recipients of information. Rather, they are thinking and sense-making individuals who are constantly constructing their own knowledge. Individual cognitive processes included in knowledge construction are further addressed by the cognitive models of learning with multimedia learning materials. The following section introduces the models used for the purpose of the present thesis. It discusses how selected visual aspects of information representation might affect learning according to these models. It also introduces the role of affective-motivational variables within this context.

2.2 Multimedia Learning, Human Cognitive System, and Affective-motivational Variables

As was already mentioned in the introduction, the present work relates to multimedia learning and multimedia instruction; domains to which ADMLMs belong. Within this context, there are generally two approaches for how to classify learning materials as multimedia. First, in the *presentation mode view* multimedia learning materials include multiple modes of information representation; for example, like the verbal and pictorial (Mayer, 2009, 2014c). As such, this approach is more related to Buckland's (1991) category of information-as-thing, because it focuses on the way how information is represented physically (i.e., tangible information). Second, in the *sensory modality view* multimedia learning materials include the usage of multiple senses: like the auditory and the visual (Mayer, 2009; 2014c). This approach is closer to the notion of information-as-process (Buckland, 1991), due to its focus on the way information is perceived by the individual. Both approaches are of use when considering human information processing during interaction with ADMLMs. For instance, from the perspective of the presentation mode view, a multimedia learning game uses multiple modes of information representation by presenting information as on-screen text and animated pictures. However, within the sensory modality view, such usage involves only the visual sense and not the auditory one. This might then have further implications for the learning process due to the inherent properties of the human cognitive system.

These properties and the ways people construct knowledge are depicted by cognitive learning models. The core model used for the purpose of this thesis is Mayer's (2009; 2020) *cognitive theory of multimedia learning*. It uses an approach similar to the influential *modal model* (Atkinson & Shiffrin, 1968) and divides human memory into multiple, interconnected memory systems (see Figure 2). Before it can be mentally processed, information represented in ADMLMs (i.e., information-as-thing) is first perceived by the senses (e.g., eyes) and stored for a very brief period in the *sensory memory*. Then it can enter the *working memory*, which centralizes the cognitive processes involved in knowledge construction. It provides a mental workspace for performing complex mental tasks needed for learning (Baddeley, Eysenck, & Anderson, 2020). During knowledge construction, working memory also interacts with the *long-term memory*, where new and prior knowledge is stored.

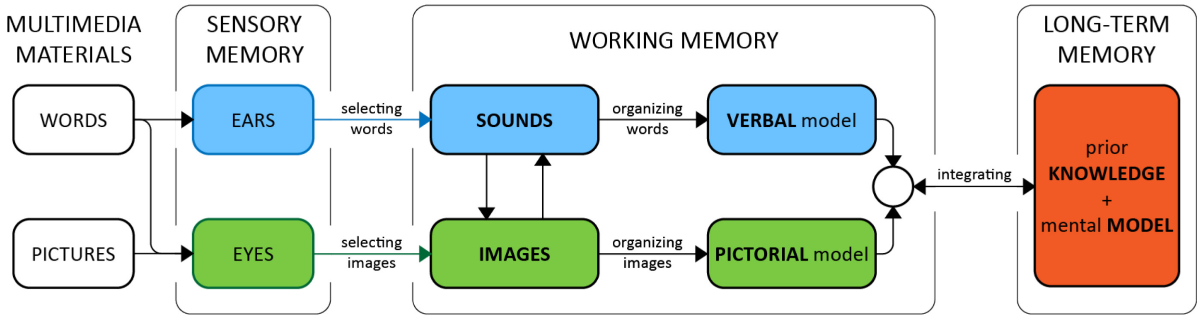

Figure 2. Schema of cognitive theory of multimedia learning. Adopted from Mayer (2009; 2014a).

Three assumptions underlie Mayer's model – *dual channels*, *active processing*, and *limited capacity*. Based on *dual-coding theory* (Paivio, 1986; 2014) and a *multicomponent model* of working memory (Baddeley, 1992; 2020b; Baddeley & Hitch, 1974), the cognitive theory of multimedia learning proposes that perceived information is processed in two separated channels: *visual/pictorial* and *auditory/verbal* (Mayer, 2009; 2014a). Each channel is related to a different sensory modality (i.e., eyes or ears) and representation mode (i.e., verbal or pictorial). Mayer's model also assumes that construction of coherent mental representations requires learners' active cognitive engagement in learning (Mayer, 2009; 2014a; Wittrock, 1989). The latter consists of three essential cognitive processes – *selecting* relevant information from sensory memory by paying attention to the material presented; *organizing* the information by building structural relationships among the selected elements in the working memory; and *integrating* the information with prior knowledge in the long-term memory (Mayer, 2014a).

These processes are inherently limited by the capacity of both processing channels (i.e., pictorial and verbal). For instance, the working memory can hold and process only a limited amount of information (Baddeley, 2020a; Mayer, 2014a; Miller, 1956; Paas & Sweller, 2014). According to the complementary *cognitive load theory* (Sweller, 1988; Sweller, van Merriënboer, & Paas, 2019), each learning task is connected with its *intrinsic cognitive load*. This type of cognitive load is caused by a natural task's complexity which is established by the irreducible number of interacting information elements included in the task (Paas & Sweller, 2014; Sweller, van Merriënboer, & Paas, 2019). The more interacting information elements that must be processed to complete the task, the higher the intrinsic cognitive load that occurs. For instance, in order to understand when it is optimal for plant to close its stomata, one must reconsider and get familiar with relations between water transportation, photosynthesis, energy consumption, and weather conditions; making it a fairly complex task.

Another type of load is called *extraneous cognitive load*. It is also caused by a task's high complexity; but in this case, it is due to poor instructional design, which requires "learners to use working memory resources to process elements that do not lead to knowledge acquisition" (Paas & Sweller, 2014, p. 38). For instance, ADMLMs about photosynthesis might include interesting, yet instructionally irrelevant, information (i.e., seductive details) about plants releasing oxygen during the night. Including such information increases the complexity of the learning task and potentially leads to extraneous cognitive load. The excessive number of interacting information elements in multimedia instruction might then lead to *cognitive overload* and hinder learning (Sweller, 1988; Sweller, van Merriënboer, & Paas, 2019). Therefore, the design of multimedia learning materials (e.g., ADMLMs) that successfully promote learning requires that one take into consideration the described inherent properties and limits of human cognitive architecture.

Such a requirement is reflected in a number of empirically proven *multimedia learning principles* (see Clark & Lyons, 2010; Mayer, 2009; 2020b). For instance, the fundamental *multimedia principle* states that learning materials using both words and pictures are more instructionally effective than learning materials using words alone (Butcher, 2014; Mayer, 2020b). This is due to better usage of both processing channels which enables working memory to encode knowledge in verbal as well as pictorial form and increases the number of integration inferences. The latter improves retention and transfer (Butcher, 2014). Other principles refer to the processing limits of the human cognitive system (e.g., modality, redundancy, segmenting). Some of the principles are, to a certain degree, related to the visual design aspects of the information presented (e.g., coherency, signaling, or spatial contiguity). For instance, according to the spatial contiguity principle, placing explanatory text near a corresponding picture helps reduce extraneous cognitive load and improve learning. However, it also affects the visual composition of the screen. Nevertheless, the potential effects of visual design aspects of ADMLMs investigated in this thesis are connected rather with noncognitive affective-motivational variables like enjoyment or interest, which are not acknowledged in Mayer's (2009) original model.

The *cognitive-affective theory of learning with media* (Moreno, 2005; Moreno & Mayer, 2007) addresses this issue by adding motivational processes to Mayer's original model (Mayer, 2009; 2020b). It serves as a mediator of the cognitive processes included in active, meaningful learning. According to this model, motivation can improve attention and cognitive engagement as well as result in better learning outcomes (e.g., Plass & Kaplan, 2016; see also Hidi & Renninger, 2006; Pekrun & Linnenbrink-Garcia, 2012; Plass & Kalyuga, 2019). The *integrated cognitive-affective model of learning with multimedia* (ICALM; Plass & Kaplan, 2016) then goes beyond this approach and expands previous models by stating affect as a separate processing channel (see Figure 3; Plass & Kalyuga, 2019). ICALM's core assumption is that "affective processes are intertwined with, and inseparable from, cognitive processes" (Plass & Kaplan, 2016, p. 150; see also Izard, 2009) needed for active learning (i.e., selecting, organizing, integrating). According to this view, the *core affect* (Russell, 2003), that is affective responses induced by the learning environment (e.g., ADMLMs), forms *emotional schemas* (Izard, 2009). These schemas are then integrated with the other mental representations into *affective-cognitive mental models* stored in the long-term memory (Plass & Kaplan, 2016).

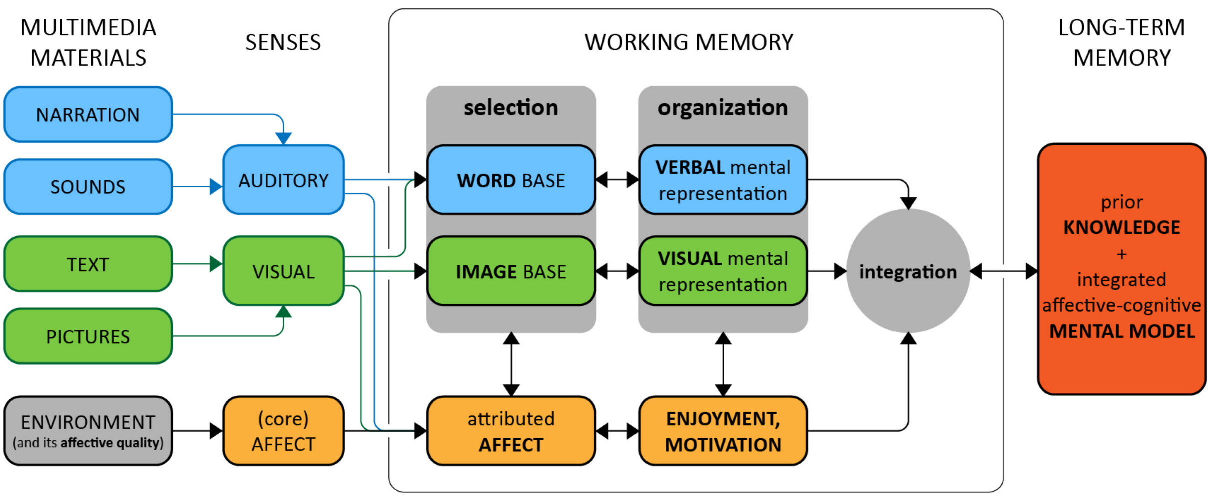

Figure 3. The integrated cognitive affective model of learning with multimedia. Adopted from Plass and Kaplan (2016).

Within the ICALM framework, the visual appearance, visual dynamicity, and visual customizability (i.e., the visual design aspects examined in this thesis) of information representation are potentially capable of impacting learning through the enhanced *affective quality* of ADMLMs. Affective quality is defined as stimuli's (e.g., ADMLM's) capacity to change core affect (Russell, 2003). This change in learners' core affect occurs when they interact with the learning environment and perceive the information represented in it. During the subsequent selection process resulting change in one's affect is attributed to its source (i.e., the stimuli), which is then regarded as a cause of this change. Such *attributed affect* (Russell, 2003) can lead to perceived *enjoyment*. Enjoyment is seen here as positive activating emotional state similar to *situational interest* defined as "focused attention and the affective reaction that is triggered in the moment by environmental stimuli" (Hidi & Renninger, 2006, p.3). ICALM assumes that learning can be fostered by such positive activating emotions (Plass & Kaplan, 2016; Pekrun, 2006; Pekrun & Perry, 2014). On the empirical level, enjoyment has been indeed generally shown to have a large effect on learning engagement and a medium effect on learning outcomes in the recent meta-analysis (Loderer, Pekrun, & Lester, 2020). ICALM presumes, that positive activating emotions, in general, are experienced by learners as motivation (Pekrun, 2006; Plass & Kaplan, 2016). These positive affective-motivational variables (i.e., enjoyment and motivation) then further guides attention to, and behavior towards, the stimuli (Russell, 2003; Plass & Kaplan, 2016). It stimulates interaction with the learning materials and can boost active and deep cognitive engagement in knowledge construction (Loderer, Pekrun, & Plass, 2020; Pekrun, 2006; Plass & Kaplan, 2016).

On one hand, enhanced affective quality of the stimulus via visual design aspects of information representation can stimulate higher cognitive engagement, foster active processing, and lead to improved learning outcomes. On the other hand, it is important to treat these visual design aspects in a such way that they do not conflict with the inherent limits of the human cognitive system. Such conflict would result in extraneous processing, which may cause cognitive overload. Cognitive overload would hamper learning. These fundamental opposing influences are related to every visual design aspect investigated in this thesis. Detailed theoretical reasoning behind each of them is further described in each study (see Chapter 4, 5, and 6).

The relatively new instructional design approach based on using alterations of various visual design aspects to impact learners' emotions and thereby enhance learning is referred to as *emotional design*[1] (Brom, Stárková, & D'Mello, 2018; Plass & Kaplan, 2016; Um, Plass, Hayward, & Homer, 2012; Wong & Adesope, 2021; see also Norman, 2004). Its general goal is to overcome described opposing influences by making these alterations in a "minimalistic" manner so as to keep learners' cognitive system from overloading and still positively impact their learning via affective-motivational variables at the same time. This is mostly achieved by avoiding the addition of extra information elements with high affective quality (e.g., interesting and appealing images) that are irrelevant to the learning task (i.e., seductive details; see Mayer, 2020b; Rey, 2012; Sundarajan & Adescope, 2020). Instead, emotional design focuses on altering only already existing information elements; thus keeping the cognitive processing demands the same or just minimally altered (see Figure 4).

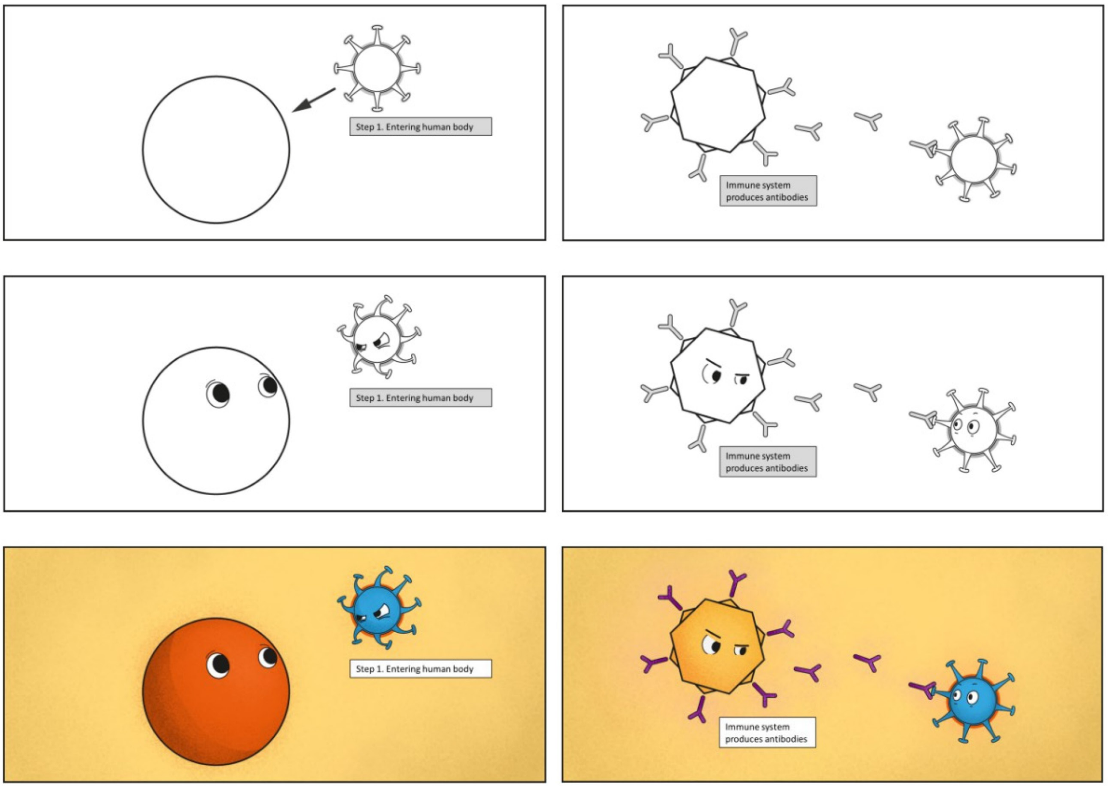

Figure 4. Example of minimalistic emotional design alteration: including change of colors and incorporation of anthropomorphizing features. Adopted from Brom et al. (2018).

[1] A better-suited term might be 'affective-motivational design' (see Brom, 2017). The term 'emotional design' is primarily used to maintain consistency with previous studies.

Emotional design alterations that have already been investigated include changing colors (e.g., Heidig, Müller, & Reichelt, 2015), typeface (e.g., Kumar, Muniandy, & Yahaya, 2016), shapes (Plass et al., 2019; Um et al., 2012), or incorporation of anthropomorphizing features (e.g., Mayer & Estrella, 2014; Park, Knörzer, Plass, & Brünken, 2015; Um et al., 2012). Although more evidence is still needed, some of them have been empirically shown to be potentially fruitful emotional design principles that positively affect learning outcomes (e.g., Gong, Shangguan, Zhai, & Guo, 2017; Mayer & Estrella, 2014; Ng & Chiu, 2017; Um et al., 2012; see also Brom, Stárková, & D'Mello, 2018). Against this background, one of present thesis' goals (RQ1) can be formulated as follows: to investigate whether visual appearance, visual dynamicity, and visual customizability can potentially serve as additional emotional design principles. Another goal is to address the general lack of data in this area in the case of primary school children (see Brom, Stárková, & D'Mello, 2018; Wong & Adesope, 2021). The relationship of these affective-motivational processes to children's information behavior, specifically their motivation to interact with the ADMLMs, is discussed in the following section.

2.3 Information Behavior and Affective-motivational Variables

Information behavior is an umbrella term for all sorts of situations and phenomena where individuals deal with information. The prominent definition of information behavior proposed by Wilson (2000) describes it as "the totality of human behavior in relation to sources and channels of information, including both active and passive information seeking and information use." (p. 49). Another definition states that "information behavior encompasses information seeking as well as the totality of other unintentional and serendipitous behaviors (such as glimpsing or encountering information)" (Case & Given, 2016, p. 6).

Overall, information behavior takes the individuals' perspectives and strives to understand their experiences with information in a broader context (Case & Given, 2016). Within such an approach, it is more important what users do with the information systems (e.g., ADMLMs) rather than what the systems do to the users. Some authors refer to this as the shift from *system-centered* (Choo, 1998) or *system-oriented* (Choo & Auster, 1993; Dervin & Nilan, 1986; Vakkari, 1999) studies to *user-centered* studies (Choo, 1998; Choo & Auster, 1993). An analogical parallel can be also found in the discussed research on multimedia learning. It unfolds around the notion that it is better to adapt technology to learners' needs, that is take a *learner-centered* approach, than to force learners to adapt to technology, that is *technology-centered* approach (Mayer, 2009; 2014c).

The group of users investigated in the present thesis are primary school children. Although the role of students is a well-studied one in the scope of information behavior (Case & Given, 2016; Julien & O'Brien, 2014), children tend to be rather an under-studied group (Bates, 2017; Case, 2006). However, during the last two decades, it has become an active area of research (Agosto, 2019). One stream of investigation has focused on youth information behavior in digital environments (Agosto, 2019; Todd, 2003). The present thesis can also be considered as belonging to this category due to its focus on interaction with ADMLMs. Yet, unlike the majority of previous information science literature, this work is interested in whether children might change their information behavior due to altered visual appearance, visual dynamicity, and visual customizability (i.e., visual design aspects).

Information behavior includes three closely-related concepts: *information need*, *information seeking* and *information use* (See Case & Given, 2016; Bawden & Robisnon, 2012). Information need can be briefly defined as the recognition of some gap in one's knowledge (Bawden & Robinson, 2012; Case & Given, 2016; Wilson, 1981), which can also be elicited by other less conscious motivators like curiosity (Case & Given, 2016). Information need is followed by the process of information seeking defined as "the purposive seeking for information as a consequence of a need to satisfy some goal" (Wilson, 2000, p. 49). It presupposes working with various formal as well as informal information sources and systems including ADMLMs. Use of information resulting from seeking (i.e., information use) "consists of the physical and mental acts involved in incorporating the information found into the person's existing knowledge base" (Wilson, 2000, p. 50). Therefore, it is closely related to learning and knowledge construction views (see Section 2.1).

Within this framework, the possible effects of investigated visual design aspects on information behavior lie in their potential ability to impact ADMLM users' affective-motivational states (see Section 2.2). Although attention given to affective-motivational processes remained rather secondary (Savolainen, 2015; Case, 2012), it has been part of information behavior debate and research for several decades (e.g., Dervin, 1983; Dervin & Nilan, 1986; Wilson, 1981). For instance, Wilson (1981) acknowledged the contribution of affective needs to motivation for information-seeking behavior. One of the first substantial steps towards encompassing the affect into the scope of information behavior research was Kuhlthau's (1991; 2017) model of *information search process*. This model is based on Kelly's (1963) and Bruner's (1973; 1986) theories emphasizing the interplay of cognitive and affective processes (Savolainen, 2015). Together with Dervin's (1983) propositions, Kuhlthau (1991; 2004) views the process of information seeking as a constructive, sense-making activity done in order to acquire knowledge. This activity "involves the whole experience of the person, feelings as well as thoughts and actions" (p. 362). Similarly, Nahl's (2007) information behavior model of s*ocial-biological information technology* also combines affective, cognitive, and sensorimotor systems (Savolainen, 2015).

Overall, the interconnectedness of affective and cognitive processes proposed by these models makes affective-motivational variables an integral part of information behavior (Savolainen, 2015; Nahl & Bilal, 2007). Affective-motivational processes can support, and also hamper users' information need; they can foster or interrupt the information seeking process; and they can directly influence the information use process (see Nahl, 2007; Nahl & Bilal, 2007; Savolainen, 2015; Wilson, 1981). Within this framework, users' information behavior can be potentially influenced by the visual appearance, visual dynamicity, and visual customizability of represented information. That is due to potential capability of these visual design aspects to improve affective quality of ADMLMs and impact users' interaction with such embellished materials. For instance, if users find the represented information visually attractive and stimulating, it may boost their motivation to engage further with the information system (i.e., ADMLMs). In the opposite case, it might result in lower enjoyment, disgust, or boredom: leading to loss of motivation to continue interacting with the system or to complete avoidance (see Loderer, Pekrun, & Plass, 2020). In such cases, any instructional design might be of secondary importance because the visual design aspects of represented information would function as a "gatekeeper" regardless of the content's instructional qualities. Therefore, users' information behavior can easily become crucial factor in the context of learning.

One of the goals of the present thesis (RQ2) is to investigate whether, and to what degree, selected visual design aspects of information represented in ADMLMs are truly capable of influencing users' (i.e., children's) information behavior. Available evidence for these effects is rather scarce and limited. For instance, Cooper (2002) found that visually presented information plays a significant role in the case of primary school children's information behavior. That is because children tend to base their information seeking on visual browsing strategies rather than an abstract analytical approach (Cooper, 2002). In their evaluations of new media formats like websites, children are sensitive to overall visual appearance and visually dynamic presentation of information (i.e., animations). Plus, they can express preferences for customizable visuals (Bilal, 2005; Large, Nesset, Beheshti, Bowler, 2004). Some studies (Agosto, 2004; Fidel et al., 1999) have shown that visual design aspects like overall visual appearance might play a significant role in adolescent users' preferences for selection of information sources. However, most of these studies work with small sample sizes in combination with qualitative methods. Plus, they do not focus directly on affective-motivational variables and the knowledge acquisition process. In the present thesis I attempt to address these limits.

2.4 Summary

In summary, this work investigates the effects of ADMLMs' visual appearance, visual dynamicity, and visual customizability (i.e., visual design aspects) on users' learning outcomes, information behavior, and additional related variables including perceived learning enjoyment, attractiveness of graphics and gaze patterns. ADMLMs are seen here as complex systems of information representation (i.e., information-as-thing; Buckland, 2001; 2012) presenting words and pictures with the intention to promote learning. Knowledge, which is an outcome of learning, is seen as solely subjective intangible information that is processed, constructed, and stored in the human mind (i.e., information-as-knowledge). The process of knowledge construction (i.e., information-as-process) is approached with the use of the cognitive-affective model of learning with multimedia (Moreno, 2005; Moreno & Mayer, 2007) and the integrated cognitive-affective model of learning with multimedia (Plass & Kaplan, 2016), which are based on Mayer's (2009; 2020b) cognitive model of multimedia learning. These cognitive-affective models state that affective-motivational processes are inseparably intertwined with cognitive processes included in learning. Affective-motivational processes are also integrally interconnected with users' information behavior (Nahl, 2007; Nahl & Bilal, 2007; Savolainen, 2015; Wilson, 1981); this is any behavior related to dealing with information sources (Wilson, 2000).

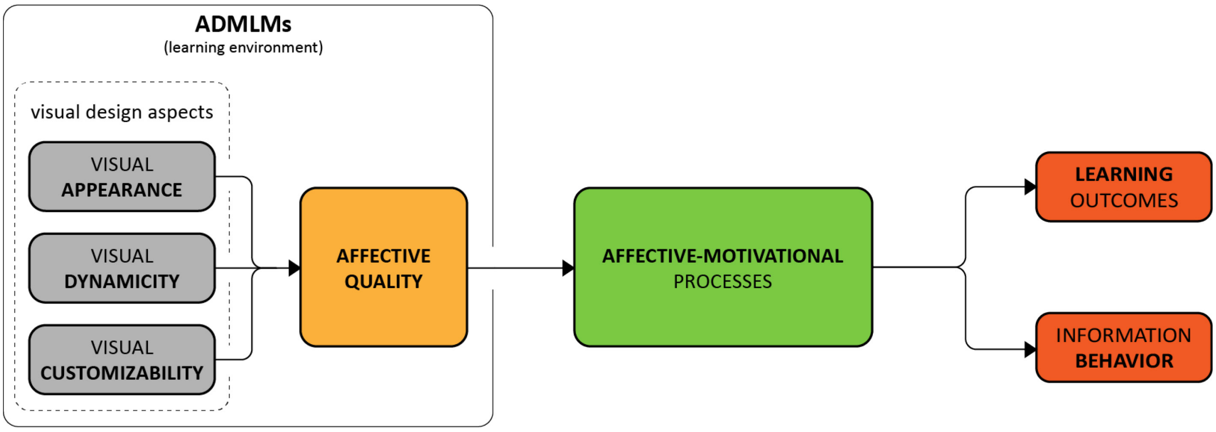

Figure 5. Summary scheme of present theoretical framework.

Within this framework, the role of selected visual design aspects (visual appearance, visual dynamicity, and visual customizability of information representation in ADMLMs) is twofold (see Figure 5). First, they can potentially influence the learning process itself by impact on learners' affective-motivational processes. Second, they can potentially influence users' information behavior and enable or prevent interaction with ADMLMs in the first place. The following chapter describes the experimental instrument used to examine these two possible roles of ADMLMs' visual design aspects. It is followed by an overview of the general methodology and the common measures used in all three studies.

3 The Common Methodology

All studies in this work use the *value-added research* approach proposed by Mayer (2014b, 2019). Research into features like usage of the spoken or printed word, explanatory feedback, pre-training of key concepts, and others (see Mayer, 2014b; 2019) falls into this category. Value-added research's general goal is to find out which features of a learning environment (i.e., educational games in the present case) improve learning and which do not. This research approach compares the effects of different versions of the same game: one with an added target feature and the other without it. The following section describes the design and content of the experimental instrument, that is digital learning game, which was developed and used for the purpose of this work.

3.1 The Digital Learning Game as an Experimental Instrument

Since all studies in this work use digital learning games as their main experimental instrument, the present thesis can be considered part of digital game-based learning (DGBL) research. This research area has gained a lot of attention, because video games in general are very popular among various age groups: including children (Rideout & Robb, 2020; Smahel et al., 2020). It is often believed that DGBL has the potential to improve learning outcomes via enhanced learning experiences (e.g., Clark, Tanner-Smith, & Killingsworth, 2016; Tsai & Tsai, 2020). Yet, a growing body of research into DGBL reveals this topic's complexity and the need to investigate the effects of specific game features on learning processes and outcomes (Mayer, 2020a; Plass, Homer, Mayer, & Kinzer, 2020). Also, experimental studies with children participants in the context of DGBL are still scarce (see Hainey, Conolly, Boyle, Wilson, & Razak, 2016; Plass, Mayer, & Homer, 2020 for reviews). Moreover, on a more general level, the minimalistic digital learning simulation game used in this work serves as a suitable representative of advanced multimedia learning materials (ADMLMs). All in all, addressing the research questions can provide us with more insights into how to use and design various types of ADMLM; including digital games that support learning.

Developing a target experimental digital learning game for this work's research purposes allowed us to control fully all the game's features, collect data during gameplay (e.g., time stamps) and manipulate the game's content and visual design aspects for each study's needs. Besides its theoretical implications (see Chapter 2), this research also potentially has practical implications for developers of ADMLMs and other multimedia learning formats. For instance, the apps and games development team[2] at the public TV service, Czech Television, and its children's channel *ČT :D* showed interest in the present research, due to its focus on the effects of ADMLMs' visual design aspects. The latter, in practice, generally require higher production costs. However, the instructional or affective-motivational function of these aspects is unknown. The ČT :D team also consulted on the target experimental game's design. Striving for ecological validity, it was modeled and designed based on the complexity, graphics, and animation type (see Figure 6) used in games on ČT :D's website (http://decko.cz/hry), which is visited by thousands of Czech children on a daily basis. The website's interface was also used to run the target game during the intervention. From the game development and instructional design perspective, the target game is a mouse-controlled, single-user, single-session, simulation mini-game.

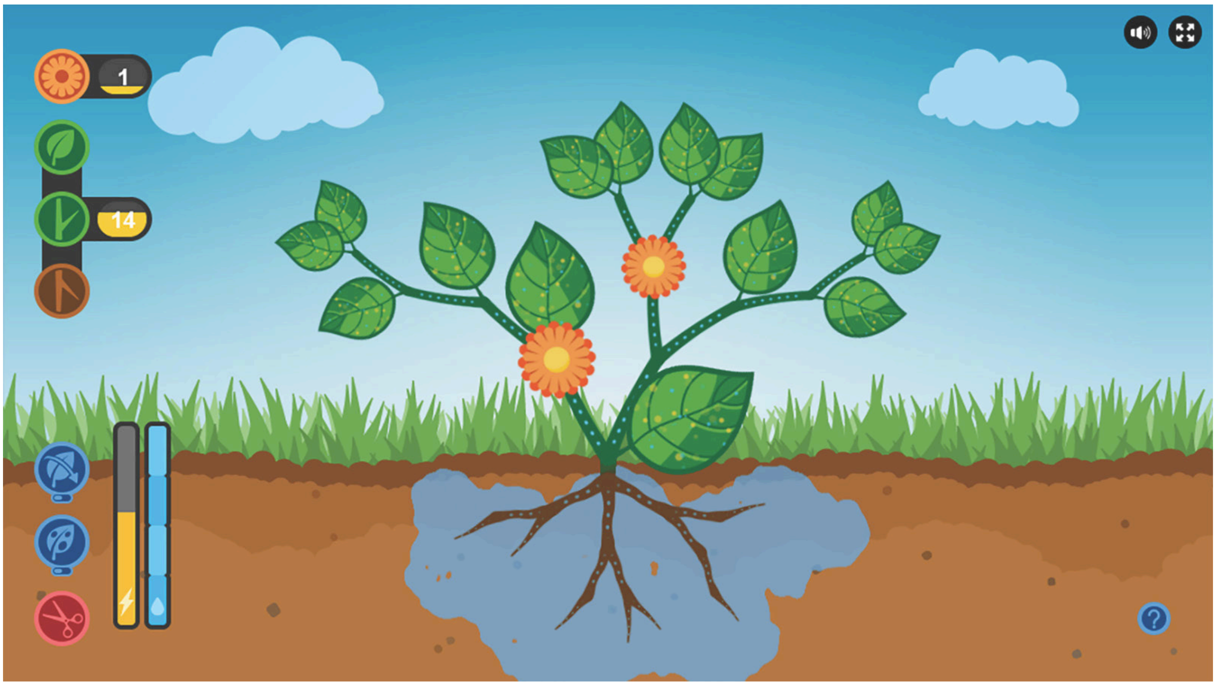

Figure 6. A screenshot from the basic version of the target learning game (i.e., learning environment).

[2] Development and New Media Department (decko.cz and ctart.cz), Czech Television©

The game's instructional goal is to acquire a mental model for water transport in plants and for photosynthesis. The biological domain was chosen during the development stage based on its supposedly higher gender neutrality, which makes it similarly appealing for girls and boys. Also, it was expected that children in the target age group (i.e., 8-11 years old) might already have some prior knowledge about the topic of photosynthesis. However, they would possibly lack understanding of its robust mental model connected to water transportation (based on curricular standards). This allowed us to introduce children to the new concept during the intervention and measure differences in acquired knowledge. To avoid possible misconceptions (including misconceptions caused by the intervention itself) and ensure instructional validity, game content was discussed and developed in cooperation with an expert (see Table 1) in the field of biology.

The instructional topic was covered in six linearly-ordered levels. Each level had its own sub-goals (e.g., to grow three extra leaves) and started with several narrated, self-paced tutorial slides (see Table 2 and Attachment A for further details). Such an arrangement is reflected in the learning intervention's instructional design, which was based on switching between the presentation of target instruction in tutorials and the interactive simulation game, where learners practiced and fixated concepts presented. These tutorial slides consisted of static images, text labels (see Figure 7), and narrations explaining the target instructional message (see Table 2). They also contained the task (sub-goal) for the subsequent gameplay and provided information about game controls. The user proceeded by pressing an on-screen button (there was no option to go back). Each tutorial section was followed by an interactive part, that is the game itself.

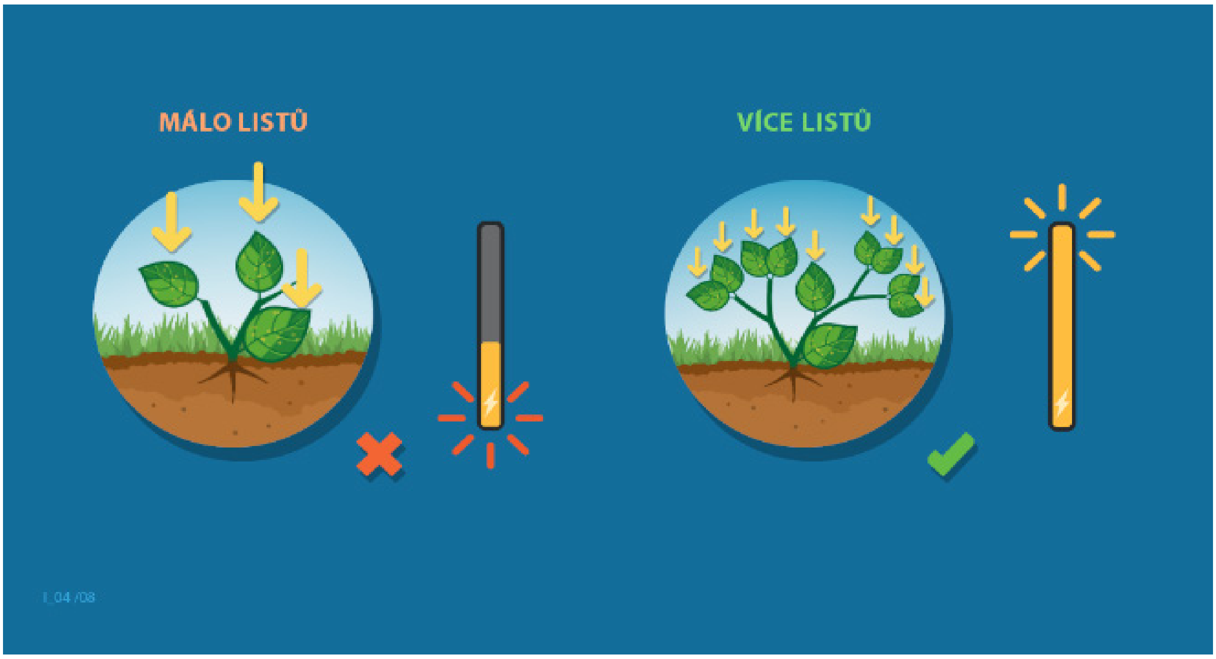

Figure 7. Sample slide from the tutorial part; left – too few leaves; right – more leaves (in Czech).

Table 2

Content of basic version of the game levels and tutorials

Lvl.	No. of slides	Task and practice in the game	Information in slides and narrations
1.	8	To familiarize oneself with control buttons and the energy indicator; to use captured energy to grow the first four leaves	Plants "capture" energy from the sun (i.e., photosynthesis occurs). This energy is needed for growth. • In this instructional game you will learn how photosynthesis works and grow your own plant. • The first thing, which you need to know, is that plants capture and store energy from the sun thanks to the green pigment in their leaves. That is what we call photosynthesis. • You will need enough energy to make your plant live and grow. This is what your energy indicator looks like. • The more of the green leaves your plant has, the more energy it captures. • The leaves and stems are grown using these buttons. • And this number shows you how many things you can grow. • Your first task is to arrange for your plant to grow three new leaves (four leaves in total).

Lvl.	No. of slides	Task and practice in the game	Information in slides and narrations
2.	10	To observe the consequences of insufficient water transport (the plant withers) and grow the plant further	Plants transpire water and thereby transport it from the soil. • On this indicator you can see how much water is in the plant. • Water evaporates from the plant through the leaves. • Thanks to evaporation, the plant draws water up from its roots. Water then flows from the roots through the whole plant up to leaves. • Most of the water evaporates except for that used for photosynthesis. The more leaves a plant has, the more water that evaporates from it. • Beware though. If the plant has too few roots, more water evaporates from it than it can absorb from the ground. • The plant must grow not just leaves, but also roots. Otherwise, it will not have enough water and will wither. • Roots are grown using this button. • Try to play with the plant a little bit. First, grow more leaves, and then let it wilt a bit. After that, grow more roots, so the plant can replenish the lost water.
3.	10	To observe the consequences of the opening/closing of stomata (in terms of energy captured and water transported from the soil)	Plants control transpiration by opening/closing stomata on their leaves. This also changes the speed of photosynthesis by altering the flow of carbon dioxide into the leaves. • The plant can stop evaporation. • It has vents on leaves – stomata – through which water evaporates. • The plant can open and close its stomata. • If the stomata are closed, evaporation stops. This also stops the absorption of water from the soil. This can be advantageous; we will discuss why later. • Beware! The plant draws carbon dioxide from the air and turns it into oxygen. Carbon dioxide flows into the plant through the stomata. • If the stomata are closed, carbon dioxide does not enter the plant and photosynthesis stops. • In summation: closed stomata result in not only evaporation stopping, but also stopped photosynthesis. • The stomata are controlled using this button. • Try to play with the plant a bit. Open and close the stomata and see what happens with evaporation and photosynthesis. You can also grow one or two new leaves.

Lvl.	No. of slides	Task and practice in the game	Information in slides and narrations
4.	10	To regulate water transportation during changing weather by opening/closing stomata; to capture enough energy to grow a first flower	The speed of transpiration depends on the weather and temperature. To conserve water, stomata must be closed when it is too hot. • Good weather for an ordinary plant is sunny and a bit warm. Photosynthesis is fast in good weather. If the plant has enough roots, it can draw more water than that which evaporates – so it replenishes water supplies. • However, excess heat is not very good for plants. • In excess heat, the plant cannot replenish its water supply. Evaporation occurs rapidly and draws a lot of water from the soil. Energy is captured more slowly. • It is advantageous for the plant to close its stomata during excess heat; especially, when there is too little water in the soil. Although this stops photosynthesis, the water does not evaporate either. • The main points are as follows: if the stomata are opened and the weather is good, the plant gains water. This is not the case when there is too much heat. • If there is excess heat, it pays to close the stomata. • The flower is grown using this button. • Your task is to open and close the stomata according to weather conditions a grow a first flower for the plant.
5.	6	To regulate water and nutrient transportation during changing weather; to grow the plant further, including adding more flowers	Water transports nutrients from the soil; these nutrients can enhance plant growth. • The plant flourishes if it can draw and absorb minerals dissolved in water. • In order to draw and absorb minerals, water must flow through the plant. • Beware: your plant can be eaten by bugs. However, you can squash them. • Your task is to grow two extra flowers.

Lvl.	No. of slides	Task and practice in the game	Information in slides and narrations
6.	7	To regulate water and nutrient transportation during changing weather via the stomata and turning the leaves; growing the plant further and producing more flowers	The leaves can turn more/less toward the sun, which enables subtler regulation of water transport in different weather conditions. • The plant can also fight rapid evaporation by turning its leaves away from the sun. This reduces the warming up of the leaves and slows evaporation. • Beware. Leaves turned away from the sun also capture less light than do leaves facing the sun. Thus, photosynthesis slows down. Similarly, photosynthesis slows down if there is cloudy weather. • You turn the leaves using this button. • Your task: control the stomata and turn the leaves; gain maximum energy and grow as many flowers as you can within the next three minutes.

Note. Narrations are directly translated from the original Czech texts in order to maintain the instructional content.

The game part consisted of one screen (Figure 6) with no text (except for numbers). Working with a set of graphic user interface (GUI) buttons, learners used this screen to manage the plant's growth (see Table 3). Gameplay consisted of growing or cutting stem parts, leaves, and roots; regulating energy and water levels; controlling stomata on the leaves; reacting to changes in weather (heat, clear sky, cloudy, rain; see Figure 8); and applying the instructions and concepts from the tutorials (e.g., closing stomata on the leaves when it is too hot to prevent water loss) to meet the respective sub-goal. In each level, the learner was also guided by an additional, limited set of narrated hints (e.g., "the plant cannot capture more energy, you have to grow it bigger"). The hints were controlled by experiment administrators based on a pre-specified protocol. This protocol outlined reoccurring gameplay situations in which the administrator had to activate the hint (e.g., the player has a small plant that is unable to capture more energy due to its small size). This ensured that all participants were provided with a limited and controlled set of instructional hints based on their progress.

Table 3

List of graphic user interface elements and their functionality

Button	Function
	Growing new flowers for the plant
	Growing new leaves for the plant
	Growing new stems for the plant
	Growing new roots for the plant
	Controlling the opening and closing of the stomata
	Controlling the turning of the leaves away or towards the sun (only in the 6th level)
	Used to remove parts of plant already grown
	Replays the voice narration of the sub-goal for the current level
	Indicator of the current water level in the plant

Button	Function
	Indicator of the current level of energy at the plant’s disposal
	Number of parts the user can afford with current level of energy at the plant’s disposal

The game’s design also followed several multimedia learning principles (Mayer 2009; 2014c; 2020b): the *segmenting principle* (level segmentation, self-paced slides); the *pre-training principle* (main concepts introduced in the slides); and the *modality principle* (narrated slides and hints during gameplay). The *self-testing principle* (Mayer, & Fiorella 2015) was also followed with the incorporation of self-testing segments after the second, fourth and sixth levels. Therein, learners answered three, yes/no questions on knowledge acquired from the previous two levels (see Figure 9). After each question, the learner received corrective feedback. The game ended when players managed to grow the plant to a point where it could capture enough energy for it to bloom or flower. The whole gameplay took about 20 minutes (i.e., the tutorial and game parts combined). Its difficulty was calibrated during the pilot studies. Children generally did not have any problem accomplishing all the levels’ sub-goals and finishing the game.

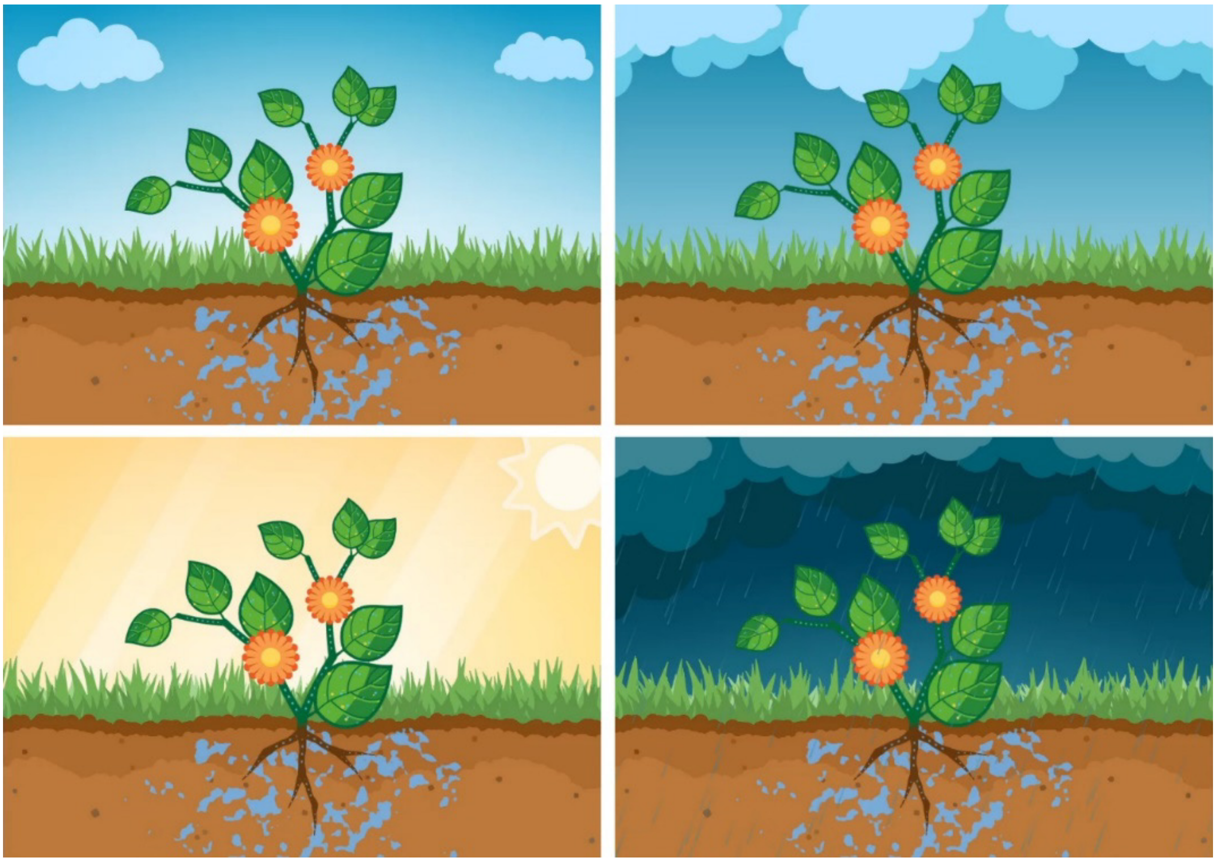

Figure 8. Different weather conditions in the game: Top-left – clear sky; top-right – cloudy; bottom-left – heat/hotter weather; bottom-right – rain.

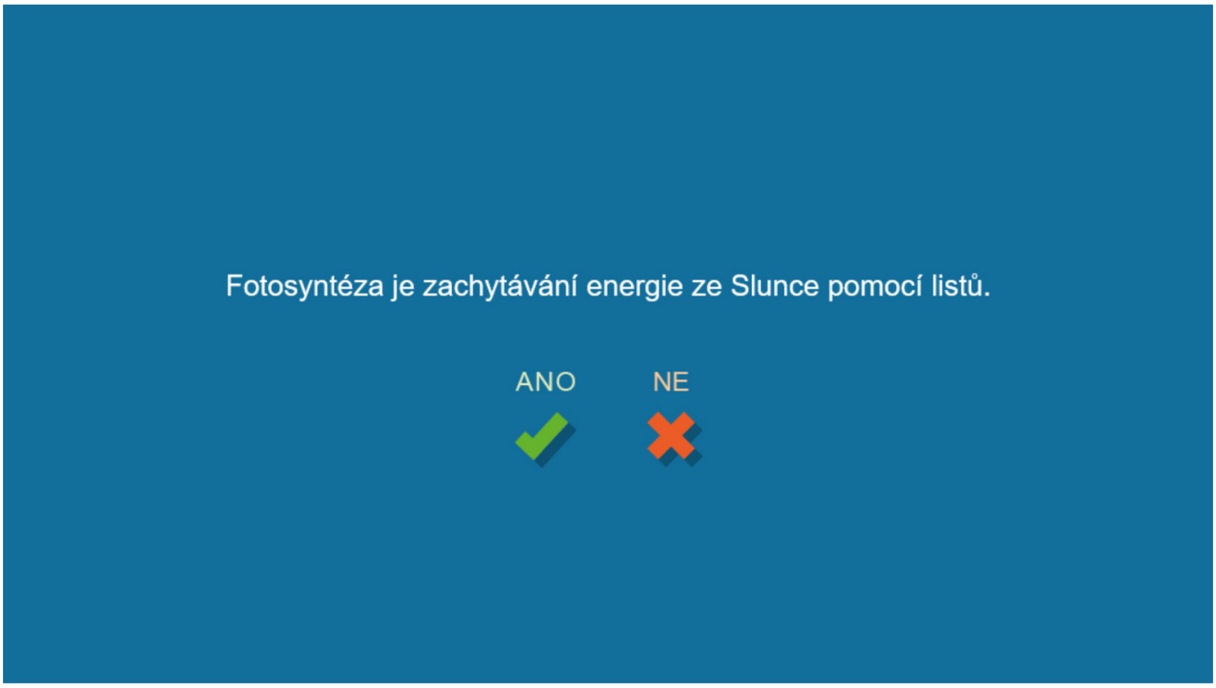

Figure 9. Screenshot of the self-testing segment: Question – “Photosynthesis is the capturing of energy from the sun with the help of the plant’s leaves.”; below – yes/no on-screen buttons (texts in Czech).

3.2 Measures

The following section focuses on the common measures used in all three studies. The measures were designed, calibrated and piloted on different child audiences (to ascertain that finding were not influenced by ceiling or floor effects) prior to this research (Brom, Hannemann, Stárková, Javora, 2018). The procedures in all three studies were also partly derived from procedures used and polished during the pilot testing. Although these measures were used in all three studies, they underwent minor changes from study to study based on previous experiences and the individual study’s needs. This was most apparent in the coding phase where the usage of different coding scales turned out to be more convenient for the coders (e.g., using mostly integers instead of decimals). Therefore, some measures (i.e., prior domain interest, prior domain knowledge, comprehension, transfer) slightly differed from study to study, yet the measured variables and the concepts they reflected remained identical.

3.2.1 Control variables

Prior domain interest is defined as voluntary re-engagement with domain content (Hidi & Reininger, 2006). In the present work, it probed children's voluntary willingness to engage in activities involving plants. It served as a control variable for checking whether the experimental and control groups were balanced in terms of prior interest in the game's theme. Semi-structured interviews were used for inquiry; asking children about their interest in a) studying about plants or doing plant-related activities in school (e.g., "Do you like learning about plants?"); b) books or films about plants (e.g., "Do you watch films about plants?"); c) plants in nature (e.g., "Do you like observing plants outdoors?"). The answers were always coded by two coders using audio recordings and based on a set rubric (e.g., "participant has directly stated that she has already learned about photosynthesis in school"; "participant likes to examine books about plants"). This differed partly in each study due to minor adjustments and different requirements between the studies. In the Visual Appearance study (see Chapter 4), the coder could assign up to 1 point for each of the three areas (i.e., total possible scale 0–3; inter-coder agreement r = .83). For the Visual Dynamicity Study (see Chapter 5), up to 4 points could be assigned for the first area (i.e., a) and up to 3 points for each of the other two areas (i.e., total possible scale 0–10; inter-coder agreement: r = .97). In the Visual Customizability Study, the extra question concerning animals was included because animal selection during gameplay was an important manipulation element in the experimental group (see Chapter 6). One coder could assign 2–4 points depending on each of the areas (i.e., a–d; total possible scale 0–12; inter-coder agreement r= .89).

Prior domain knowledge was examined during a structured interview with two cueing questions. It consisted of two measures: retention of domain-related **terms** and comprehension of domain-related **concepts**. Participants were first shown two multiple-choice questions and asked to select the correct answers: "Which words relate to plants? A) photosynthesis, b) transpiration, c) hydrogen, d) carbon dioxide"; "Why do plants have leaves? A) they help them withstand the wind, b) they breathe in oxygen and create carbon dioxide, c) they capture energy from the sun, d) they help plants 'absorb' water from their roots, e) they capture mineral substances from the air." The multiple-choice questions were not graded, as they primarily served as cues. The interviewer then asked about the reasons behind children's choices. Two evaluators using audio recordings then graded the answers based on a pre-defined rubric: Visual Appearance Study (terms: r =.95; possible scale 0–3; concepts: r = .83; possible scale 0–9); Visual Dynamicity Study (terms: r =.98; possible scale 0–3; concepts: r = .94; possible scale 0–9); Visual Customizability (terms: r = .84; scale 0–8; concepts: r = .80; scale 0–10). Due to the inclusion of items covering expert-level prior knowledge, attainment of the total score amount was not expected.

Additional control variables included **age**, **grade**, **place of residence** (urban vs. rural areas), and **time-on-task** (i.e., interfacing with the slides plus gameplay).

3.2.2 Learning enjoyment

This affective-motivational variable was measured by means of self-reports using a 6-point *smiley scale* (Figure 10). The scale's asymmetry was intentional because pilot projects have shown that children tend predominantly to use the positive part of the symmetrical scale. To avoid potential ceiling effects the positive part of scale was extended. Also, the symmetric 5-point scale was insufficiently sensitive; whereas, a symmetric 7-point scale appeared to be too complex and confusing for children this age. Such limits also prevented use of more complex measures (e.g., the Visual Aesthetics of Website Inventory; Moshagen & Thielsch, 2013). It was assessed using smiley scales printed on a sheet of paper along with two statements: "I enjoyed learning how a plant works."; "I enjoyed learning from the slides." (r_{VA} = .69; r_{VD} = .50; r_{VC} = .63). Children were asked to circle one of the smileys based on the statement's perceived validity.

Figure 10. Smiley scale used for evaluations.

3.2.3 Attractiveness of graphics

This variable, focused on the aesthetical evaluation of the materials, served as an additional affective-motivational measure (in the Visual Appearance Study and the Visual Dynamicity Study). It was also assessed by means of self-reports using an identical 6-point smiley scale (see Figure 10). Children were asked "Did you like how the game looked?" Smileys were printed on paper cards (6x6 cm) or displayed on the computer screen and children were tasked with selecting one of them based on their preferences.

3.2.4 Free-choice behavior

The classical behavioral measure referred to as *free-choice behavior* was also used (e.g., Deci, Koestner, Ryan, 1999; Habgood & Ainsworth, 2011; Patall et al., 2008; Ryan & Deci, 2000). Children directly re-engaged in interactions with one of the versions of the target game (i.e., the experimental or the control one) or the comparison game (depending on the given study's procedure; see below) during the free-choice period at the end of each intervention. Participants were told by the administrator that there is still some time left before sessions ended and that they could choose whether they wanted to continue interacting with one of the versions (i.e., experimental or control) of the target learning game (in the Visual Appearance Study and the Visual Dynamicity Study) or the comparison game (in the Visual Appearance Study and the Visual Customizability Study; see below). The proportion of participants who voluntarily chose to spend time with any of the options was measured.

The role of this measure is twofold within the current framework. First, within the context of the CATLM and ICALM frameworks, it serves as an additional affective-motivational measure. Evaluating the attractiveness of graphics and learning enjoyment with self-reports may not reflect users' motivation to interact with target materials when more options are available. Voluntary choice in the free-choice period is better suited for this purpose. Second, the free-choice behavior measure also revealed children's information behavior(s). That is because the free-choice period allowed children to seek information based on their needs and preferences (see Section 2.3), when confronted with multiple ADMLMs options. On one hand, this interconnectedness of motivation and information behavior does not enable us to draw any implications about the relationship between them. On the other hand, free-choice behavior still enabled us to examine the impact of investigated visual design aspects on information behavior/motivation.

3.2.5 Comparison game

A game from the Czech TV children's channel website (http://decko.ceskatelevize.cz/hry) served as a baseline for comparison with the target game (except for in the Visual Dynamicity Study, due to that study's specific requirements; see Chapter 5) in the free-choice period (see above). It also helped to familiarize participants (i.e., children) with the experimental environment and activities needed for the main intervention (e.g., mouse navigation). The comparison game's topic was astronomy (see Figure 11), and thus it was instructionally irrelevant to the target game (see Section 3.1). The goal was to obtain a comparison of ecologically valid relevance. Therefore, an "average" game from a website visited by a substantial portion of the Czech Republic's child population was picked. It had an average online rating on the website and appealed (on average) similarly to both boys and girls; as was checked during the pilot programs. Such properties make it comparable to the target game and suitable for the purpose of the present work.

Figure 11. Sample screenshot from the comparison game. With permission from the Development and New Media Department (decko.cz and ctart.cz), Czech Television© (texts in Czech).

3.2.6 Comprehension

This measure focused on the understanding of key concepts was assessed using a drawing test (see Figure 12). It was part of the pre-testing phase, complementing the control variable of prior domain knowledge (see above); as well as the post-testing phase, complementing the transfer measure (see below). Participants were introduced to the test with the following instructions: "Imagine you are drawing a **picture** for a botany textbook for your classmates. The image should **show** how photosynthesis works. Draw or write in the following image what happens during photosynthesis **in a way that your classmates can easily understand**. You can also draw info bubbles, arrows, and other symbols." (emphasis in the original). After the instruction, participants were given a sheet of paper with a printed picture to fill in (see Figure 12). The possible scale was 0–9 (based on the scoring rubric, see Table 4), where 9 points represent a teacher-expert level, while child "experts" can be expected to gain around 4–5 points for their answers (based on conducted pilot programs and curricular standards). The tests were, in the case of all studies, graded by two independent evaluators and showed substantial agreement: Visual Appearance Study (pre-comprehension: r = .99; post-comprehension: r = .97); Visual Dynamicity Study (pre-comprehension: r = .97; post-comprehension: r = .95); Visual Customizability Study (pre-comprehension: r = .99; post-comprehension: r = .99).

Table 4

Scoring rubric for the comprehension drawing test

Concepts	**Max. score**[a]
Water is explicitly depicted flowing upward from the roots.	1 point
Water transpiration from the leaves is depicted.	1 point
Carbon dioxide is correctly drawn as an input (for photosynthesis).	1 point
Oxygen is correctly drawn as the output (of photosynthesis).	1 point
A sun ray/light is clearly depicted as playing a role in the photosynthesis process (e.g., the ray ends up on a leaf into which carbon dioxide enters and oxygen leaves).	1 point
Stomata are depicted.	1 point
It is depicted/mentioned that leaves can turn toward/away from the sun.	0.5 points
It is mentioned that more roots can absorb more water.	0.5 points
It is mentioned that nutrients can be absorbed through water.	0.5 points
Sugar is mentioned/drawn as a product of photosynthesis.	0.5 points
Chlorophyll is mentioned/drawn.	0.5 points
Oxygen is depicted as part of the cellular breathing process.	0.5 points

Note. The scoring rubric was created during extensive pilot projects before the studies began (n > 40).

[a] Participants could earn the following number of points for a correct drawing; or 0.25, 0.5, or 0.75 points for a partially correct solution.

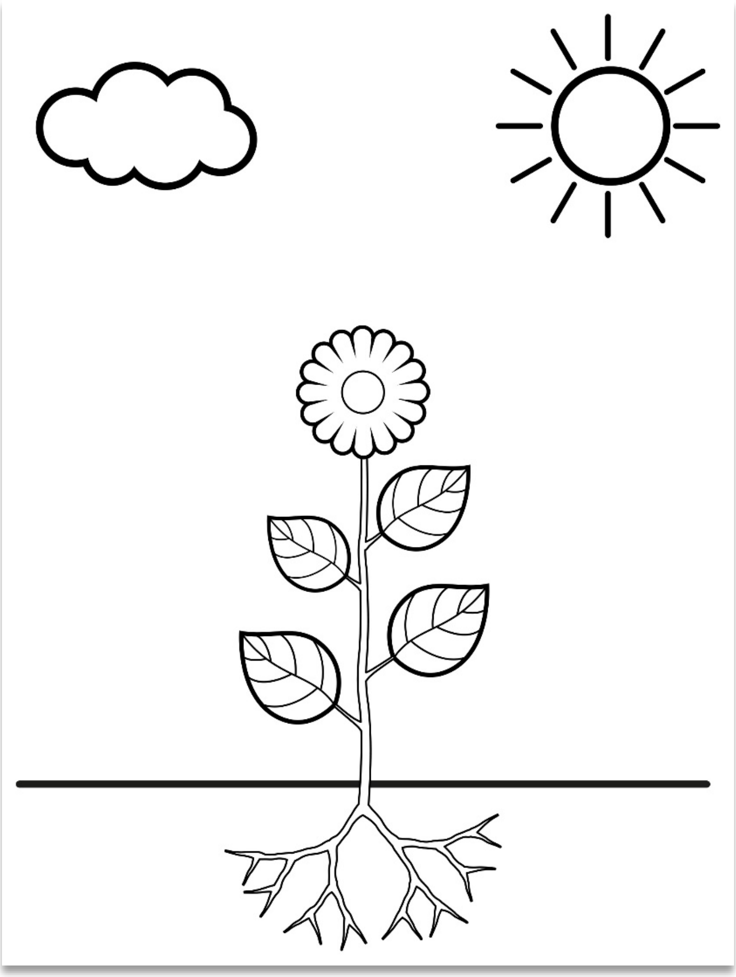

Figure 12. Drawing test.

3.2.7 Near transfer

It examines the quality of the constructed mental model reflected by the ability to use acquired knowledge in new, but related, situations (see Section 2.1) immediately after the learning intervention. Due to time constraints and to avoid potential cueing of what should be learned and remembered during the intervention, it was assessed only in the post-testing phase. Up to seven questions were used for oral inquiry (see Table A1), such as: “If the plant’s stomata are constantly closed what will happen? Say everything that comes to mind.” Or “What should the plant do if there is too little water in the soil?” A list of solutions was compiled for each question. Participants could receive up to 1 point for every solution (or 0.25, 0.5, or 0.75 points for a partially correct solution). A maximum score would be awarded for a professional expert-level answer, while the child “expert-level” stands at around mid-range values (based on conducted pilot projects and curricular standards). Children could express the ideas in their own words (exact wording was not required). Vague answers based on general prior knowledge were not rewarded. The tests were always evaluated[3] by two independent raters based on audio recordings: Visual Appearance (total possible scale 0–25; between-rater agreement r = .98); Visual Dynamicity (total possible scale 0–23; between-rater agreement r = .96); Visual Customizability (total possible scale 0–26; between-rater agreement r = .88).

[3] The possible scales vary slightly among the individual studies due to minor changes in evaluation rubrics for reasons of higher convenience. Still, they reflect the measure of identical concepts.

PART II. – Individual Studies of Selected Visual Design Aspects

4 Visual Appearance Study

4.1 Study Background

Visual appearance of interactive materials influences user experience. For example, for adults and adolescents, visual appearance affects perceived usability of a mobile phone (Sondergger & Sauer, 2010) or websites' trustworthiness and credibility (Robins & Homes, 2008). Adult users form stable aesthetic impressions of webpages after tens of milliseconds long exposure (Lindgaard, Fernandes, Dudek, & Brown, 2006; Tractinsky, Cokhavi, Kirchenbaum, & Sharfi, 2006). Visual aesthetics play an important role in user evaluation of interactive systems in general (Tractinsky et al., 2006).

Child audiences are less researched. It is nevertheless known that children can distinguish between different visual styles (although this varies among different age groups) and make aesthetic judgments and justifications that influence their preferences (Chang, Lin, & Lee, 2005; Large & Behesti, 2005; Machotka, 1966; Rodway, Kirkham, Schepman, Lambert, & Locke, 2016; Wang & Lin, 2019). Could children's preferences for different visual styles influence learning processes and information behavior when studying from ADMLMs like digital learning game? Harrington (2012) showed that higher visual fidelity can indeed positively affect children's learning outcomes when studying from a 3D virtual learning environment. However, aside from that, little is known about possible connections between children's aesthetic preferences and learning processes in the context of ADMLMs. For instance, the research of digital game-based learning including primary education (Hainey et al., 2016; Mayer, 2020; Zainuddin, Chu, Shujahat, & Perera, 2020) identified only a few experimental studies examining the impact of game elements on learning effects.

Design principles of multimedia learning (e.g., Mayer, 2014c, 2020b; see also Section 2.2) make it clear that changing a visual design can substantially impact how learners process instructional messages. The effects can be positive or negative and improve or harm learning; depending on the modifications. For example, *spatial contiguity principle* (presenting corresponding texts and pictures closer to rather than far from one another) and *signaling principle* (including visual cues that highlight the organization of key information), both improve learning (see Mayer, 2014c, 2020b). On the other hand, embellishing learning materials with seductive details, generally hampers learning (i.e., the coherence principle; see Rey, 2012; Mayer, 2014c, 2020b; Sundarajan & Adescope, 2020). When improving visual design, one can, of course, facilitate learners' cognitive processing by following these and similar design principles. However, what if we have two visual designs equally optimized by multimedia learning principles, but one is less and the other more visually appealing (i.e., emotional design alteration; see Section 2.2)? Will one of them enhance learning and influence information behavior? For practical purposes, this is also an important question, because these two designs can have notably different development costs.

From the perspective of present theoretical framework, attractive aesthetical design improvements (i.e., that do not intentionally capitalize on established multimedia learning principles but rather focus on attractiveness in and of itself) of ADMLM's visual appearance have potentially two conflicting effects mentioned in Section 2.2. They can potentially stimulate positive affective-motivational processes, motivate leaner's information behavior towards interaction with ADMLMs, increase learners' cognitive engagement and thereby facilitate learning. In contrast, they can impose extraneous cognitive load on learners (Sweller, Ayeres, & Kalyuga, 2011), redirecting limited cognitive resources (needed for learning to occur) to the processing of learning-irrelevant things. Consequently, some types of attractive improvements to visual design can be beneficial to learning; whereas other types may have no effect or be even detrimental (depending on whether the positive influence outweighs the negative one) and fail to serve as emotional design (see Figure 13). The theories make only limited predictions on whether the former or the latter will happen.

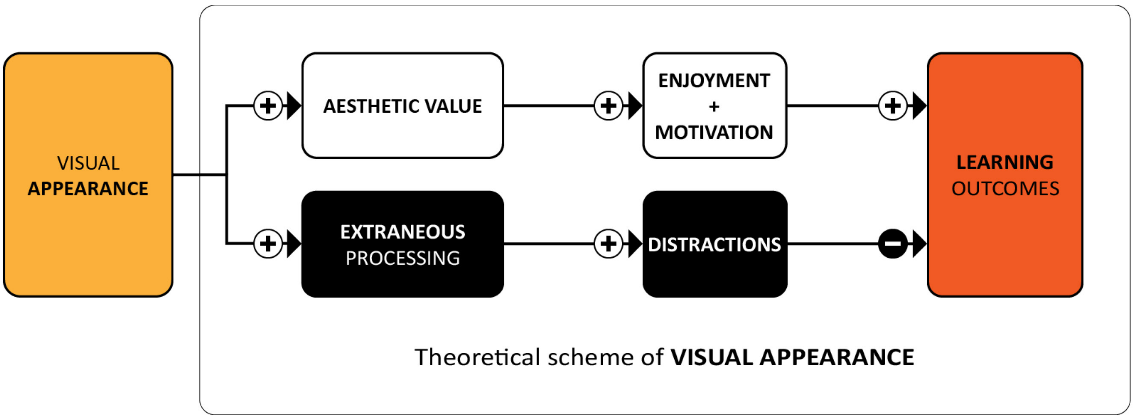

Figure 13. Theoretical scheme of the possible contradicting effects of visual appearance.

Several studies examining the effects of “minimalistic” emotional design alterations (See Section 2.2) of visual appearance have been conducted in the context of learning from computerized slides, animations, and hypermedia materials. Redesign of schematic and/or grey-scale versions of computerized slides, animations or hypermedia materials by adding anthropomorphic faces, incorporating round shapes, and/or pleasant colors was shown to facilitate learning (e.g., Chiu, Jong, & Mok, 2020; Mayer & Estrella, 2014; Gong et al., 2017; Ng & Chiu, 2017; Schneider, Häßler, Habermeyer, Beege, & Rey, 2019; Um et al., 2012; see also Brom, Stárková, & D’Mello, 2018; Wong & Adescope, 2021 for meta-analyses). Whether this was due to affective-motivational processes is still not clear, but some of these studies suggests that at least part of the learning improvement might indeed be of affective-motivational origin (e.g., Ng & Chiu, 2017; Schneider, Nebel, Beege, & Rey, 2018; Um et al., 2012; but see also Mayer & Estrella, 2014).

According to the most recent meta-analyses (Brom, Stárková, & D’Mello, 2018; Wong & Adescope, 2021) only three such studies focused on young children. Chiu et al. (2020) have reported improved retention and children’s enjoyment in case of using face-like shapes and warm colors. Ng and Chiu (2017) showed that colorful anthropomorphisms enhanced children’s problem-solving skills and motivation[4]. Schneider, Häßler, et al. (2018) showed that both modest and high amounts of anthropomorphic features enhanced motivation, but only the former increased learning outcomes. This

[4] The paper by Ng and Chiu reports erroneous means (Table 1 therein), but correct descriptive data has been received by email (dating from 23 April 2018) that indeed confirms positive findings (Javora, et al., 2019)

suggests that a high number of anthropomorphic features may increase complexity in terms of cognitive load theory (hereafter refered to as *CLT complexity*) too much.

One possibly limiting aspect of this type of "minimalistic" manipulations is decreased ecological relevance. Multimedia learning materials can be perceived from an aesthetics point-of-view more holistically, i.e., as a system of visual relationships rather than a set of independent elements (Arnheim, 1992; Gombrich, 2000; Kulka, 1996). In practice, graphic designers aiming for visually appealing materials work with categories that reflect these holistic visual relations: including color harmony, compositional balance, and overall visual style. Application of design principles such as "make all shapes round/anthropomorphic rather than square/schematic" would still be subordinated to these categories. Mere focus on separated visual elements can generate visual style inconsistency and, in the end, harm the overall aesthetic value of the final design. Therefore, this study investigates the effects of a more holistic, yet still "minimalistic", approach to visual design.

This approach was derived from Kulka's (1996) theory of aesthetic value, which expands on the work of Beardsley (1981) and Dickie (1989). He posits unity and visual complexity as variables of *aesthetic value* and puts them in a mutual relationship. As concerns pictorial presentations, *unity* is defined as an overall inner order and consistency of all visual elements. To alter unity in present target experimental game's (see Section 3.1) visual design, the following aspects were manipulated: color hue, color saturation, color gradients, image quality, line thickness, line quality, and shape quality (see Figures 14 and 15). Low unity was achieved through the disorderly usage of different levels of these variables among and within different pictorial elements (e.g., heavy saturated versus low saturated elements, precise shapes combined with loose shapes, different line qualities and line thicknesses, low image quality in some parts but high quality in others, gradients randomly combined with solid colors, etc.); whereas, high unity was achieved by keeping consistency and order among these variables across all visual elements in the picture (e.g. continuous and consistent color saturation, all shapes precise, all shapes with the same line quality and consistent thickness, constant image quality, dominant usage of solid colors, etc.).

Visual *complexity* is defined as a number of visual elements (Kulka, 1996). It does not reflect just the number of semiotically separable objects in a picture, but rather the level of detail within the picture. In our game, it is reflected using different renderings (e.g., detailed blossoms or leaves defined by more shapes; see Figures 14 and 15). Visual complexity is to be distinguished from CLT complexity (see below). Kulka (1996) posits the relationship between unity and visual complexity as one that is multiplicative. Therefore, more successfully united and more visually complex pictorial elements lead to higher aesthetical value for the picture.

Although this theory was originally intended for the fine arts domain[5], it is possible, by manipulating levels of its variables, to develop varied but clearly distinctive designs. For example, Deng and Poole (2012), who used a similar approach to visual design, have shown that order and complexity (i.e., Kulka's aesthetic categories) influence users' shopping motivation and preferences in the case of e-commerce websites. For present purposes, it is important that more "visually complex and united" design is posited to be more aesthetically valuable (Kulka, 1996).

It is possible to increase visual complexity (i.e., in the terms of Kulka) and the CLT complexity (i.e., as described by cognitive load theory) separately. For instance, when a designer increases a graphical level of detail without adding information elements, the number of visual elements (i.e., Kulka's visual complexity) rises, but the number of information elements (i.e., CLT complexity) stays the same (see Figure 14). It can be argued that the addition of simple anthropomorphisms is also such an example: adding a few anthropomorphic features (e.g., schematic eyes and mouth) increases the visual complexity but may not increase (or only slightly increases) CLT complexity, because changes have been made within just one information element. However, the study by Schneider, Häßler, et al. (2018) suggests that, in the case of children in Grades 5-6, too many anthropomorphic features (that is, eyebrows, nose, hands, hairs, and legs in addition to eyes and mouth) may also increase complexity in CLT terms; as measured by increased extraneous load.

[5] Kulka also works with the variable of intensity, which we are intentionally leaving out. This is because it is suited specifically for fine arts, and it is hardly applicable in the context of learning materials.

The holistic visual design approach chosen in this study manipulates both unity within and among individual elements (i.e., inner order and consistency) and visual complexity (i.e., level of detail) at the same time. It also tries to minimize growth of CLT complexity. To isolate the effect of aesthetic value, both designs (one with a supposedly high aesthetic value and another with a low aesthetic value) follow multimedia learning principles to the same extent: The designs do not differ, at least not intentionally, in features stemming from established principles of multimedia learning.

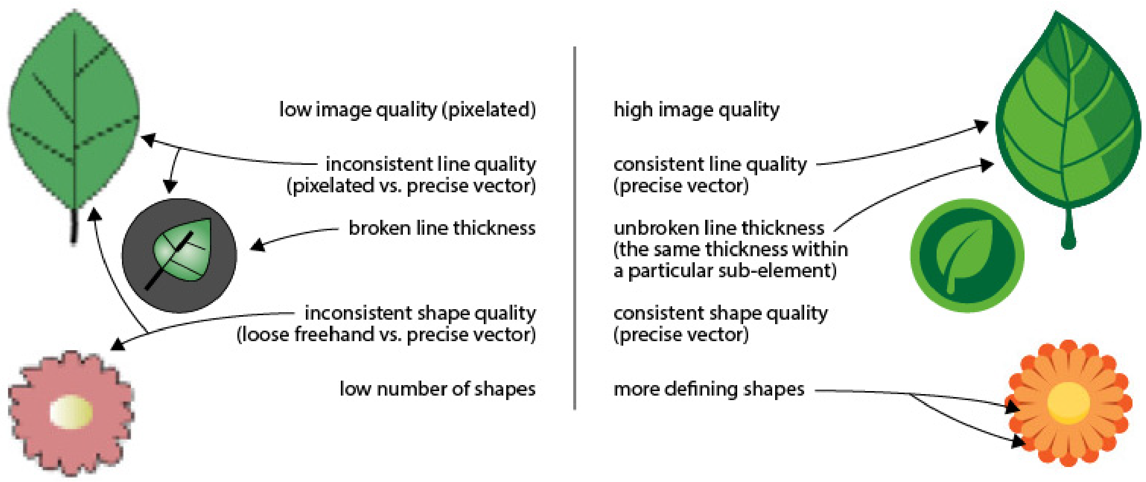

Figure 14. Visual complexity and unity: Left: a leaf, a GUI button, and flower having low complexity and unity. Right: a leaf, a GUI button, and flower having high complexity and unity (note that the level of unity and complexity also varies among the elements). From the CLT perspective, one can argue that no additional information element has been added when increasing the visual complexity of the flower and leaf.

4.2 This Study – Visual Appearance

This study examines the effects of a holistic, appealing visual design (i.e., overall visual appearance) for a learning game on perceived attractiveness, learning enjoyment, free-choice behavior, and learning outcomes. Children studied photosynthesis and water transport in plants. They did this for about 20 minutes: either from a learning game with a supposedly *low* aesthetic value design (control version) or one with a supposedly *high* aesthetic value (experimental version). Children's preferences for the two graphical designs, motivation to interact with one version of the game, and learning outcomes were assessed.

Based on the reasoning above, two hypotheses were put forward:

H1: Children will enjoy learning from the experimental high aesthetic value version (i.e., high unity and complexity) of the target game more (H1a), and they will consider the experimental high aesthetic value version of the target game more attractive than the control low aesthetic value version (i.e., low unity and complexity). (H1b).

H2: Children will be more motivated to interact with it compared to the control low aesthetic value version or comparison game

Because it is not possible to derive, based on prior empirical evidence and from theories, a directional prediction regarding learning outcomes, the following exploratory goal was put forward:

Exploratory Goal: What is the effect of overall visual appearance on learning outcomes?

4.3 Method

4.3.1 Participants

Participants included 53 Czech children (M_{age} = 9.45; SD_{age} = 0.75; 23 girls), recruited through calls on the website for Czech TV's children's channel. Thirty-nine children were from urban areas (large cities or their suburbs); 8 children were from rural areas (small, rural cities or the countryside); 6 did not report their residence. Children were randomly (with gender and residence type balanced) assigned to high (*n* = 26) and low (*n* = 27) aesthetic visual design groups ("low" and "high" for brevity). Two children were excluded on technical grounds; two due to mental disabilities. Children received a LEGO set worth ~20 EUR and Czech Television souvenirs for their participation.

4.3.2 Materials

Target game's (see Section 3.1) versions differed only in their elements' visual appearance (i.e., visual unity and complexity); composition and content were identical. The two visual designs of the game (see Figure 15) were piloted intensively (*N* = 45) prior the experiment. This was important for manipulation check ensuring measurable differences between the groups, because children generally had a strong tendency to evaluate both versions as highly visually appealing.

At the beginning of the experimental session, children also played a comparison game (see Section 3.2.5) from the Czech TV children's channel website, which had graphics complexity similar to the target game (Figure 11).

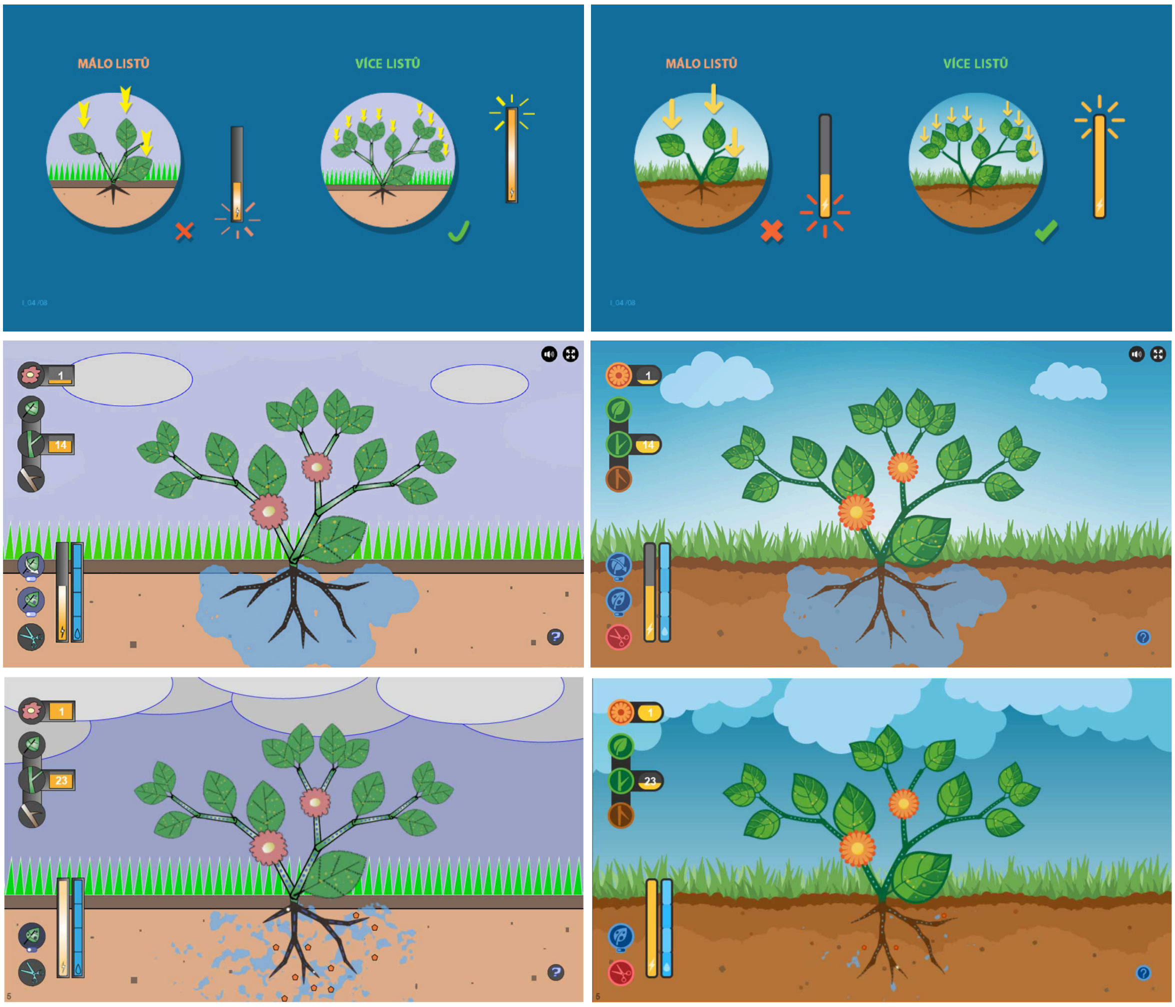

Figure 15. Visual designs used in Visual Appearance Study: Left – low aesthetic value; right – high aesthetic value. Top – slides; middle – clear sky; Bottom – cloudy (texts in Czech language).

4.3.3 Procedure

Children were tested one at a time in a lab. After an introduction, they were familiarized with our 6-point smiley scale. Next, they played the comparison game from the Czech TV children's channel website for 5 minutes. These two activities also served to familiarize children with the experimental environment (e.g., some children were somewhat nervous at the very beginning; something we wanted to overcome). Thereafter, their domain knowledge and developed interest were asked about. Next, they completed the comprehension (drawing) pre-test. Instructions were read for children who were not strong readers. Thereafter, they played the target game (either high or low version) for about 20 minutes. Next, they rated their learning enjoyment using the smiley scale. They were then given comprehension (drawing) and transfer (oral) tests. Next, they were shown one screenshot from the game version they played (see Figure 15) and rated the appeal of the game's visual style using the smiley scale. Afterwards, they were (for the first time) shown the second version of the graphics (see Figure 15) and rated the latter's visual style. They were then shown both versions of the graphics at the same time and rated them (i.e., children saw both figures next to each other on the screen). Finally, they were given the choice to continue playing, for a few minutes, either the comparison game or the target game with high or low graphics. The whole session took about an hour.

4.3.4 Data analysis

All tests were computed in R version 3.5.0 (R Core Team, 2018). To check whether the groups were balanced with respect to gender and origin (urban vs. rural areas) a chi-squared test was used. Otherwise, between-group differences were analyzed through unequal variances t-tests. Data was generally not normally distributed, but t-tests are robust as regards normality violations (e.g., Rasch, Teuscher, & Guiard, 2007). To ascertain the findings' stability, the t-tests results were compared to results obtained from Wilcoxon rank sum tests with continuity correction. In one case, the groups were not balanced with respect to a control variable, so ANCOVAs with this control variable as a covariate were used as well. All alternative test results were similar to the main (t-test) results with one exception. This exception is mentioned further on in this text. Effect sizes are expressed in terms of Cohen's d, which can be classified into small ($d \sim 0.2$), medium ($d \sim 0.5$), and large ($d \sim 0.8$) (Cohen, 2013).

4.4 Results

4.4.1 Control variables

Descriptive results of all control variables are presented in Table 5. Dependent variables, except for attractiveness ratings, are presented in Table 6. The attractiveness ratings are presented in Table 7 and Table 8.

The groups were balanced in terms of all control variables, except for prior knowledge of concepts related to the instructional domain. Therefore, this variable was also considered a covariate in ANCOVAs (along with comprehension gain and transfer as dependent variables).

Table 5

Control variables, including t-tests or chi-squared tests results

	Control group		Exp. Group							
	Mean	SD	Mean	SD	*t*	*df*[a]	*p*	*d*	95% CI *d*	
Domain interest	1.06	0.68	0.97	0.56	-0.55	49.91	.586	-0.15	-0.70	0.40
Terms prior	1.30	0.61	1.53	0.50	1.52	49.68	.134	0.42	-0.14	0.98
Concepts prior	0.85	0.42	1.23	0.76	2.25	38.70	**.030**	**0.62**	0.05	1.18
Compre. prior	1.35	1.33	1.60	1.66	0.59	47.83	.558	0.16	-0.39	0.72
Time on task	18.92	3.00	18.49	2.50	-0.56	49.68	.576	-0.15	-0.71	0.40
Age	9.52	0.89	9.39	0.57	-0.65	44.44	.517	-0.18	-0.73	0.37
	Boys	Girls	Boys	Girls	x^2					
Gender	16	11	14	12	0.01	1	.904			

[a]*Df* corrected for unequal variances.

4.4.2 H1: Learning enjoyment and visual attractiveness

Self-reported learning enjoyment strongly correlated with the score of the attractiveness evaluation of the first picture shown to children (i.e., visual design of the game they played) (experimental group: Spearman's $r(26) = .491$, $p = .011$; control group: Spearman's $r(27) = .622$, $p < .001$), yet significant between-group difference for enjoyment was not found (Table 6). Ratings of enjoyment are thus partly associated with ratings of the graphics' attractiveness, but a higher attractiveness of the graphics does not necessarily imply higher learning enjoyment, as measured by self-reports. Thus, H1a has not been supported.

However, children clearly preferred the experimental (i.e., high aesthetic value) version of the graphics and found it more attractive (Table 7 and 8). During the graphics evaluation period, children in control group were given a low graphics screenshot as their first picture to judge. In the experimental group, children were first given a high graphics screenshot. When these judgments of the first screenshot seen (i.e., when the children still did not know about existence of the second version) were compared between conditions, children having the more aesthetic version rated their graphics higher (the first row of Table 8). Next, children were introduced to the complementary version of the graphics and rated it. The two evaluation scores were compared for each child (i.e., scores of the low and high graphics versions for each child; within-subject comparison; the second row of Table 8). Children clearly favored the high graphics version again. Finally, children were given both images at the same time (Figure 15) and rated both versions. Again, they preferred the high aesthetic value version (the last row of Table 8). Therefore, H1b has been supported.

Table 6

Dependent variables – learning outcomes and enjoyment – including t-tests results

	Control group		Exp. Group							
	Mean	SD	Mean	SD	*t*	*df*[a]	*p*	*d*	95% CI *d*	
Compreh. Post	2.31	1.52	1.96	1.36	-0.86	49.39	.392	-0.24	-0.80	0.32
Compreh. Diff.	0.92	1.21	0.37	0.58	-2.13	35.83	**.040**[b]	**-0.59**	-1.16	-0.02
Transfer post	10.36	2.65	9.92	2.75	-0.59	50.73	.558	-0.16	-0.71	0.39
Enjoyment[c]	1.33	0.48	1.62	0.85	1.48	39.12	.148	-0.41	-0.96	0.15
					x^2					
Free choice					21.27	2	**< .001**			

[a]*Df* corrected for unequal variances.

[b]The result is similar when tested using ANCOVA with prior knowledge of concepts used as a covariate (*p* = .041) or Wilcoxon rank sum test (*p* = .061). The result is not significant though when the Holm-Bonferroni correction for multiple comparisons is used (Holm, 1979).

[c] Lower values mean higher enjoyment; *d* is thus reverse coded.

Table 7

Attractiveness ratings – descriptive data

Picture	Control group		Exper. Group	
	Mean	SD	Mean	SD
1st round of evaluation – low design picture	2.37	1.08	4.04	1.46
1st round of evaluation – high design picture	1.56	1.09	1.58	0.70
2nd round of evaluation – low design picture	2.85	0.91	4.00	1.44
2nd round of evaluation – high design picture	1.44	0.80	1.31	0.55

Note. Possible scale: 1 (best) – 6 (worst).

Table 8

Attractiveness ratings – t-test results

Comparison	Control design graphics		Exp. design graphics							
	Mean	SD	Mean	SD	*t*	*df*	*p*	*d*	95% CI *d*	
	Control group participants		Exp. Group participants							
1st exposure (between-subject)	2.37	1.08	1.58	0.70	-3.18	44.88[a]	.003	0.87	0.29	1.45
	All participants		All participants							
1st comparison (within-subject)	3.19	1.52	1.57	0.91	-6.90	52	< .001	0.95	0.54	1.35
2nd comparison (within- subject)	3.42	1.32	1.38	0.69	-10.20	52	< .001	1.40	0.97	1.83

Note. Lower values mean higher attractiveness; *d* is thus reverse coded.

[a]*Df* corrected for unequal variances.

4.4.3 H2: Free-choice behavior

Children also clearly preferred the high aesthetic value version in the free-choice period (Table 6). Thirty-three children (62.3%) chose the experimental version, 9 (17.0%) the control version, and 10 (18.9%) the non-target comparison game, $x^2(2, N = 52) = 21.27$, $p < .001$ (due to technical issues, the free-choice period was skipped for one child). Therefore, H2 has been supported. Given the alternative game is “average” material from a website with dozens of children’s games, this is also a manipulation check: target learning game stands in comparison to an ecologically valid alternative. All children who picked the control version in the free-choice period rated the attractiveness of the experimental version higher than attractiveness of the low version. Seven of these children were originally assigned to the high graphics version. The interviews indicated that they probably chose the low (control) version in the free-choice period out of curiosity. Overall, the H2 has been supported.

4.4.4 Exploratory goal: Learning outcomes

As evident from Table 6, children having the higher aesthetic version did not learn better. On the contrary, gain in comprehension was smaller for the experimental group; though this finding has borderline statistical significance and should be interpreted cautiously.

4.5 Interim Discussion

This study examined the effects of overall visual appearance; that is, a learning game's holistic, appealing visual design. First, it examined the following affective-motivational variables: perceived learning enjoyment and motivation to interact with the experimental version of the target learning game. Children did not enjoy the learning from the embellished experimental version more, yet they were clearly more motivated to interact with this version. Within the information behavior framework, it can be also concluded that the free-choice period revealed the ability of overall visual appearance to significantly impact children's information behavior. This is because the majority of them avoided the target learning game's control version and continued to interact with the experimental version. Second, this study researched whether children found the game's high aesthetic experimental version more attractive (compared to a low aesthetic control version). They clearly did. Third, it examined whether learning through the high aesthetic version improved learning outcomes. It did not. On the contrary, pre-post improvement in comprehension was marginally worse in the high aesthetic condition. However, this effect is only modestly negative: it is of borderline significance and could be spurious. The key point is that the high aesthetic version did not enhance learning outcomes.

4.6 Limitations

An obvious limitation of this study is that cognitive engagement and extraneous cognitive load were not measured. Doing so is notoriously problematic even with adults (e.g., Brünken, Plass, & Leutner, 2003; Brünken, Seufert, Paas, & 2010; de Jong, 2010). In fact, it has been attempted to measure cognitive load during the pilot phase, but this data had to be discarded due to low validity. Without knowing visual design's impact on these variables, it is possible to reconcile alternative explanations in previous section only indirectly (as is often done in multimedia learning research; cf. de Jong, 2010). In the present case and within present explanatory framework, the negative finding concerning comprehension gains can be accounted for only by assuming increased extraneous load. This interpretation has some support from the recent study by Schneider, Häßler, et al. (2018; Exp. 1). They reported, albeit with an older audience (Grades 5-6; $M_{age} = 11.14$), that graphical design with visually complex anthropomorphisms increased extraneous load and decreased learning outcomes compared to a design with visually simpler anthropomorphisms. In contrast, simple anthropomorphisms were shown to increase both motivation and learning outcomes compared to no-anthropomorphism baselines (Chiu, Jong, & Mok, 2020; Ng & Chiu, 2017; Schneider, Häßler, et al., 2018, Exp. 1). Despite support from related studies, this interpretation should be treated cautiously: it is a post hoc explanation and, as already stated, present negative finding is only modest and, statistically, a borderline case. Also, anthropomorphisms can have additional influences, which are unlikely in present approach: For example, by anthropomorphizing visual elements, designers create "characters" from these elements, which can influence perceptions of the entire scene (e.g., the scene can be memorized as a story fragment). Anthropomorphisms' positive effects on learning outcomes thus may not be (or not only be) due to stimulated affective-motivational processes.

Another limitation of this study is a relatively small sample, resulting in low power ($1 - \beta = 43\%$ for $d = 0.5$ and $\alpha = .05$). This was due to intensive pilot stage and the notorious complexities of recruiting and running experiments with children outside a school context (e.g., a parent must always bring the child and wait until the experiment ends). Such small power is not uncommon. For example, the seminal game-based learning paper by Cordova and Lepper (1996) used an even smaller sample

(n ~ 12 per cell). This limitation is addressed by two following studies in the present thesis (i.e., Visual Appearance Study and Visual Dynamicity Study) by allocating research resources on larger samples. Although this focus on larger samples made conducting of these studies generally more demanding, it also allowed to boost statistical power.

Furthermore, only one specific emotional design approach to manipulate visual appearance was used, that is changing unity and visual complexity by adjusting the above-mentioned variables (i.e., shape quality, line quality, color saturation, etc.). Visual appearance and resulting aesthetics are influenced also by a number of other variables: most notably composition. The direct effects of composition on cognitive processing are difficult to disentangle from indirect effects (i.e., through enhanced motivation). That is because compositional arrangement can be changed not only when aesthetics is altered, but also when applying the cognitive principles of multimedia learning (e.g., the signaling or spatial contiguity principle mentioned above). Present study strived to manipulate aesthetics only, so changing of composition was avoided. The key issue is that cognitive principles and aesthetics rules can sometimes work in opposite directions (e.g., placing captions outside an instructional image can be an aesthetically better solution; however, it violates the spatial contiguity principle). Sometimes though, they work in concert (e.g., overall logical structure and visual arrangement of a page lead to higher unity and, at the same time, enhance readability). The congruent and conflicting influences of cognitive principles and aesthetics rules on learning processes could be examined in future research.

A related point is that higher aesthetical value does not always imply greater attractiveness (as measured in this study). For example, Kulka (1996) sees kitsch as emotionally stimulating and therefore attractive. Yet, he also views it as aesthetically defective. Investigating the impact of kitsch in instructional materials on learning outcomes is another possible direction for future research.

These limitations do not lessen the implications of the study’s results for practical application. A less attractive design does not seem to harm learning when it carries all information needed to understand the key educational message and follows the design principles of multimedia learning. That said, one should also take into consideration other possible functions provided by aesthetically valuable graphics: such as helping children develop their sense of aesthetics. Furthermore, it is unclear whether present results would generalize to longer timeframes: Children's attention can decrease differently when they study from materials with high (as opposed to low) aesthetic graphics for more than 20 minutes.

4.7 Conclusions

This study should not be taken as definite guidance for how to (and when to) develop appealing graphics in children's learning games. Rather, it is a first step. Understanding the effects of overall visual appearance and the latter's attractiveness on learning outcomes and information behavior among child audiences is nascent and should be further expanded to a great degree. For instance, it is not clear whether and when increasing visual complexity (without adding new information elements) increases extraneous cognitive load and when it does not. This is an open question that deserves attention. Also, it is important to keep in mind that this study used a relatively small sample and focused on one specific visual design aspect of ADMLMs (i.e., overall visual appearance). This issue is addressed in the following study, which focuses on another potential emotional design principle, visual dynamicity (usage of animated elements) involving a bigger sample.

5 Visual Dynamicity Study

5.1 Study Background

This second study investigates whether overall visual dynamicity operationalized here as the amount of *contextual animation* (i.e., the non-expository animation of context providing representational pictures) in advanced digital multimedia learning materials (ADMLMs) for children fosters or hampers the learning process and impacts children's information behavior. Animation is defined here as "… any application which generates a series of frames, so that each frame appears as an alteration of the previous one, and where the sequence of frames is determined either by the designer or the user" (Bétrancourt & Tversky, 2000; cited from Berney & Bétrancourt, 2016, p. 313). Most importantly, this definition excludes any live action footage captured in point-to-point correspondence with real-life (Ploetzner & Lowe, 2012). The key difference lies in the deliberately defined sequence of pictures typically done by animators.

Animation in multimedia learning materials can be categorized as *expository* and *decorative* (cf. Höffler & Leutner, 2007; Ploetzner & Lowe, 2012). Expository animation refers to animated elements intended specifically for instructional purposes; for instance, for the sake of representing dynamic processes (Ploetzner & Lowe, 2012; Lowe & Schnotz, 2014). It consists of animated representational, explanatory, and mnemonic pictures (see Carney & Levin, 2002; Clark & Lyons, 2011). Consider the target digital learning game about photosynthesis used in this work (see Section 3.1). The flowing water inside the plant is an example of expository animation (see Attachment A & B). Expository animation is also the most explored type of animation from an instructional point of view (see Berney & Bétrancourt, 2016; Lowe & Schnotz, 2014; Ploetzner, Berney, & Bétrancourt, 2020; Ploetzner & Lowe, 2012).

In the case of decorative animation, the "primary instructional function [of the animated elements] is to motivate the learner" (Höffler & Leutner, 2007, p. 725). This characterization is adapted from the taxonomy of pictures by Carney and Levin (2002). It views decorative animation as an animated decorative picture added to the materials. A decorative picture is defined as an interesting, yet instructionally irrelevant, element (Carney & Levin, 2002) adding visual appeal or humor (Clark & Lyons, 2011). It is also generally considered to be a seductive detail (see Section 2.2).

Contextual animation lies somewhere between expository and decorative animation. It consists of animated representational pictures (see Carney & Levin, 2002; Clark & Lyons, 2011) that create the context for the target instruction. Although such animation can depict the behavior of given elements and support representational fidelity, its function is not expository. Therefore, image motion added by contextual animation is instructionally irrelevant and can be omitted. For instance, weather conditions (e.g., rain) present the context for the photosynthesis process, but animation added to them (e.g., animated falling raindrops) is not needed for the target instruction. Even though the essential function of contextual animation is to increase materials' attractiveness and motivate learners, it is fundamentally distinct from decorative animation. It does not consist of animated decorative pictures, and it does not add any extraneous instructionally irrelevant elements. This is because it works only with the representational pictorial elements already present in the materials (e.g., the mentioned weather conditions). Therefore, animation in this case should be seen as an attribute that adds image motion to originally static pictorial elements. Contextual animation thus fulfils the criterion of new, potentially beneficial, emotional design alteration.

Visuals of digital learning game used in this work (see Section 3.1) consist of (apart from the graphical user interface) two sets of elements: Central and contextual. *Central* elements are key for the target instruction. In this case, the elements involve the representational depiction of a plant and interpretive depictions of water and minerals (see Carney & Levin, 2002; Clark & Lyons, 2011). *Contextual* elements are not key to the target instruction, but they provide contextual information. These elements include representational depictions of environmental features and weather conditions (see Figure 17). In general, animation applied to central elements differs from animation applied to contextual elements. In the former case, animation has expository function and in the latter case it has contextual function.

On one hand, both cognitive affective theory of learning with media (CATLM; Moreno, 2005; Moreno & Mayer, 2007) and integrated cognitive affective model of learning with multimedia (ICALM; Plass

& Kaplan, 2016) assumes that stimulation of affective-motivational processes can potentially lead to improved learning outcomes (see Section 2.2). Yet, empirical research on contextual animation's ability to induce such effects (and thereby impact learning outcomes and information behavior) is limited. On the other hand, higher amount of contextual animation in ADMLMs is also potentially connected with extraneous mental processing due to excessive information. According to cognitive load theory (CLT; Sweller, Ayres, & Kalyuga, 2011; Sweller, van Merriënboer, & Paas, 2019) overloading of mental resources by excessive information can results in detrimental effects on learning outcomes (see Section 2.2).

The goal of this study is to address and investigate these theoretical opposing influences of higher visual dynamicity in ADMLMs provided by contextual animation on learning and information behavior. As was already mentioned, contextual animation can be assumed to serve as a form of emotional design alteration (see Section 2.2). It alters only the elements which are already present in the materials and can potentially boost the materials' attractiveness and affective quality (see Figure 16) due to increased image motion (i.e., visual dynamicity). According to previous studies, animations with increased image motion indeed impact core affect (Russell, 2003; see also Section 2.2) by eliciting greater arousal and sustain attention compared to static pictures (Detenber, Simons, Bennett, 1998; Simons, Detenber, Roedema, & Reiss, 1999; Simons, Detenber, Reiss, & Shults, 2000; Sundar & Kalyanaraman, 2004).

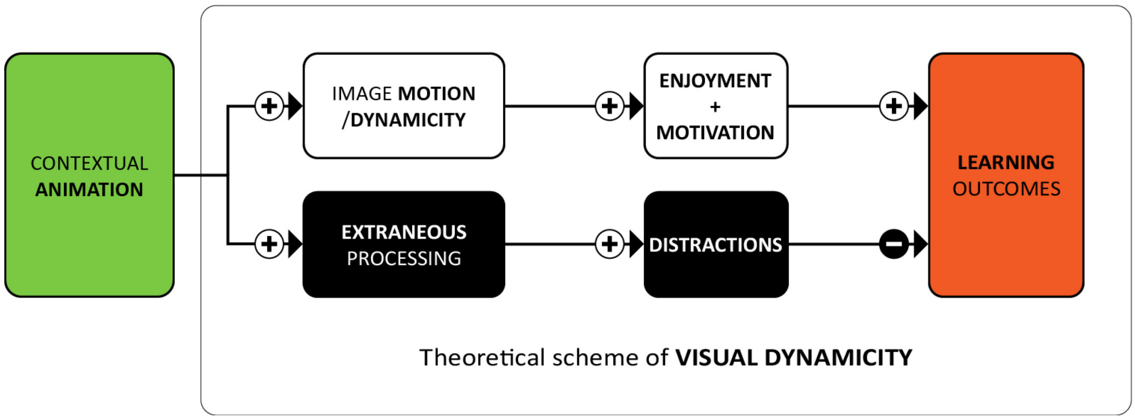

Figure 16. Theoretical scheme of the possible contradicting effects of visual dynamicity.

It is developers' common assumption that multimedia learning materials for children with contextual animation will be superior to more static learning materials (cf. Lowe & Schnotz, 2014). However, as already said, actual evidence to support the affective-motivational and instructional superiority of ADMLMs with contextual animation for children is limited. For instance, a study by Kim et al. (2007) showed that fourth graders found instructional videos with expository animation more enjoyable and motivating than static materials. Yet no between-group difference in comprehension has been detected. That study also examined expository rather than contextual animation. Research has also examined how children improve their language literacy skills by means of interacting with electronic storybooks (which are often animated). However, these studies rarely report affective-motivational variables (cf. meta-analysis by Takacs, Swart, & Bus, 2014). Altogether, no conclusions can be drawn from the abovementioned studies as regards to whether contextual animation in children's learning games increases motivation and/or the prevalence of positive-activating emotional states and thereby facilitates learning. Filling in this gap could shed more light on the possibilities of instructional utilization of contextual animation.

Animation also serves as a tool for visual cueing. This is done by making certain elements more perceptually salient by increasing their *dynamic contrast*. The latter can be defined as higher image motion for a given element compared to its surroundings (Lowe, 1999; Lowe & Schnotz, 2014). This utilization is referred to as *directing the function of animation* (Lowe & Schnotz, 2014; see also van Gog, 2014), and it mostly relates to expository animation (e.g., Ploetzner & Lowe, 2012). For example, when the entire visual display is static except for one animated element, this element will have a higher dynamic contrast compared to its surroundings. Such an element would attract the learner's visual attention regardless of its instructional function. This means that, if the perceptually salient element is instructionally irrelevant (e.g., decorative animation with high dynamic contrast), it can become a misleading visual cue. Such an element makes selection of relevant information from the materials more difficult and hinders learning (cf., Johnson & Mayer, 2012; Mayer, 2010). This reasoning also applies to contextual animation added to an *already existing* static contextual element in the emotional design fashion (i.e., not a seductive detail in the classical sense). Multiple animated contextual elements with high dynamic contrast may grab learners' visual attention and obstruct the cognitive processes of selection and organization. This negative, misleading effect may theoretically annul or outweigh contextual animation's potential benefits.

Measures of learners' visual attention allocation are required to investigate such possibly misleading effects in the case of contextual animation. One of the common methods for achieving this is the usage of eye-tracking technology. This technology allows researchers to measure and analyze perceptual processes during interaction with the learning materials and relate those materials to cognitive processes (Coskun & Cagiltay, 2021; Mayer, 2014a). Gaze patterns mostly related to learners' attention are based on temporal measures of eye *fixations* like *dwell time*; that is, time-based measures of eyes resting or focusing on a defined spot (Coskun & Cagiltay, 2021; Lai et al., 2013). Related studies showed that children indeed look longer at animated elements in narrated story books compared to complementary static pictures (Takacs & Bus, 2016; Sun, Loh, Roberts, 2019). However, such eye-tracking studies with children participants are rare, as was revealed by a recent review (see Coskun & Cagiltay, 2021). It is not clear whether similar gaze patterns will appear in a different instructional domain or in the case of primary school children interacting with ADMLMs featuring contextual animation.

Altogether, the described theories make conflicting predictions regarding the effects of contextual animation on learning outcomes. According to CATLM and ICALM contextual animation, much like other emotional design alterations, can positively stimulate learners' cognitive engagement via affective-motivational processes, and thus improve learning (see Section 2.2; cf., Moreno, 2005; see also Plass & Kalyuga, 2019). Also, contextual animation can accordingly impact children's information behavior (see Section 2.3). However, the increased dynamic contrast of elements with contextual animation may result in a neglect of the target information due to the negative effect of misleading visual cueing (see Lowe, 2003). Even though contextual animation does not involve the addition of extraneous informational elements, it can still hamper the learning process. Evidence that would reconcile these conflicting predictions is currently limited.

5.2 This Study – Visual Dynamicity

Present study examines the effects of contextual animation in multimedia learning games for children on the perceived attractiveness of graphics, learning enjoyment, free-choice behavior, attention allocation, and learning outcomes. Children learned about photosynthesis and water transport in plants from one of two versions of a target multimedia learning game (i.e., a between-subject design). One of these versions featured contextual animation (experimental) and the other lacked it (control). Both versions were instructionally and pictorially identical.

The visual display of both versions of the game featured three sets of game elements (see Table 9 for a summary):

a) *contextual elements* (clouds, rain, grass, etc.) having increased image motion and high dynamic contrast in the experimental, but not the control, version due to contextual animation

b) *expository elements* on the central plant (water flowing in the plant, minerals, etc.) with increased image motion in both versions due to expository animation

c) *graphical user interface* (GUI; see Figure 17 and 18) with low or no image motion in both versions

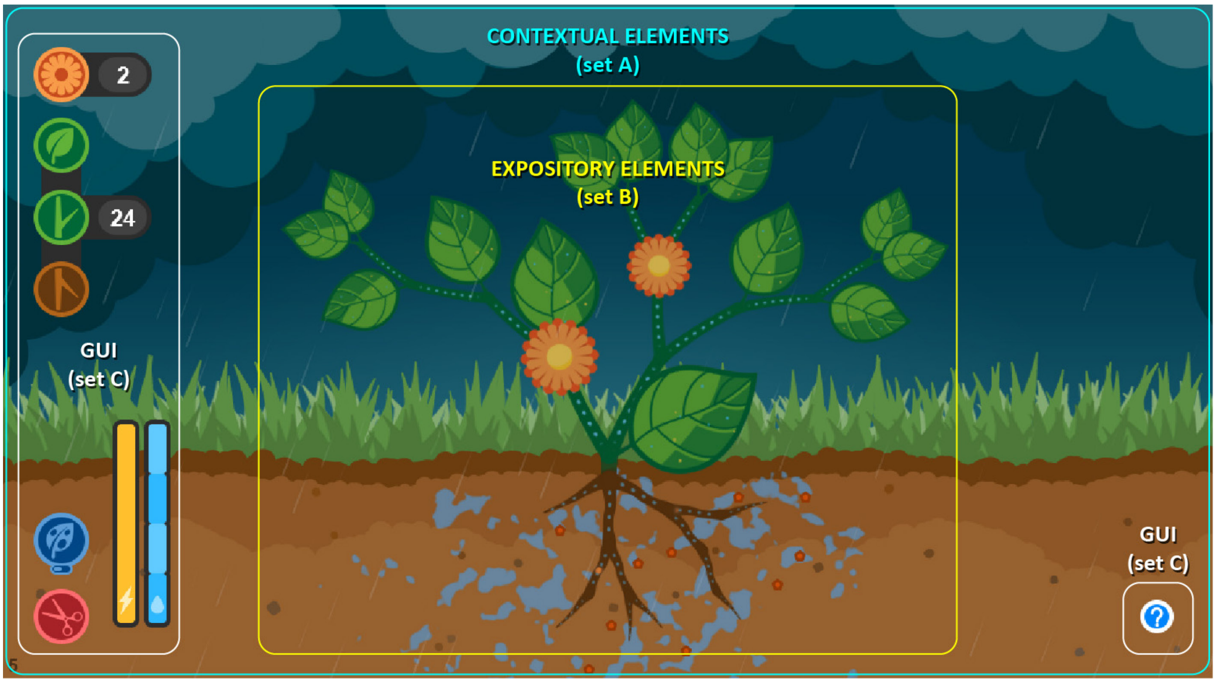

Figure 17. The learning environment with GUI, a screenshot from the target game.

In the experimental version, contextual and expository elements (sets [a] and [b]) had similarly high dynamic contrast, because they were both animated. On the other hand, in the control version, only the expository elements (set [b]) had high dynamic contrast, because no other elements were animated. The graphical user interface (set [c]) had low or no dynamic contrast in both versions (see Table 9 for further details). Three hypotheses and one exploratory goal are put forward:

H1: Based on the reasoning in previous section, children will enjoy learning from the experimental version more (H1a), and they will find it more attractive than the static control version (H1b),

H2: Children will be more motivated to re-engage with the dynamic experimental version than with the static control version.

H3: Based on the reasoning in previous section, average fixation durations and normalized dwell times (i.e., dwell time divided by the total fixation time on the entire picture) will be *lower* for the GUI elements (H3a) and *higher* for the animated contextual elements (H3b) in the experimental version compared to the control version. This is because, in the experimental version, attention will be drawn away from the GUI elements to the animated contextual elements, which have higher dynamic contrast in the experimental version (see Table 9 for a summary). No hypothesis is stated regarding expository elements, as the dynamic contrast of these elements does not change between the versions.

Table 9

Dynamic contrasts used in the game versions and predictions for Hypothesis 3

	Experimental version		Control version		
Elements	animation	dynamic contrast	animation	dynamic contrast	Hypothesis
Contextual (a)	YES	HIGH	NO	NO	higher attention in exp. Version (H2b)
Expository (b)	YES	HIGH	YES	HIGH	not stated
GUI (c)	LIMITED	LOW	NO	NO	lower attention in experimental version (H2a)

Because current theories make conflicting predictions regarding the effects of contextual animation on learning outcomes, a directional hypothesis concerning this cognitive variable is not posited. Instead, between-group differences are explored:

Exploratory Goal: What is the contextual animation's effect on learning outcomes in the experimental version compared to the control version?

5.3 Method

5.3.1 Participants

Participants included 134 Czech children from third or fourth grade (aged 8-11 years; $M = 9.25$; $SD = 0.66$). They were recruited online and via TV broadcast calls made by Czech TV's children's channel. Ninety-six children came from urban areas (large cities or suburbs); 38 children were from rural areas (small, rural towns or the countryside). An additional seven children were excluded from the data analysis due to technical issues. Children were randomly assigned either to the experimental condition with contextual animation ($n = 71$) or the control condition ($n = 63$) without contextual animation.

Random assignment was balanced based on children's gender and age. Children were given a LEGO set (worth ~20 EUR) and Czech TV promo merchandise as a reward for their participation. The sample size was determined based on a priori power calculations in G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007). The 64 participants per group were needed to detect medium effect size (Cohen's $d = 0.5$) using t-tests (for $\alpha = .05$ and $1-\beta = .80$).

5.3.2 Materials

Two versions of target digital learning game introduced in Section 3.1. were used in this study. The versions differed primarily in the presence/absence of contextual animation in the interactive part of the game. The visual display featured three sets of elements (see Figure 17). The first set (a) included contextual elements (i.e., sun, sun rays, clouds, rain, and grass), which set up the context for the plant (i.e., the weather and environment). These elements had increased image motion and high dynamic contrast in the experimental version. In the control version, they remained static (i.e., without any animation). In other words, continuous contextual animation (see Figure 18) was applied to them only in the experimental version. The second set (b) included the expository elements with salient expository animation in both versions: Water flowing through the stems and roots, water evaporating from the leaves, the leaves capturing energy, and minerals flowing through the roots (from the Level 5 on). These expository animations were important for target mental model construction (e.g., water transport in plants), and thus they were present in both versions. The last set (c) included GUI elements, which had low dynamic contrast in both versions. In the control version, this set was static. In the experimental version, it was static except for a short transitional animation during interaction (i.e., animated change from one state to another). This short transitional animation was included for ecological validity reasons (i.e., the same as it would be implemented in an actual game).

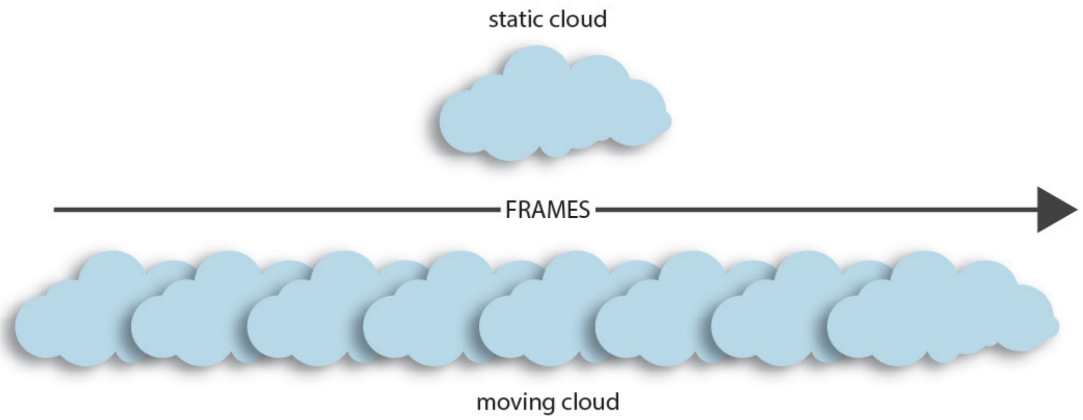

Figure 18. Example of the difference in the applied contextual animation between conditions: Moving cloud: top – the control version; bottom – experimental version.

Likewise, for ecological validity reasons, the plant in the experimental version also featured additional contextual animations: namely, the growing of stems, roots, leaves (transitional, when clicking on a control button); the turning of leaves (transitional, when clicking on a control button); the drying out of the plant (transitional, when water was lacking); and the slight swaying of the plant (continuous). The dynamic contrast across the entire set (b) was therefore likely a bit higher in the experimental than in the control version, yet the overall difference between versions was minimal. These additional animations were less salient compared to the continuous expository animations.

5.3.3 Additional Measures – Eye tracking

Apart from common measures shared by all studies (see Section 3.2), this study also included collection of gaze data. Two groups of gaze pattern variables were used: Normalized **dwell times** in each area of interest (AOI) group (i.e., total fixation time within the area relative to the total fixation time on the entire picture) and **average fixation durations** within each AOI group. The areas of interest were collapsed into three groups corresponding to the three sets of elements described above (see Table 9): The contextual elements – set (a); expository elements – set (b); and GUI – set (c) (see Figure 17). Some AOIs were dynamic because of the transient nature of target materials (the plant was growing, the weather was changing, etc.). In cases of overlapping elements (e.g., the plant and the background elements), AOIs were created based on the upper element (see Figure 19). The dynamic AOIs were defined manually in *EyeLink Data Viewer* with a temporal accuracy of 30 fps. Eye movements were recorded only in the fifth level, which contained almost all of the target game's functionality (see Table 2). Thus, it had the highest amount of contextual animation in the experimental version.

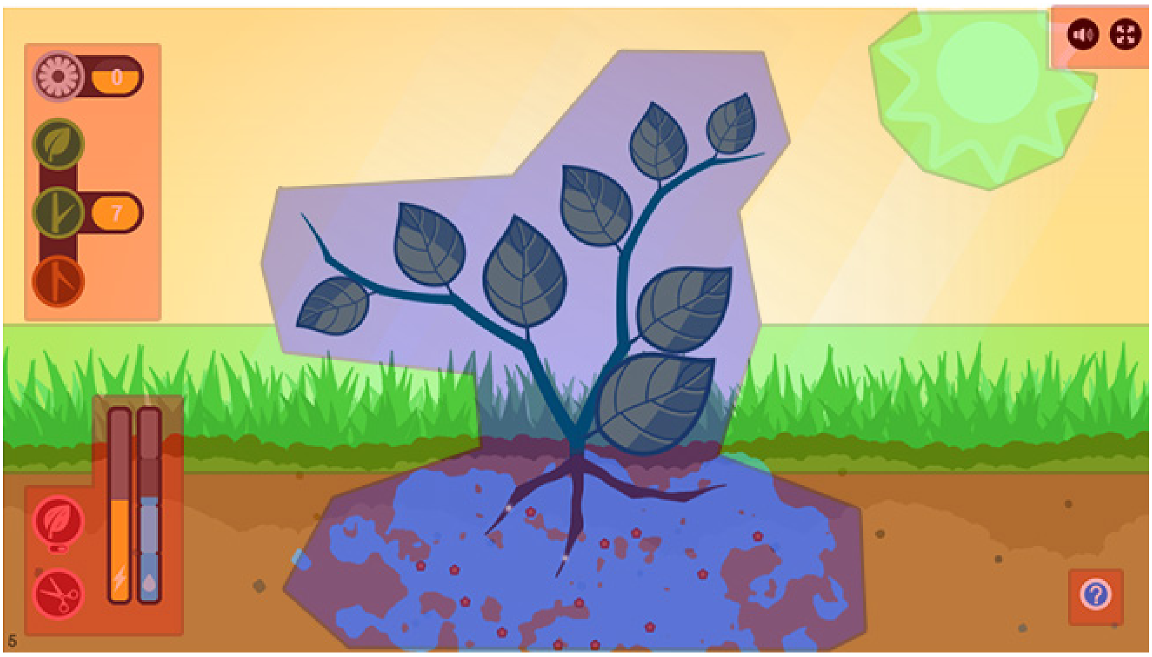

Figure 19. Three sets of areas of interest for the gaze data analysis: Green – contextual elements (dynamic AOI); blue – expository elements (dynamic AOI); red – GUI (static AOI).

5.3.4 Apparatus

The eye tracker **apparatus** used was the EyeLink 1000 Plus (SR Research) with a 500 Hz sample rate. The 9-point calibration procedure was used. The parsing algorithm supplied with the device for the detection of saccades and fixations was used (thresholds: velocity 30°/s, acceleration 8000°/s^2, saccade motion 0.1°; saccade pursuit fixup 60°/s). A chin rest was used for head stabilization. Participants were seated at a 55-60 cm distance from the 1920 x 1080 px display with the stimulus.

5.3.5 Procedure

Participants were tested in a laboratory (one child at a time). The whole session lasted for about an hour. After the child and the parent were briefly introduced to the experiment (without revealing the experiment's design and goals), the parent signed the informed consent agreement and left the lab. Participants were then familiarized with the smiley scale. Next, they were interviewed as regards domain interest. Afterwards, they completed the drawing pre-test (comprehension). Next, their prior knowledge was inquired.

Thereafter, participants moved to the second room with the eye tracker. Participants were briefly introduced to the device and how to sit comfortably with their head on the chin rest. Next, the eye tracker was calibrated and validated with the 9-point calibration procedure. Thereafter, participants played the game (either the experimental or the control version) without their eye movements being registered. The whole treatment (i.e., the gameplay) took around 20 minutes. The gaze data were collected only for Level 5 of the game (average time on task for Level 5 ≈ 2 minutes), because game features were introduced gradually, and the key elements and functionality were not present until this point in the game.

Prior to Level 5, the calibration procedure was repeated. Participants were again instructed to keep their head on the chin rest during the interaction with the game (we found the chin rest to be rather comfortable for the children). After Level 5 was completed, participants rated perceived learning enjoyment. Next, they were given the drawing post-test and the oral transfer test.

Thereafter, participants were shown the second game version (for the first time). Their subsequent task was to evaluate the graphical attractiveness of both game versions (see Attachment B). The evaluation period had four trials. In each trial, the participants were shown two side-by-side screens: Each with the video from the target game. One video was taken from the experimental version, the other from the control version (the two videos from each trial were otherwise identical; the positions [left or right] – experimental vs. control – were randomized). In each trial, the two videos started at once and they were 12 seconds long. Each trial showed different weather (hot weather, clear sky, cloudy, rain; see Figure 8). The order of weather conditions was randomized across the trials. After watching each video pair, children were asked to pick the one with more image motion. Then, they were asked to evaluate the attractiveness of both videos using onscreen smiley scales (see Section 3.2.3). This presentation format (i.e., split-screen videos) can create a split-attention effect (e.g., Ayres & Sweller, 2014); however, pilot sessions revealed that children did not have any problem with this task.

After that, the free-choice period started. Participants were informed that they still had approximately 5 minutes before the end of the session. They were asked which version they would like to continue playing during that time. The children picked their preferred version and played it until the end of the session (they played Level 6 of the game).

5.3.6 Data analysis

Data analysis was performed in R version 3.5.0 (R Core Team, 2018). To check whether the groups were balanced with respect to gender a chi-squared test was used. Between-group differences in other control variables, attractiveness ratings, enjoyment, and learning outcomes were analyzed through t-tests. Data were often not normally distributed, but t-tests are robust as regards normality violations (e.g., Rasch, Teuscher, Guiard, 2007). However, these differences were also tested using non-parametric Wilcoxon rank sum tests with continuity correction: The findings were similar to t-test results in all cases. Attractiveness ratings (i.e., H2) were also analyzed using a three-way ANOVA, as this was a repeated measure (four trials) with an additional factor (position of the video on the screen).

For the eye tracking data, the differences were tested between the experimental and control versions using independent sample t-tests. As there were several outliers present, the analysis was re-run by removing samples more than 2 SD away from the mean. The differences were also tested using a Yuen-Welch test, which is a robust version of a t-test with respect to outliers and violence of normality assumptions (Yuen, 1974; Wilcox, 2012). Robust testing was performed using a WRS2 package (Mair & Wilcox, 2018). The results were similar in all cases, so we report on independent t-tests in the texts (for clarity).

The effect sizes for t-tests were expressed using Cohen's d with classification into small ($d \sim 0.2$), medium ($d \sim 0.5$), and large ($d \sim 0.8$) categories (Cohen, 2013). For the ANOVA, the effect sizes were expressed using η_p^2 with classification into small ($\eta_p^2 \sim .01$), medium ($\eta_p^2 \sim .06$), and large ($\eta_p^2 \sim .14$) groups.

In the light of debate about reporting statistical significance and p-values (e.g., Cumming, 2013; Hackshaw & Kirkwood, 2011; Lakens et al., 2018), the setting of $p = .05$ as a fixed threshold separating outcomes into significant vs. non-significant categories was refrained from. Instead, the term “borderline significance” was used for outcomes having *p*-values around .05 (especially, when this threshold was crossed in some statistical tests, but not in others).

5.4 Results

5.4.1 Control variables

Descriptive results of all control variables are presented in Table 10. The groups did not differ in these variables (*p*s > .364), so they were dropped from subsequent analyses.

Table 10

Control variables, including t-tests or chi-squared tests results

	Experimental group		Control group							
	Mean	SD	Mean	SD	*t*	*p*	*df*	*d*	95% CI *d*	
Domain interest	3.45	1.90	3.47	1.68	-0.04	.966	131	-0.01	-0.35	0.34
Terms prior	1.37	0.56	1.41	0.55	-0.45	.656	126	-0.08	-0.43	0.27
Concepts prior	1.16	0.56	1.13	0.55	0.34	.731	126	0.06	-0.29	0.41
Compreh. prior	1.59	1.39	1.52	1.37	0.27	.789	132	0.05	-0.30	0.39
Time on task	0.32	0.05	0.32	0.04	-0.36	.722	125	-0.06	-0.42	0.29
Age	9.24	0.66	9.27	0.65	-0.27	.790	132	-0.05	-0.39	0.30
Grade	3.48	0.50	3.46	0.50	0.21	.831	132	0.04	-0.31	0.38
	Boys	Girls	Boys	Girls	x^2	*df*	*p*			
Gender	43	28	35	28	0.17	1	.681			

5.4.2 H1: Learning enjoyment and visual attractiveness

Ratings of enjoyment (i.e., enjoyment of the entire 20 minutes of gameplay) did not significantly differ between groups (Table 11). Notably, enjoyment was high in both conditions, so this could be due to a ceiling effect.

However, children found the experimental version more visually attractive when they were shown both versions simultaneously (Table 12). Differences in attractiveness evaluation were tested using a three-way ANOVA with within-subject factors: Weather (hot, clear sky, cloudy, rain) and stimulus type (control vs. experimental); and a between-subject factor: Experimental group (control vs. experimental). The differences were large between control and experimental stimuli (p < .001, η_p^2 = .56; Table 13). Additionally, there was a small effect of borderline significance for interaction between weather and stimulus type (p = .032, η_p^2 = .02) caused by somewhat better evaluation of the control stimulus in the case of clear skies (Table 12). When the effect of the weather and participant groups was averaged out, large effect was obtained again, t(133) = -12.90, p < .001, d = 1.11, 95% CI d = [0.86, 1.37] (Figure 20). Therefore, H1a (enjoyment) has been rejected, whereas H1b (attractiveness) has been supported.

Table 11

Learning outcomes and enjoyment

	Exp. group		Control group							
	Mean	SD	Mean	SD	*t*	*p*	*df*	*d*	95% CI *d*	
Comprehension post	2.77	1.46	2.98	1.55	-0.78	.434	131	-0.14	-0.48	0.21
Comprehension diff.	1.18	1.32	1.44	1.15	-1.19	.237	131	-0.21	-0.55	0.14
Transfer post	9.19	2.90	9.58	2.55	-0.83	.409	132	-0.14	-0.49	0.20
Enjoyment[a]	1.43	0.69	1.33	0.60	-0.86	.391	132	-0.15	-0.49	0.19
					x^2					
Free-choice					87.04	1	**< .001**			

[a]Lower values mean higher enjoyment; *d* and *t* are thus reverse coded.

Table 12

Attractiveness ratings per experimental group, weather, and stimulus type: Means and SDs

	Experimental group				Control group			
Stimulus	Clear	Cloudy	Heat	Rain	Clear	Cloudy	Heat	Rain
Experimental	1.87 (1.37)	1.70 (1.26)	1.82 (1.23)	1.72 (1.30)	1.84 (1.14)	1.83 (1.21)	1.81 (1.27)	1.70 (1.25)
Control	3.41 (1.17)	3.46 (1.30)	3.38 (1.26)	3.51 (1.24)	2.92 (1.13)	3.30 (1.21)	3.25 (1.32)	3.27 (1.21)

Note. Lower values mean greater attractiveness.

Table 13

Attractiveness ratings – ANOVA results

Effect	*df*	*F*	*p*	η_p^2
(Intercept)	1, 132	1190.00	<.001	.90
Participant group (control vs. experimental)	1, 132	0.64	.423	<.01
Stimulus type (control vs. experimental)	1, 132	167.00	<.001	.56
Weather (clear, cloudy, heat vs. rain)	3, 396	0.52	.672	<.01
Participant group: Stimulus type	1, 132	1.28	.261	.01
Participant group: Weather	3, 396	2.24	.083	.02
Stimulus type: Weather	3, 396	2.96	.032	.02
Participant group: Stimulus type: Weather	3, 396	0.57	.635	<.01

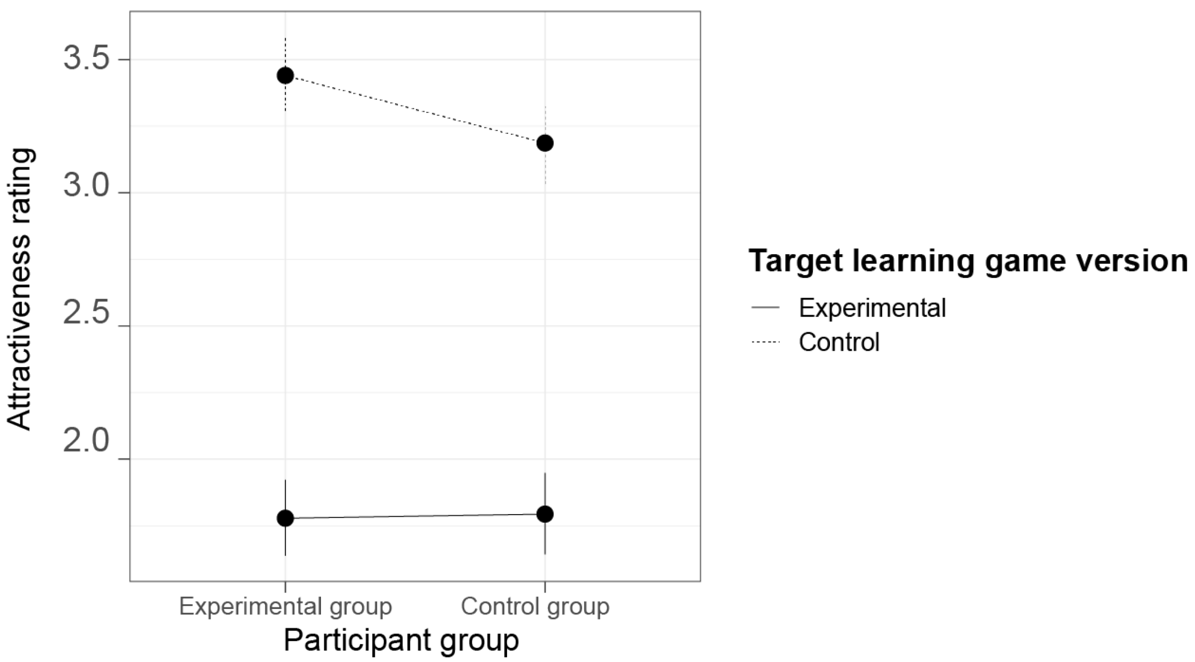

Figure 20. Attractiveness ratings averaged across weather. Lower values mean greater attractiveness. Whiskers denote bootstrapped standard error of the mean.

5.4.3 H2: Free-choice behavior

Children clearly preferred the experimental version in the free-choice period (both groups combined: $n_{\text{experimental}} = 121$; $n_{\text{control}} = 13$, $\chi^2 = 87.04$, $p < .001$). H2 was thus supported.

5.4.4 H3: Attention distribution

For average fixation durations (Table 14) and normalized dwell times (Table 15), there were small differences in the case of contextual elements' AOIs (set [a]). These were in favor of the experimental game version, and thus supported H3b; but non-significant when correcting for multiple comparisons.

Table 14

Means, SDs and t-test results for average fixation durations

	Game version						
AOI group	Experimental	Control	*t*	*df*	*p*	*d* [95% CI for *d*]	$p_{corrected}$[a]
Context. elements (a)	218.60 (66.28)	199.83 (72.21)	1.47	116	.144	0.27 [-0.10, 0.64]	.432
Exposit. elements (b)	378.84 (63.68)	385.46 (70.75)	-0.53	116	.594	-0.10 [-0.46, 0.27]	.670
GUI elements (c)	278.07 (47.89)	286.90 (51.13)	-0.97	116	.335	-0.18 [-0.54, 0.19]	.670

Note. Average fixation durations are given in ms.

[a] p-values corrected with Holm correction.

Table 15

Means, SDs and t-test results for normalized dwell time

AOI group	Game version		t	df	p	d [95% CI for d]	$p_{corrected}$[a]
	Experimental	Control					
Context. elements (a)	6.84 (5.31)	5.25 (3.61)	1.90	116	.060	0.35 [-0.02,0.72]	.120
Exposit. elements (b)	60.70 (8.91)	59.25 (8.16)	0.92	116	.362	0.17 [-0.20,0.53]	.362
GUI eleIts (c)	32.46 (7.90)	35.50 (7.58)	-2.13	116	.035	-0.39 [-0.76,-0.02]	.105

Note. Dwell time is given in percentages of total time spent on this game level.

[a] p-values corrected with Holm correction.

There was also a small difference (non-significant when correcting for multiple comparisons) for GUI elements in the case of dwell time: Participants in the experimental group looked slightly *less* at the GUI elements compared to control group learners. This interaction is in support of H3a. It is also apparent when both dwell times and average fixations are analyzed using a two-way ANOVA (interaction between the AOI group and the participant group – dwell times: $F[2, 232] = 2.65$, $p = .073$, $\eta_p^2 = .02$; fixation duration: $F[2, 232] = 3.09$, $p = .047$, $\eta_p^2 = .03$; see Figure 21 and 22). All in all, support for Hypotheses 3a and 3b is weak.

No notable differences between game versions were detected as concerns the expository elements; that is, the plant and its constituents. Participants looked less at the contextual elements (set [a]) compared to the expository elements in both versions. This suggests that they generally did not have problems selecting target information from the game. This is also consistent with the assumption that the plant had high dynamic contrast in both game versions.

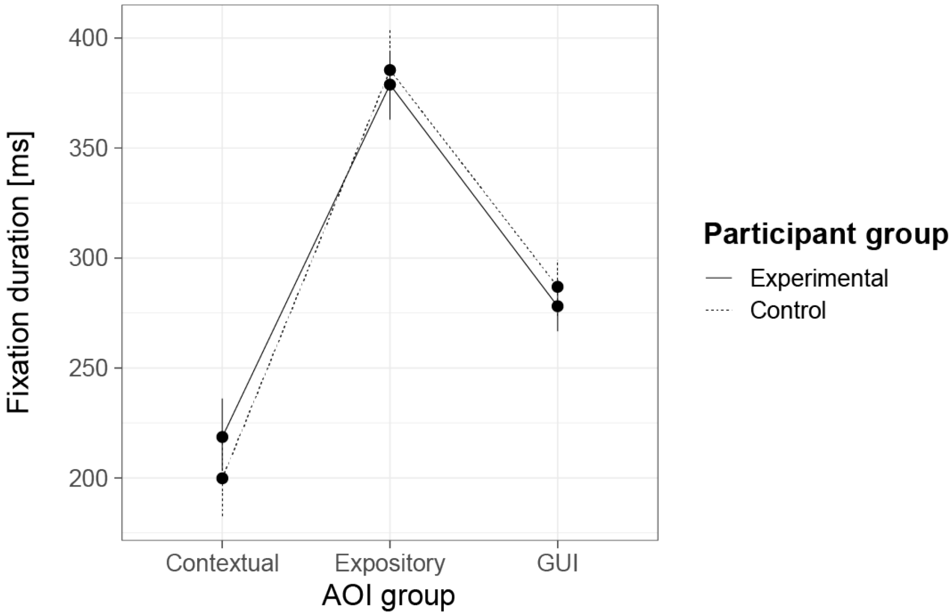

Figure 21. Average fixation duration per participant group and AOI group. Whiskers denote bootstrapped standard error of the mean.

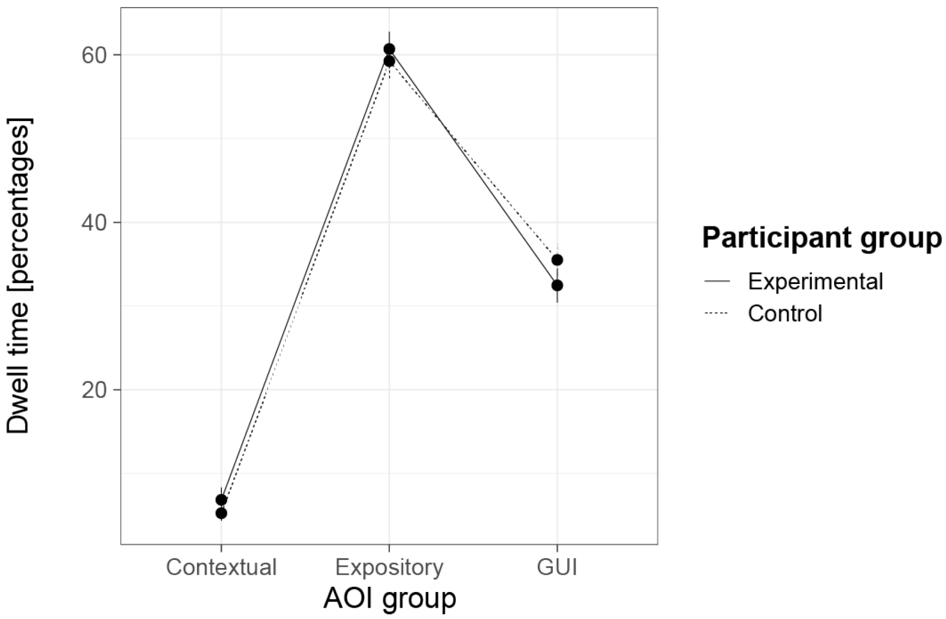

Figure 22. Dwell time per participant group and AOI group. Whiskers denote bootstrapped standard error of the mean.

5.4.5 Exploratory goal: Learning outcomes

Although both groups improved their learning outcomes, as shown by comparison of comprehension pre-tests and post-tests, no significant difference occurred between the groups (Table 11). Therefore, no evidence was found that contextual animation affects comprehension or transfer and report null results.

5.5 Interim Discussion

This study examined the effects of contextual animation (in a multimedia learning game for children) on affective-motivational processes, free-choice behavior, attention, and learning outcomes: Using a relatively large sample. As regards affective-motivational variables, the children did not report that they enjoyed learning from the experimental version more. Yet, they evaluated (on a smiley scale) the graphics from the experimental version as being substantially more attractive compared to the control version. Also, the children were clearly motivated to interact with the experimental version, because ~90 % of them chose to interact with it in the free-choice period. In other words, from the information behavior perspective, children predominantly avoided the control version of the target learning game.

As concerns attention allocation effects, borderline support was found for the idea that attention was shifted in the experimental version compared to the control version. In the experimental version, it moved away from low dynamic contrast elements (i.e., GUI) to high dynamic contrast elements (i.e., contextual elements; see Table 9; see Figure 17). However, the effect sizes were small. Average fixation duration and normalized dwell times for the central, expository element, in this case the plant (having high dynamic contrast in both conditions), did not differ between game versions: Participants did not have problems focusing on this key visual object (normalized plant dwell time was ~60% in both conditions). Finally, as concerns learning outcomes, no between-group difference was found in comprehension and transfer.

Why were there no effects of contextual animation on enjoyment, but large effects on attractiveness and motivation? First possible answer is that enjoyment was measured before the participants were familiarized with the second game version, so they could not contrast the two versions. Second possibility is that this measure is generally less sensitive: It is a summative, self-reported variable concerning the entire experience during the last approx. 20 minutes. It may be relatively difficult for children 8-11 years of age to self-assess this variable compared to the more approachable rating of attractiveness (i.e., a 12-second-long video the child just saw) or picking one of the options during the free-choice period. Furthermore, the enjoyment measure may have ceiling effect issues, despite the usage of the same asymmetrical smiley scale measure intentionally designed for limitation of such issues (see Section 3.2.2). Previous study of visual appearance (see Chapter 4) also revealed null results (and a possible ceiling effect) as concerns enjoyment but found between-group differences as concerns rating of visual attractiveness and motivation to interact with the target game. Yet, some of these attractiveness ratings in the study of visual appearance were asked about before the children were shown both versions of the target game (see Section 4.3). Therefore, the second possibility of enjoyment's measure low sensitivity is at least partly to blame (though the first possibility could also play a role).

Why is support for the attention shift only weak? Related studies (Takacs & Bus, 2016; Sun, Loh, & Roberts, 2019) found more robust evidence than the present study did for shifts in attention to animated elements in storybooks for kindergarten children. Aside from methodological differences (e.g., different age groups, knowledge domains, and learning materials), the present results are possibly weaker because the target game's visual display featured the central, expository element (the plant), which had two attention-relevant characteristics. First, the plant had higher dynamic contrast in both conditions (i.e., it attracted "bottom-up" attention). Second, it was the target of all game sub-goals such as 'add more leaves' (i.e., it was the target of "top-down" attention; cf. Lowe & Schnotz, 2014). Therefore, in the case of environmental elements, the ability of contextual animation to attract additional attention could be limited.

As concerns learning outcomes, the comparable studies (Takacs & Bus, 2016; Sun, Loh, & Roberts, 2019) revealed that an animated storybook enhances story comprehension. So why has the present study not revealed similar effects on comprehension and transfer? First, in the present study, the contextual animation in the experimental version of the target learning game may not have been sufficient enough to stimulate children's learning enjoyment. In such case, cognitive engagement would not increase and result in improved learning outcomes (cf. Moreno, 2005; Plass & Kaplan, 2016; see also Section 2.2). More stimulating manipulations may be needed to achieve that (Takacs & Bus, [2016] did not report affective-motivational variables). In addition, the fact that children were more motivated towards interaction with learning materials containing contextual animation does not automatically imply that they were not equally cognitively engaged during learning from instructional materials without contextual animation. In other words, both versions might have been comparably cognitively engaging, despite the differences in motivation and visual dynamicity, and thus no significant difference has occurred. Second, because Takacs and Bus (2016) also found robust evidence for attention shift, their animation probably had a directing role, which could enhance learning in and of itself. In the present game, contextual animation probably did not have a similar role, because it did not consist of key instructional elements (the central expository element was the plant). Attracting attention to contextual elements may not suffice to enhance learning of target instructions. Plus, the attraction was only small. All in all, participants in this study preferred to interact with the experimental version. Yet, the contextual animation appeared to have neither immediate instructional benefits (such as higher cognitive engagement) nor any disadvantages (such as distraction). Children thus learned equally from both versions in a controlled lab setting.

This means that contextual animation in ADMLMs does not necessarily lead to negative seductive detail effects and overload children's cognitive systems (see Sundarajan & Adescope, 2020; Sweller, et al., 2019; see also Section 2.2). More research on "stronger" visual dynamicity alterations and in various contexts (than those used in the present study) is needed. Would the affective-motivational effect of such manipulations eventually be so profound that they (the alterations) would enhance learning outcomes? Or would they, at some point, start to distract attention away from the instructional message? These open questions could be addressed in future research.

The present results, along with some prior research on the effects of *expository* animation (Kim, et al., 2007), indicate that higher amounts of image motion can potentially affect motivation and related information behavior, but not the perceived enjoyment in learning experience. This, in and of itself, may not suffice to boost immediate learning outcomes. However, this motivational function of animation can be combined with animation's directing function. In other words, a single animation can simultaneously motivate learners to interact with learning materials and improve cognitive selection of target information. The effects of such combinations of animation's functions have not been explored much. More research in this regard is needed, as this combination may be a hidden educational gem.

Lastly, the present results seem to suggest that instructional designers and game developers can omit contextual animation in learning materials for children, because it does not have any instructional benefits. However, this interpretation would seem to go too far. It is unclear what would happen in uncontrolled settings, for example, during home learning. The higher motivation/attractiveness and changes in information behavior caused by contextual animation may result in longer time-on-task and thus enhanced learning performance. Moreover, in the less controlled scenarios like browsing on the internet, children's information behavior can play an important "gatekeeper" role and they may hesitate to interact with ADMLMs without contextual animation in the first place. Future studies should therefore examine the effects of contextual animation in uncontrolled settings.

5.6 Limitations

One limitation of this study is that the plant (e.g., the central expository element) in the control version featured only expository animation, whereas in the experimental version it also featured some contextual animation. Even though dynamic contrast of the plant was high in both versions, it could have been somewhat higher in the experimental one. However, as the contextual animation applied to the plant was occasional or unobtrusive, I do not consider this to be a real issue. In contrast, the animation applied to the contextual elements was continuous and salient thanks to the high dynamic contrast (e.g., clouds moving across the sky).

Second, knowledge tests were administered immediately after the game, as is typically done in multimedia learning studies. Delayed knowledge tests might show a different picture. It is important for the entire research field to start aiming at delayed knowledge assessments.

Third, the contextual animation was applied in a specific multimedia learning game developed for this study, thus it raises the question of to what context the results can be generalized. On the one hand, present findings may generalize to less interactive ADMLMs than games, such as self-paced slides or animated slides: the medium supposedly does not make much of a difference, provided it enables animation (cf. Clark, 2012). Also, present results may generalize to other learning domains pertaining to mental model acquisition (the difference in results between present study and that of Takacs and Bus [2016] may be caused due to the fact that their study focused on story comprehension rather than acquisition of mental models of natural phenomena). On the other hand, the results may be different for non-child audiences because children and older learners differ in numerous developmental factors, such as in the amount of available mental resources (Gathercole, Pickering, Ambridge, & Wearing, 2004). The findings may also vary depending on the amount of contextual animation and the characteristics of the latter, as discussed above.

Finally, eye tracking data were measured only in Level 5 of the game (i.e., ~2 minutes). Using a longer measuring period may be more sensitive, yet it would be difficult to conduct.

5.7 Conclusions

This study focused on the effects of another visual design aspect in ADMLMs; that is, visual dynamicity, and unexplored potential emotional design alteration of contextual animation. Also, an eye-tracker was used to investigate possible changes in attention allocation. On the one hand, the study's results suggest that ADMLMSs with ecologically plausible contextual animation (i.e., as used in "mainstream" educational games for children) may not suffice to boost learning outcomes. On the other hand, ADMLM with contextual animation did not hamper learning. Children found it to be more attractive, and it was clearly preferred by them their information behavior was impacted. At the same time, the combination of animation's motivational and directing functions may lead to learning benefits and should be examined in future studies. The message for designers of multimedia learning games and other ADMLMs is similar to the previous study focusing on the visual design aspect of overall visual appearance. Investment into contextual animation (when used cautiously) may be worthwhile provided the ADMLMs are meant to be used in uncontrolled settings (i.e., when children can choose materials with which they wish to interact). It is less clear whether or not this investment is needed in contexts where children cannot choose these materials (e.g., in schools).

Another potentially new emotional design principle is visual customizability. The effects of this remaining visual design aspect of information representation in ADMLMs are investigated in the following chapter.

6 Visual Customizability Study

6.1 Study Background

The last study of this thesis is concerned with the visual customization features in advanced digital multimedia learning materials (ADMLMs) in the context of digital game-based learning (DGBL). In general, *customization* features can be viewed as a specific type of choice provision; for instance, when players are asked to choose their virtual appearance, name, and other elements of the game, based on their preferences (Plass & Pawar, 2020). For instance, in case of the target game about photosynthesis used in this work (see Section 3.1), children can be allowed to choose the look of two key visual elements: a plant and its environment.

On a more general level, as concerns software applications, websites, and other virtual environments, an important distinction is made between s*ystem-initiated personalization* and *user-initiated customization* (Frias-Martinez, Chen, & Liu, 2009; Sundar & Marathe, 2010). The former is also referred to as a system's *adaptivity* (Ku, Hou, & Chen, 2016; Plass & Pawar, 2020), and it concerns changes made by the system based on specified parameters; for instance, derived from previous user behavior (e.g., web browsing). The key distinction in the case of the latter (i.e., user-initiated customization) lies in users' involvement in the tailoring process. It allows users to control the changes by making choices based on their own preferences. In other words, they are given more autonomy and control over the game's environment. Such user-initiated customization is in the scope of this study.

Additional research into massively multiplayer online games has further categorized user-initiated customization into three types: *functional customization*; *customization affecting usability*, and *cosmetic customization* (Turkay & Adinolf, 2010; 2015). Functional customization directly affects the content and gameplay experience; for instance, by setting the difficulty of mathematical tasks in the game. The usability customization affects the user's performance in the game (Turkay & Adinolf, 2015); for instance, by choice of a specific user interface layout. Cosmetic customization refers to making choices about a game's visual or audio attributes without directly affecting the gameplay itself. Unlike the other types, it does not affect the game's content or usability, but modifies its surface (see also Plass & Pawar 2020). Thus, in the context of multimedia learning, it can be considered an *instructionally irrelevant choice* (i.e., irrelevant to the learning content; see Patall, Cooper, & Robinson, 2008). Cosmetic customization, for instance, includes any color changes to game elements, choice of background pictures, avatar customization (i.e., a user's virtual representation), but it may also include selection of background music (cf. Schneider, Nebel, Beege, & Rey, 2018), sounds, and other features. The present study is concerned with user-initiated cosmetic visual customization (note: *user-initiated* and *visual* is afterwards left out of the text for brevity).

According to Plass and Pawar (2020), the general goal of customization is "to optimize the acceptance of the game by the player" (p. 264). For instance, prominent cosmetic customization's subcategory - avatar customization - positively affects players' identification with their virtual representations (Turkay & Kinzer, 2014) and subjective feelings of presence, flow, or engagement (Bailey, Wise, & Bolls, 2009; Chen, Lu, & Lu, 2019; Ng & Lindgren, 2013). However, its effect on learning outcomes is still not clear (Plass & Pawar, 2020) and it falls outside the scope of this study. The present study is concerned with more general cosmetic customization features determining the look of the game's screen; for example, by enabling players to choose the central elements' appearance, background pictures, icons, and so forth. Within present study, this type of visual customization is referred to as *environmental cosmetic customization*. It is generally easier to implement than avatar customization, regardless of the genre, because it does not require any central characters. Such characteristics also make it possible to implement environmental customization features in other ADMLMs like instructional presentations or simulations lacking any game features.

Little is known about the instructional effects of these choice providing environmental cosmetic customization features in ADMLMs (Mayer, 2014b; Mayer, 2020a). On a practical level, filling in this gap would help instructional designers and ADMLMs developers by providing them with empirical evidence regarding the learning effects of environmental cosmetic customization features. On a more general level, the results can provide more insights into research of ADMLMs, like which design elements and features in instructional games have an impact on affective-motivational processes, learning outcomes (Mayer, 2014a; 2020a) and users' information behavior.

The present study addresses these issues by investigating environmental cosmetic customization features in ADMLMs within a theoretical framework of cognitive affective theory of learning with media (Moreno, 2005; Moreno & Mayer, 2007) and integrated cognitive affective model of learning with multimedia (ICALM; Plass & Kaplan, 2016; see Section 2.2). Similarly to the previous studies (see Chapter 4 & 5), the potential instructional and information behavioral effects of cosmetic customization features again lies in their ability to enhance the affective quality (Russell, 2003) of the learning materials (i.e., the game). According to ICALM's framework, which is informed by the *control value theory of achievement emotions* (Pekrun, 2006; Plass & Kaplan, 2016), the perceived controllability of activity influences the perceived enjoyment (Pekrun, 2006; Pekrun & Perry, 2014; Plass & Kaplan, 2016). This learners' sense of higher control can be potentially supported by choice provision included in environmental cosmetic customization features. Sense of higher control over game's design (e.g., the look of the plant and its environment) is also linked to increased positive states in the context of aesthetic emotional experience (Loderer, Pekrun, & Plass, 2020). In addition, choice provision (given here by the cosmetic customization features) is, by itself, capable to foster motivation to engage in target activity (i.e., the learning game in our case) by supporting the need for autonomy (Patall, Cooper, & Robinson, 2008; Ryan & Deci, 2000; 2017). All in all, resulting higher sense of control and autonomy supported by environmental cosmetic customization features in ADMLMs is likely to have a positive impact on affective-motivational processes (Pekrun, 2006; Plass & Kaplan, 2016). These processes then can impact learning and information behavior by boosted cognitive engagement and motivation drawn towards interaction with the target ADMLMs (Moreno, 2005; Moreno & Mayer, 2007; Plass & Kaplan, 2016).

However, evidence to support the described theoretical predictions in the specific case of environmental cosmetic customization features in ADMLMs is limited. Cordova and Lepper (1996), in their seminal study, let primary school children customize various features (e.g., a spaceship icon, its name, etc.) of a math game embellished by a fantasy context setting. Their investigation of customization's effects on motivation and learning outcomes included (apart from other things) a comparison of three versions of the game: a non-customizable basic version; a non-customizable fantasy version; and a customizable fantasy version (Cordova and Lepper used the term 'choice' to denote what is called here the *customizable version*). On the one hand, comparison of the basic version with either of the fantasy versions showed enhanced intrinsic motivation and improved learning outcomes in favor of the fantasy versions. On the other hand, the non-customizable and customizable fantasy version differed only in their levels of enjoyment (interpreted as an indirect measure of intrinsic motivation), but not in their learning outcomes. In other words, there were no differences in learning outcomes when only the customization features were manipulated.

Although the sample size per condition was small in this study (n = 14) and any conclusions are therefore limited, these results might point to limits of the learning effects of customization features in DGBL. The discrepancy between positive theoretical predictions and Cordova and Lepper's (1996) findings can possibly be explained within ICALM and CATLM by the inherent processing limits of working memory (Mayer, 2009; 2014b; Plass & Kaplan, 2016; Sweller 1994; 2011; see also Section 2.2). In this context, cosmetic customization features can be viewed as instructionally irrelevant elements, and thus causing extraneous processing and distractions that draw limited cognitive resources away from the target instructional task. This mechanism can possibly annul the potential learning-related beneficial effects of customization features (see Figure 23). In the case of children learners, this issue can be even more prominent due to their smaller amounts of available mental resources (Gathercole, et al., 2004).

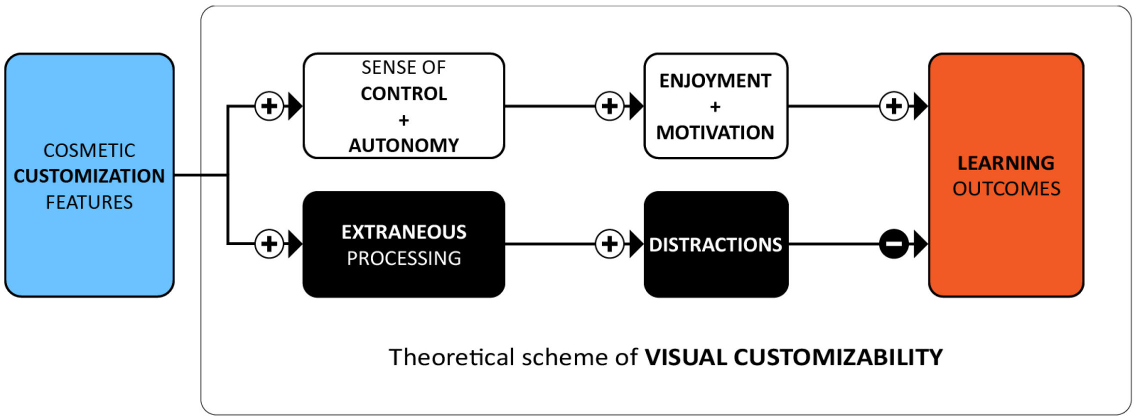

Figure 23. Theoretical model scheme of the possible contradicting effects of cosmetic customization features.

Iyengar and Lepper (1999; Exp. 2) used the same intervention (as Cordova & Lepper, 1996) and worked with a larger sample (*N* = 88), but they focused instead on the effects of cultural context and not on the presence or absence of customization features as such. Plus, both aforementioned studies were done in the mathematical domain; that is, they addressed the acquisition of cognitive skills. It is not clear whether these results would also apply in cases like learning how natural systems or processes work; that is, to transfer including the construction of mental models (see Section 2.1). Partly related studies examined the effects of the already discussed *avatar customization* (e.g., Bailey, et al., 2009; Chen, et al., 2019; Ng & Lindgren, 2013; Turkay & Kinzer, 2014), which, however, only included the specific customization of virtual characters representing users. Although avatar customization seems to be potentially beneficial for learning (Ng & Lindgren, 2013; Tam & Pawar, 2020), these studies did not focus on more general customization of learning environment as Cordova and Lepper (1996) and Iyengar and Lepper (1999) did.

All in all, the instructional effects of environmental cosmetic customization features in DGBL appear only to have been examined by the two studies described above (i.e., Cordova & Lepper, 1996; Iyengar and Lepper, 1999, Exp. 2). Available empirical evidence is therefore limited due to the small sample size of these studies, their narrow focus on mathematical cognitive skills, and also their outdated target game design. The present study addresses these limits and examines the effects of environmental cosmetic customization features in ADMLMs on affect-related variables and learning outcomes in cases involving primary school children and using a larger sample.

6.2 This Study – Visual Customizability

The focus of this study is the environment visual cosmetic customization features. Effects of such features on perceived learning enjoyment, free-choice behavior, and immediate as well as delayed learning outcomes are investigated in an educational game for primary school children. Children studied about the process of photosynthesis from one of two versions of a target multimedia learning game. The experimental version of the game included environment cosmetic customization features, the control version did not. Both versions of the target game were identical from the instructional and visual appearance design perspective. Based on the reasoning above, following hypotheses were put forward:

H1: Environmental cosmetic customization features will lead to enhanced self-reported enjoyment.

H2: Environmental cosmetic customization features will motivate children to re-engage in interaction with the experimental customizable version of the target game more than with the control version.

However, even if these customization features enhance children's perceived enjoyment and free-choice behavior, their effect on learning outcomes is not clear. This is due to the contradicting perspectives on the possibly beneficial cognitive-affective but also negative extraneous processing effects of such features within chosen theoretical frameworks (see Figure 23). Therefore, the following exploratory goal was put forward:

Exploratory goal: What is the effect of environmental visual cosmetic customization features on immediate as well as delayed learning outcomes compared to the ADMLMs without such features.

6.3 Method

6.3.1 Participants

Participants were Czech children (N = 143) aged 9-11 years old (M_{age} = 9.41; SD_{age} = 0.67; 59 girls), recruited via a call for participants on Czech Television's children's channel's website. Data was originally collected from 156 participants, of which 13 were excluded due to the technical deficiencies of audio recordings needed for analysis or technical issues where the target game caused loss or distortion of data. Participants were randomly assigned (balancing for gender) to either the control (n = 73) or the experimental group (n = 70). All participants received Czech Television merchandise and a LEGO set (of ~20 EUR in value) at the end of the session. Sample size was determined based on a priori power calculations in G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007). Sixty-four participants were needed per group to detect medium effect size (Cohen's d = 0.5) using independent t-tests (for α = .05 and 1-β = .80).

6.3.2 Materials

The target game's (see Section 3.1) content and functionality were further adjusted to fit the needs of the present study (see Figure 24). Apart from previous studies (see Chapter 4 & 5), players' global goal, introduced at the beginning of the game, was to build a full-grown plant in order to feed an animal. Yet, players' central task to keep the plant hydrated by controlling the number of roots and to collect more energy through photosynthesis, remained the same.

Figure 24. Visual customizability version of the target learning game. Example screenshot from the target learning game.

The customizable version (experimental), at the beginning of the game, allowed participants to choose the animal, name it, pick a plant they wanted to grow and the environment wherein they wanted to grow it (see Table 16). The options were consulted with an expert on this topic to ensure that all the combinations could appear in nature so as to avoid misconceptions (see Table 1). In the non-customizable version (control), a specific animal, its general name, plant, and the environment were given without the possibility to rename the animal or to choose from any of the other options (the existence of other options was not revealed). Every control group participant was yoked (i.e., paired) with an experimental group participant, in such way that combinations given to the former corresponded to the choices made by the latter. Therefore, for each pair of yoked participants, the selected options were the same in order to eliminate bias for one specific combination. All the other aspects of the game remained identical.

A manipulation check was done in a pilot study (N = 9, different than the main study's participants). Both versions were shown to the children who were asked to choose the version they would like to interact with the most. All of them preferred the customizable version.

Table 16

Customizable elements of the target game's environment

Customizable elements	Options		
Animal children are tasked to feed by the plant (icon in the game)	 Sheep	 Deer	 Hare
Name of the animal		(Free text input)	
Plant children are tasked to grow (central element)	 Knautia	 Aster	 Cornflower
Environment where children are tasked to grow the plant (background element)	 Meadow	 Balk	 Forest

6.3.3 Additional Measures – Delayed transfer

The same questions and evaluation as in case of near transfer knowledge test (see Section 3.2) were in present study used for the *delayed transfer knowledge post-test*, which was conducted via phone approximately two weeks after the initial intervention. Evaluation of the test by two independent raters showed sufficient agreement (r = .91).

6.3.4 Procedure

The children were individually tested in laboratory conditions with one administrator. At the very beginning of the session, adults accompanying the children filled in the informed consent form and left the lab. Participants were then briefly introduced to the experiment and familiarized with the six-point smiley scale (see Section 3.2.2). After the introduction, they played the comparison game for approximately 5 minutes. Thereafter, they were asked about their prior domain interest during the semi-structured interview, which was followed by the comprehension drawing pre-test. Prior domain knowledge was inquired after orally. This was done following the pre-test so that the multiple-choice cueing questions did not confound the results of the pre-test. In the next phase, the participants played the target game (a customizable or non-customizable version based on their assigned group) for approximately 20 minutes. After the game, participants reported their learning enjoyment using the smiley scales printed on paper. Next, they were given the drawing comprehension post-test and subsequent oral transfer test questions. At the end of the session, participants were told that there was still some time left, and they could choose (free-choice period) if they wanted to continue to play the target game or the comparison game (see Section 3.2.5). The whole session took approximately one hour on average.

6.3.5 Data analysis

Data was analyzed using the statistical software R 3.6.0 (R Core Team, 2019). Differences between the experimental and control groups were tested using independent t-tests and with a one-way analysis of covariance (including interaction between grouping variables and covariates, ANCOVA). ANCOVA was used to strengthen the findings by including covariates regarding prior interest and knowledge. Effect sizes for t-tests were expressed using Cohen's d with classification into small

(Cohen's d ~ 0.2), medium (Cohen's d ~ 0.5), and large (Cohen's d ~ 0.8) as suggested by Cohen (2013). Effect size η_p^2 for the ANCOVAs was used with similar classification (Cohen, 2013) into small (η_p^2 ~ 0.01), medium (η_p^2 ~ 0.06), and large (η_p^2 ~ 0.14). X^2 tests of independence were used for categorical variables regarding game selection in the free-choice period.

6.4 Results

6.4.1 Control variables

To verify that experimental and control groups were sampled equally, differences between groups for prior interest and prior knowledge (concepts and terms) were measured. As shown in Table 17, the differences were not significant.

Table 17

Prior checks – Differences between customized and control group in selected sampling variables

	Group					
Variable	Experimental	Control	*t*	*df*[a]	*p*	Cohen's *d* [95% CI]
Domain interest	5.34 (2.22)	5.58 (1.85)	-0.65	117	.517	-0.12 [-0.48, 0.24]
Terms prior	2.41 (1.34)	2.43 (1.27)	-0.09	141	.930	-0.01 [-0.35, 0.32]
Concepts prior	1.08 (0.73)	1.02 (0.68)	0.49	139	.626	0.08 [-0.25, 0.42]
Compre. prior	1.57 (1.39)	1.62 (1.33)	-0.25	141	.805	-0.04 [-0.37, 0.29]
Time on task	16.21 (2.07)	15.60 (2.47)	1.59	141	.114	0.27 [-0.07, 0.60]
Age	9.32 (0.66)	9.50 (0.68)	-1.65	141	.101	-0.28 [-0.61, 0.06]
	Girls		x^2			
Gender	30 (41%)	29 (41%)	<0.01	1	.968	

[a]*Degrees of freedom differ due to missing responses for the given variable.*

6.4.2 H1: Enjoyment

The comparison of differences in self-reported enjoyment with the use of a smiley scale (see Section 3.2.2) has not revealed any differences between the groups (see Table 18). Therefore, no measurable effect of environmental customization features on enjoyment was found.

6.4.3 H2: Free-choice behavior

In the case of the free-choice behavior measure, the proportions of choices between the target game and the comparison game in each group were compared and no significant difference has occurred (see Table 18). Thus, H2 has not been supported. Of note, however, this does not mean that the manipulation check failed. On the contrary: all children did prefer the experimental version when they were shown *both* versions during the manipulation check conducted with participants different from this study's participants ($N = 9$; see Section 6.3.2).

6.4.4 Exploratory goal

To explore the learning effect of environmental cosmetic customization features, both groups were compared based on comprehension and transfer scores including the delayed posttests. As shown in Table 18, there were no differences between groups. Similar results were obtained when prior knowledge (concepts, terms) or prior interest were added as covariates (all ps ≥ .175). Additionally, the correlations of variables are presented in Table 19. To summarize, no expected detectable effect of environmental customization features on learning outcomes has been observed.

Table 18

Differences between customized and control group in learning outcomes, enjoyment and motivation

	Group					
Variable	Experimental	Control	*t*	*df*[a]	*p*-value	Cohen's *d* [95% CI]
Comprehension post	3.14 (1.84)	3.27 (1.61)	-0.48	141	.635	-0.08 [-0.41, 0.25]
Comprehension diff.	1.57 (1.34)	1.65 (1.55)	-0.34	141	.737	-0.06 [-0.39, 0.27]
Transfer post	8.78 (2.64)	8.42 (2.61)	0.80	139	.423	0.14 [-0.20, 0.47]
Transfer delayed	7.93 (2.60)	7.90 (2.45)	0.08	135	.938	0.01 [-0.32, 0.35]
Enjoyment[c]	1.38 (0.79)	1.30 (0.55)	0.73	141	.466	-0.12 [-0.45, 0.32]
	Target game preference		x^2			
Free-choice[b]	75%	67%	0.73	1	.394	

[a] Degrees of freedom differ due to missing responses for given variable.

[b] Numbers and percentages of those picking the plant growing game (the assigned version) are given.

[c] Lower values mean higher enjoyment; *d* is thus reverse coded.

Table 19

Correlation between variables in Visual Customizability Study

	Concepts prior	Terms prior	Domain interest	Comprehension pre	Comprehension post	Transfer post
Terms prior	0.62*** (141)					
Domain interest	0.32** (117)	0.41*** (119)				
Comprehension pre	0.48*** (141)	0.58*** (143)	0.28* (119)			
Comprehension post	0.40*** (141)	0.43*** (143)	0.26** (119)	0.59*** (143)		
Transfer post	0.43*** (139)	0.32*** (141)	0.30*** (117)	0.35*** (141)	0.43*** (141)	
Transfer delay	0.45*** (135)	0.30*** (137)	0.22* (113)	0.37*** (137)	0.46*** (137)	0.68*** (135)

* $p < .05$ ** $p < .01$ *** $p < .001$

6.5 Interim Discussion

This last study examined the effects of user-initiated environmental visual cosmetic customization features in ADMLM game-based instances on children's perceived learning enjoyment, learning outcomes, and information behavior. The manipulation was done in an ecologically relevant fashion and in line with previous studies (Cordova & Lepper, 1996; Iyengar & Lepper, 1999). The results showed no detectable effect of the manipulation on any of these variables. From the theoretical perspective of ICALM (Plass & Kaplan, 2016) informed by control-value theory (Pekrun, 2006; Pekrun & Perry, 2014), the investigated cosmetic customization features were insufficient to support learners' sense of greater control; hence, the features did not have a significant effect on the affective-motivational processes, and, in turn, did not lead to enhanced learning outcomes. Yet, in terms of information behavior, children might still prefer the customizable version when they are given the possibility to directly compare it with the non-customizable one: as shown in the pilot study.

At the same time, as relates to potential cognitive distraction caused by the investigated customization features, either no or undetectable negative effects of extraneous processing occurred. Otherwise, learning outcomes would have been lower in the experimental group, because no significant differences in affective-motivational variables occurred (see Figure 23). This could be because the choices (i.e., customization features) were provided in the ecological fashion (and in line with the study by Cordova & Lepper, 1996) at the beginning of the gameplay. Thus, they did not directly interfere with the subsequent instructional content.

All in all, environmental cosmetic customization features appeared to have limited effects on the affective-motivational variables and no measurable effects on learning outcomes. Therefore, environmental cosmetic customization features appear to be a less promising design element in ADMLMs from the emotional design perspective: especially when children cannot choose between the target task (i.e., the game) and alternative material, as tends to happen in more formal settings (e.g., in schools). The jury is still out as concerns situations when children's information behavior plays an important role and they *can* choose the material they wish to interact with (e.g., doing one's homework, web browsing in leisure time, etc.).

Empirically, present results agree with the findings of Cordova and Lepper (1996) as concerns null results for learning outcomes. However, contrary to their findings, this study did not reveal any effect of environmental customization features on children's perceived enjoyment and motivation. It is worth mentioning that Cordova and Lepper (1996) used a small sample ($n \sim 14$ per cell), so confidence intervals were quite large in their case, but the effects they have found still cannot be dismissed. One possible explanation for the discrepancy between the present and Cordova and Lepper's (1996) findings is the different cultural context, which can potentially be an important factor (Iyengar and Lepper, 1999). Investigated customization features can have limited affective-motivational effect in the case of Central European children. A previous study (Stárková, Lukavský, Javora, Brom, 2019) showed another case where a multimedia learning study examining an intervention's motivational factors yielded different results on a sample from Central Europe compared to samples from the United States or Germany.

Another explanation of the null results could be the fact that both versions of the target game were already well-optimized from the perspective of design principles for multimedia learning (Mayer, 2009; Mayer, 2014b). That is, they both followed several multimedia learning principles (see Section 2.2 & Section 3.1 for further details) to support the efficient use of cognitive resources during the learning process. Plus, the graphical design of the game was already visually appealing for children (as detailed in the Visual Appearance Study; see Chapter 4) and potentially increased positive emotions in the context of the aesthetic emotional experience (Loderer, Pekrun, & Plass, 2020). Therefore, it is possible that the target learning game was already affectively stimulating and cognitively efficient enough in both conditions. The present data supports this assumption because in both conditions it shows relatively high perceived enjoyment, overall preference for the target learning game over the comparison game (see Table 18), improved comprehension, and relatively high transfer scores (see Table 18). Thus, it is possible that environmental cosmetic customization features in the experimental version were not able to cause any additional difference. Had the target game's design not followed multimedia learning principles and had it not been visually appealing, as could have been the case with Cordova and Lepper's study (1996; see Figures 1 and 2 in their paper), positive affective-motivational effects of the customization features might have occurred. Finally, null results could be also explained by the relatively short duration of the intervention (15-20 minutes on average; one session). For instance, children in the study by Cordova and Lepper (1996) attended three 30-minute-long experimental sessions. Although investigated cosmetic customization features in the present study did not have any effects after one session, prolonged or repeated interactions with the target game could be an important moderating factor requiring further investigation.

The present results also stand in contrast to the effects of avatar customization, which has been shown to be potentially instructionally beneficial (e.g., Ng & Lindgren, 2013) or to improve affective-motivational variables (Chen et al., 2019; Turkay & Kinzer, 2014). Compared to avatar customization, cosmetic customization features used in the present study intentionally omitted customization of the learner's virtual character appearance. The only seeming exception is the choice of an animal and its name because it is similar to the concept of avatar customization done prior to the gameplay. In both cases (environmental and the avatar customization), the choice is irrelevant to the instructional content and its outcome is visually manifested during the interaction. However, the animal did not represent the learner's virtual appearance. Therefore, it may have lacked the ability to affect sufficiently the learners' sense of identification. This supports the assumption that the identification factor might be a promising area for further research (see Tam & Pawar, 2020).

From a practical perspective, the implication appears to be that the development and implementation of environmental cosmetic customization features investigated in this study can be omitted in the case of ADMLMs for children. This is because it affords negligible affective-motivational and learning benefits. However, the possibility that when children can choose materials to interact with, environmental customizable features may increase the chances that children will start to interact with such learning materials in the first place, or interact with them longer (i.e., information behavior), cannot be excluded. In this regard, it is important that the present manipulation did not have any observable detrimental effects on learning (e.g., due to extraneous processing). Present approach was also ecologically relevant because customization is generally done prior to gameplay. In short, when developers *do* implement cosmetic customization features at the beginning of gameplay, it may help to draw children's attention to the game without compromising learning processes; but more empirical evidence is needed.

6.6 Limitations

There are several limitations present in this study. First, it included a population with a specific cultural background and thus generalization to other cultural contexts may be problematic (cf. Iyengar & Lepper, 1999, discussed above). More research in different cultural contexts is needed to draw general conclusions. Second, the study was conducted in a laboratory setting. As discussed above, results may differ in contexts that offer children several alternative choices (i.e., other than playing the learning game). Third, the results could be influenced by the ways which environment cosmetic customization features are implemented. It has already been discussed that avatar customization features, so far, appear to be more beneficial to learning. Additionally, Cordova and Lepper (1996) made the case that user-initiated cosmetic customization may be more beneficial when implemented in combination with system-initiated personalization features. They used, in their experiment, two additional groups ($n \sim 14 + 14$) that both applied the same levels of system-initiated personalization features. One of these two additional groups included user-initiated cosmetic customization features (i.e., choice provision) and the other did not. Differences between these two groups were detected both in learning outcomes and in motivational variables: in favor of the customizable version (i.e., having also system-initiated personalization features). Therefore, combination of customization with other features, and the possible moderating effects of those additional features, should be examined in future research. Fourth, as already mentioned, the intervention was relatively short (15-20 minutes on average) and it occurred in one session (this enabled to work with a large sample, which was one of the initial goals of this study). Longer durations of the intervention and reoccurring sessions might potentially reveal positive effects of the investigated customization features. Fifth, the used measures might not have been sensitive enough. As concerns the affective-motivational measures, this idea cannot be excluded; especially because children preferred the customizable version in the pilot study. However, this limit is less likely in the case of knowledge tests, as they were calibrated and used also in the previous studies (see Chapter 4 and 5). Finally, distraction, or cognitive load (Sweller 1994; 2011), induced by the cosmetic customization features, was not measured as this is notoriously difficult with children. Hence, it can be only indirectly theorized about the degree of distraction cosmetic customization features have.

6.7 Conclusion

Considering the results of the present and previous studies, it can be concluded that environmental cosmetic customization features (i.e., specific types of visual customizability) in ADMLMs for children are not necessarily instructionally beneficial. Their implementation in the learning game investigated in this study did not have significant impact on affective-motivational variables. It also did not foster learning outcomes; though it did not hinder them either. Yet children are sensitive to this type of manipulation, as witnessed when they were tasked with contrasting the customizable vs. the non-customizable versions in the pilot study. However, the effects on children's information behavior are not fully clear and further evidence is needed. The practical implication is that development and implementation of environmental cosmetic customization features can be omitted in ADMLMs for children. This holds true especially when the materials are already appealing to children without these features, or provided the material appropriately adheres to proven multimedia learning principles and children's autonomy to choose instructional materials is limited. Other types of user-initiated cosmetic customization, such as avatar customization or combinations of customization with system-initiated personalization, could be more promising for learning. However, empirical evidence is still limited, and additional research is needed. The following chapter discusses possible general implications and conclusions that can be derived from the results of all three studies combined.

PART III. – Summary

7 General Discussion

The three experimental studies included in the present thesis focused on the effects of visual appearance, visual dynamicity, and visual customizability (i.e., visual design aspects) in advanced digital multimedia learning materials (ADMLMs) on children's learning and information behavior. These two key concepts were expected to be influenced by children's affective-motivational processes based on the reasoning from the chosen theoretical frameworks. These frameworks included the cognitive affective theory of learning with media (CATLM; Moreno, 2005; Moreno & Mayer, 2007), the integrated cognitive affective model of learning with multimedia (ICALM; Plass & Kaplan, 2016) and several information behavior models (Kuhlthau, 1991; 2017; Nahl, 2007; Nahl & Bilal, 2007; see also Savolainen, 2015).

The results of all studies revealed several reoccurring patterns and trends (see Table 20). As concerns the first research question, whether investigated visual design aspects of information representation in ADMLMs (i.e., information-as-thing) influence primary school children's learning outcomes (i.e., information-as-knowledge); they generally did not significantly impact the outcomes in any direction. Yet, as concerns the second research question, all the manipulations showed some capability of the investigated visual design aspects to influence children's information behavior. This was reflected in their willingness to interact with the embellished ADMLMs (i.e., the target learning game) when the children could directly compare both versions of the target learning game.

Table 20

Results of all studies combined

	Experimental group		Control group							
	Mean	SD	Mean	SD	*t*	*df*	*p*	*d*	95% CI *d*	
Comp. post VA	1.96	1.36	2.31	1.52	-0.86	49.39[a]	.392	-0.24	-0.80	0.32
Comp. post VD	2.77	1.46	2.98	1.55	-0.78	131	.434	-0.14	-0.48	0.21
Comp. post VC	3.14	1.84	3.27	1.61	-0.48	141	.635	-0.08	-0.41	0.25
Comp. diff. VA	0.37	0.58	0.92	1.21	-2.13	35.83 [a]	**.040**[b]	**-0.59**	-1.16	-0.02
Comp. diff. VD	1.18	1.32	1.44	1.15	-1.19	131	.237	-0.21	-0.55	0.14
Comp. diff. VC	1.57	1.34	1.65	1.55	-0.34	141	.737	-0.06	-0.39	0.27
Transf. post VA	9.92	2.75	10.36	2.65	-0.59	50.73 [a]	.558	-0.16	-0.71	0.39
Transf. post VD	9.19	2.90	9.58	2.55	-0.83	132	.409	-0.14	-0.49	0.20
Transf. post VC	8.78	2.64	8.42	2.61	0.80	139	.423	0.14	-0.20	0.47
Transf. del. VC	7.93	2.60	7.90	2.45	0.08	135	.938	0.01	-0.32	0.35
Enjoyment VA	1.62	0.85	1.34	0.48	-1.48[c]	39.12 [a]	.148	-0.41[c]	-0.96	0.15
Enjoyment VD	1.43	0.69	1.33	0.60	-0.86[c]	132	.391	-0.15[c]	-0.49	0.19
Enjoyment VC	1.38	0.79	1.30	0.55	-0.73[c]	141	.466	-0.12[c]	-0.45	0.32
Attract. VA	1.58	0.70	2.37	1.08	3.18[c]	44.88[a]	**.003**	**0.87**[c]	0.29	1.45
Attract. VD	1.79	1.14	3.32	1.06	12.90[c]	133	**< .001**	**1.11**[c]	0.86	1.37
					x^2					
Free choice VA					21.27	2	**< .001**			
Free choice VD					87.04	1	**< .001**			
Free choice VC[d]					0.73	1	.394			

Note. VA – Visual Appearance Study; VD – Visual Dynamicity Study; VC – Visual Customizability Study.

[a]*df* corrected for unequal variances.

[b]The result is similar when tested using ANCOVA with prior knowledge of concepts used as a covariate (p = .041) or a Wilcoxon rank sum test (p = .061). The result is not significant though when the Holm-Bonferroni correction for multiple comparisons is used (Holm, 1979).

[c]Lower values mean higher scores; *d* and *t* are thus reverse coded.

[d]The table shows a comparison of target game versions only with the comparison game (unlike in the case of the VA and VD Studies). Direct comparison of both target game versions against each other in the pilot of the Visual Customizability Study revealed that 9 out of 9 children preferred the experimental version.

Although the investigated visual design aspects in none of the present studies have led to improved learning outcomes, their capability to potentially impact children's information behavior still makes them instructionally rather beneficial. On one hand, as concerns short-term learning scenarios and their effects on immediate (and also delayed, see Chapter 6) learning outcomes, it can be concluded that all of the investigated visual design aspects failed as potential new emotional design principles. This is because the investigated visual design aspects did not show any detectable positive impact on the children's knowledge construction (i.e., meaningful learning, see Section 2.1) and resulted learning outcomes (see Table 20). On the other hand, the discussed effects of investigated visual design aspects on children's information behavior can turn out to be potentially instructionally beneficial in the case of long-term learning scenarios. That is due to the capability of such visual design aspects to function as "gatekeepers", which might enable or prevent their interaction with the target ADMLMs in the first place. In addition, as shown by Enders, Weyreter, Renkl and Eitel (2020), they can potentially sustain learner's interest and motivation to interact with the learning materials in the long run. These effects might eventually lead to higher total time-on-task, and thereby, improved learning outcomes. However, more research and empirical evidence is needed in this direction.

These possible long-term related beneficial instructional effects have potentially the biggest implication for the formally uncontrolled learning settings. This includes situations like self-controlled formal learning (e.g., doing homework, school-related studying), informal learning (e.g., learning about one's own interests), or leisure time (e.g., web browsing), where individual preferences, decisions and information behavior play a crucial role. For instance, the overall visual appearance of learning materials might lead children to prefer one instructional material over the other, regardless of the content's quality. Such a scenario is highly probable due to everyday usage of information technology (Rideout & Robb, 2020; Smahel et al., 2020), which puts an immense number of various ADMLMs of varying quality (e.g., online videos, websites, apps, and games) at children's disposal.

It is also important to stress here that design aspects were not harmful to learning in any of the present studies investigated, as was supposed by cognitive load theory (Sweller, 2014; Sweller, van Merriënboer, & Paas, 2019, see also Plass & Kalyuga, 2019). In other words, potential detrimental seductive detail effects (see Mayer, 2020; Rey, 2012; Sundarajan & Adescope, 2020) of investigated visual design aspects were not found. On the contrary, additional eye-tracking measures in the Visual Dynamicity Study (see Chapter 5) showed a rather unobtrusive nature of dynamic visual design embellishments treated in emotional design fashion. An alternative explanation, where investigated visual design aspects have beneficial effects on cognitive processes but these effects were annulled by detrimental effects connected to extraneous processing, is less likely. That is because in such cases, the higher scores of perceived learning enjoyment in instances of experimental embellished versions should have occurred in combination with no, or small observable differences in the learning outcomes. Yet, no such pattern was revealed in any of the present studies (see Table 20).

Finally, the absence of any learning improvements could have also been caused by the application of several multimedia learning principles simultaneously. All versions of the target learning game were designed (see Section 3.1) using multiple multimedia learning principles (Mayer, 2014c; 2020) to ensure the game's instructional efficiency and ecological relevancy; and all of these versions applied these principles to similar extents. As has already been discussed above, all versions of the target learning game in the present thesis were accompanied by improved pre-post comprehension and relatively high transfer scores and reports of perceived learning enjoyment (see Table 20). In this perspective, all versions can be considered instructionally efficient and stimulating. It is not clear whether the investigated visual design aspects are able to cause any detectable difference in learning outcomes when the learning materials are already stimulating and instructionally sufficient. In other words, there might be certain levels of individual cognitive engagement, which cannot be or only barely further improved.

What would happen if the target learning materials were *instructionally* poorly designed but embellished as concerns the visual design aspects? Whether differences in affective-motivational variables and learning outcomes would occur is not clear. Yet, such a situation is ecologically relevant because game designers, graphic designers (making learning games or animations), or teachers (making slides), for example, do not have to be necessarily aware of proven instructional design principles and cognitive processes involved in learning. In addition, situations when the ADMLMs are poorly *visually* designed can also be ecologically relevant in some scenarios. For instance, some teachers and professional lecturers producing ADMLMs (e.g., interactive slides, videos, etc.) for their students, might lack a visual design background. In such cases, it is even more important to assure the ADMLMs' instructional efficiency because poor visuals can hamper students' motivation and possibly cause detrimental changes in their information behavior. This applies especially to less controlled settings (e.g., self-controlled formal learning, homework assignments, etc.) where students have more alternatives at their disposal. All in all, the investigated visual design aspects' capability to cause significant differences in learners' preferences and motivation (which are related to information behavior) again speaks in favor of the overall importance and usefulness of visual design aspects in ADMLMs.

Present findings also revealed possible limits of the affective-motivational measures used in this study. These limits were especially apparent in the experimental design of the Visual Customizability Study (see Chapter 6), which differed from the rest through seemingly slight changes in the procedure. Participants in this study were intentionally not provided with the direct comparison of both versions of the target learning game during the free-choice period: They only knew about the existence of the version assigned to them (i.e., either customizable or non-customizable). Thus, they were able to compare that version only with the comparison game and not with the alternative version of the target game. Under such circumstances, no detectable differences in free-choice behavior occurred. However, at the same time, the pilot study showed that children are sensitive to the presence or absence of visual customizability features in ADMLMs (when shown both versions): Children tended to prefer strongly the interaction with the embellished (i.e., customizable) version of the target learning game. Similar issues could also occur in the case of perceived learning enjoyment, which lacked the direct comparison of both versions in all three studies. All in all, the direct comparison of alternative learning materials (or mere awareness about alternatives) can substantially influence changes in children's preferences and impact motivation/information behavior.

However, when the effects of visual design aspects are strong enough, the detectable differences may appear also in cases of between-subjects study design lacking direct comparison of multiple stimuli.

For instance, in the case of the Visual Appearance Study, the significant difference in the evaluation of the target game's attractiveness had already occurred before the revelation of the alternative version (see Chapter 4). In this case, the direct comparison of both versions made the difference in the attractiveness evaluations stronger (see Table 7). Nevertheless, when children know about the more stimulating alternative materials, there is a high chance that they will prefer them. Yet, in the opposite case, when children do not know about any alternative learning materials, or they have limited options for direct comparison, their information behavior might stay intact. For future value-added studies (see Mayer, 2014b; 2019), which include comparison of different versions of the target stimuli, it might be beneficial to use multiple measures: that is, before the direct comparison of both versions (reflecting situations in controlled learning settings like schools) and after the comparison (corresponding to uncontrolled learning settings like leisure time activities).

Despite the abovementioned limitations (i.e., direct comparison vs. no comparison) of used measures, for the sake of discussion let us assume that these limitations are minimal; that is, the measures (perceived learning enjoyment, free-choice behavior) reveal the true impact of the interventions on underlying constructs (enjoyment and motivation). What would that mean within the context of the chosen theoretical frameworks? Present findings would appear to be consistent with the ICALM's theoretical framework (Plass & Kaplan, 2016). This is because no study has shown any contradictions between perceived learning enjoyment and learning outcomes. In fact, the enjoyment evaluations were generally high regardless of the given version of the target game (see Table 20). Thus, both versions of the target game in each study would be, in this perspective, equally stimulating as concerns enjoyment and, thereby, cognitive engagement. At the same time, participants improved in immediate comprehension (pre-post), and transfer test scores were relatively high regardless of the assigned version of the target learning game in each study (see Table 20).

However, overall high enjoyment in all studies differed from the children's motivation towards interaction with one of the target game's versions (i.e., free-choice behavior measure; see Section 3.2.4). Although the generally high enjoyment did not significantly differ between the groups, children still showed significant differences in their motivation by strongly favoring interaction with the target game's visually embellished version in the free-choice period. Within the ICALM framework, this difference might provide additional, more detailed information about a learner's affective-motivational processes and possible impacts on learning. In other words, in cases when multiple options are equally stimulating in terms of enjoyment and related immediate learning outcomes (as in the case of different target learning games' versions), the significant differences in motivation/information behavior can still potentially influence users' learning in the long run. Although more investigation is needed in this area, it still advocates for the incorporation of multiple affective-motivational measures in similar future value-added studies.

8 Future Research

As concerns future research, the discussed gaps in the findings of the present thesis can help to delineate possible directions for further investigation. More attention could be given to the possible beneficial effects of ADMLMs' visual design aspects in long-term learning contexts. Such studies could include formal as well as informal learning scenarios. Allowing participants to interact freely with the target learning materials outside of controlled laboratory settings could potentially bring more insights into the role of motivational factors and information behavior in relation to learning. This could also provide designers and developers with more information about the role of visual design aspects in ADMLMs and help them to make better evidence-based decisions during the production process.

Another possible area of future research is the investigation of simultaneous application of multiple multimedia learning principles. Such studies may answer the question of whether presumed limitations and ceiling effects in relation to learning outcomes occur at all. They also might reveal differences in the instructional efficiency and significance of already proven instructional design principles.

Future studies could also replicate and expand present findings by involving additional audiences; using different ADMLMs and learning domains; and investigating other ADMLMs' visual design aspects.

9 Final Comments

The present dissertation investigated the effects of ADMLMs' visual design aspects on learning and information behavior in the case of primary school children. These aspects (including overall visual appearance, visual dynamicity, and visual customizability) were individually examined in three consecutive studies. None of the studies found any significant beneficial effects on children's learning outcomes. Therefore, all visual design aspects investigated in this thesis failed as potential new emotional design principles that could improve cognitive processing involved in learning. Yet, all studies also showed these visual design aspects' ability to impact children's preferences, motivate children to interact with the target learning materials, and thus influence their information behavior. Moreover, none of the studies revealed any notable instructionally detrimental effects of these visual design aspects.

Should makers of ADMLMs allocate limited production resources to the enhancement of ADMLMs' visual design aspects, given that they are often connected with higher production costs? First, the present findings suggest that in uncontrolled learning settings (e.g., doing homework, web browsing), investment in enhanced visual design aspects may be justified. The use of information technology allows access to countless alternative entertainment contents and information sources with stimulating visuals. Therefore, neglecting visual design aspects in the case of target ADMLMs can lead to information behavior where children completely avoid such materials, despite any of their content qualities. However, enhancement of visual design aspects should always be carried out in emotional design fashion to avoid any possible subsequent detrimental effects on learning (e.g., caused by extraneous cognitive processing). Second, in controlled learning settings (e.g., a formal schooling context) where children are not aware of alternative learning materials, or they are not able to choose them, enhancements to ADMLMs' visual design aspects could probably be omitted. This is due to no, or a negligible, direct impact of visual design aspects on the learning process. This applies especially to cases in which learning outcomes are the main and only priority. However, other possible functions of ADMLMs visual design aspects, like cultivation of children's aesthetical tastes, should be considered.

The overall instructional role of ADMLMs' visual design aspects is still rather beneficial. That is because they do not harm learning, yet they are able to impact positively children's information behavior by motivating them to interact with target ADMLMs.

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List of Abbreviations

ADMLM	Advanced Multimedia Learning Materials
CATLM	Cognitive-affective Theory of Learning with Media
CLT	Cognitive Load Theory
DGBL	Digital Game-based Learning
ICALM	Integrated Cognitive-affective Model of Learning with Multimedia
VA	Visual Appearance
VC	Visual Customizability
VD	Visual Dynamicity

Attachments

Attachment A

Video showing excerpt (up to 5th level) from a gameplay of the target learning game used in this work (see Section 3.1) in case of experimental version in Visual Dynamicity Study. The English subtitles were added during the editing, and they were not part of the gameplay. The video does not reflect the real average gameplay duration (~20 min) and does not include narrated hints, which were controlled by experiment administrators based on a pre-specified protocol (see Section 3.1).

Attachment B

Video showing side-by-side screens with the videos from target learning game used for evaluation period in Visual Dynamicity Study (see Section 5.3).

Appendix

Table A1

Near transfer questions with a range of possible answers

No.	Question	Answers
1.1	In what type of weather it is beneficial for plant to close its stomata?	• Excess heat/ where there is a lot of sun.
1.2	And why?	• It does not lose water.
2.	If the plant's stomata are constantly closed what will happen? Say anything that comes to mind.	• Photosynthesis stops. • No CO_2 goes in (and/or no O_2 goes out). • It does not absorb water. • It does not lose water (alternatively – water cannot do anything). • It will stop growing and wither.
3.	What does the plant use energy captured through photosynthesis for?	• To grow. • To live.
4.1	What should the plant do if there is too little water in the soil? (Regardless of weather conditions)	• Close the stomata.
4.2	And why?	• In order to stop evaporation / prevent water loss. • *alternative* – It must slow down photosynthesis (possible extra points for explanation).
5.1	When does the plant absorb little water and when does it absorb a lot?	• A little when there is excess heat and a lot when there is ideal weather.
5.2	What is this dependent on (what influences it)? Say anything that comes to mind.	• The state of the stomata. • The amount of water in the soil. • The leaves/roots rationing water. • The heat/weather. • The size of the plant/number of leaves.
6.	Imagine that the plant has been infested by a rare fungus that clogs the vessels in the plant's stems so the water cannot flow up to the leaves anymore. What does this mean for the plant?	• Evaporation stops (and/or absorption of water stops). • Photosynthesis stops (and/or the plant cannot capture energy). • The plant withers/dies.
7.	Why it is better for the plant when there is cloudy weather, rather than when there is excess heat?	• There is a better ratio of captured energy/ water loss.

Note. Participants could receive up to 1 point for every answer (or 0.25, 0.5, or 0.75 points for a partially correct answer). Participants could express the ideas in their own words (exact wording was not required). Vague answers based on general prior knowledge were not rewarded.

List of Figures

List of Tables