Multimedia and Simulation Design for Effective Adult Learning: Implications for Educational VR

A systematic literature review into proven multimedia and simulation design principles

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Master thesis

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Summary

In practical occupations it is often difficult to prepare employees fully for their responsibilities, due to high unpredictability of the job. Known on-the-job and off-the-job methods are often intensive methods that only prepare employees partially. The increased accessibility to IVR simulations therefore seems promising, digital simulations make it possible to combine real-life irregularities with the safety of a practice area. However, there is limited to no understanding how IVR simulations should be designed in order to help the individual learn.

This thesis conducts two systematic literature reviews into multimedia educational design and educational simulations for adults. The first Study investigated proven multimedia educational design principles and investigated the different principles to reduce extraneous processing, manage essential processing, and foster generative processing. A total of nineteen articles were included in the results, in total for 31 experminetal groups the effect of multimedia design principles were investigated.

It was found that few design principles lead to positive results in multiple experiments, these were the signalling-, spatial contiguity-, redundancy- and modality principle. The segmenting principle had varying results but could be promising when segments are divided into information provided before a task and during a task. Finally, the self-explanation- and worked example principles cannot be recommended for the design of IVR simulations for adults.

The second Study investigated the potential simulation design principles for adult education. A total of four articles fulfilled the inclusion criteria of this systematic literature review. The results included different types of simulation and applied gamification. Although the results reported positive learning effects, it was unclear what caused these positive effects. Thus, unfortunately, this thesis cannot provide recommendations for IVR simulations for adults based on the results in Study 2. However, this thesis did shed light on an important trend in educational science. Namely, most of the knowledge that we currently have about effective educational design stems from research conducted in traditional school settings often with university or college students as participants. This knowledge cannot be generally applied to the targeted professional population, due to differences in age and literacy and numeracy skills.

Overall, this thesis adds to the knowledge base about educational design for adults. The Studies lead to practical recommendations for educational design as well as a critical note related to the necessary future research. This thesis demonstrated that more input is needed to unveil what adults with different study backgrounds need to effectively learn skills.

Keywords: skill learning, multimedia design, Immersive Virtual Reality, educational simulations, adult learning.

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Introduction

Environments in which practical skills are needed pose an educational challenge. Employees working in these environments need to know facts *and* they should know how and when to apply these facts in executing actions (Kraiger et al., 1993; Kratwohl, 2002; Yang et al., 2022). Examples of professions in which this is needed are nurses and operators. Currently, practical skills are taught through methods such as on-the-job coaching and simulating work situations (Alipour et al., 2009). However, on-the-job coaching is a resource intensive training method and therefore not ideal since a senior employee must always be available. Moreover, not every occupation nor situation lends itself for on-the-job coaching. First, on-the-job coaching can be a risky endeavor there is a higher chance of damage to material and injury (Carruth, 2017). Second, there is not always a senior employee available to train new employees through this method, for example due to retirement. In these instances, organizations need to redirect towards off-the-job training methods, such as physically simulating potential work situations (Nikendei et al., 2014). Unfortunately, simulating work scenarios follow a certain set of events or pre-written script, thus not accounting for the unpredictability that is the real world. Therefore, in using the known and understood methods, it is close to impossible to construct a training method in which the employees are fully trained in all aspects of the procedural skills. However, new technologies provide new opportunities.

Digital simulations delivered via Immersive Virtual Reality (IVR) could solve the issues that are currently being experienced in teaching practical skills, these simulations will henceforth be referred to as IVR simulations. IVR simulations can provide the learner with the possibility to place themselves in a digital simulated environment by using head-mounted displays (Kwon, 2019). By immersing a learner in a digital simulation of the real-world setting, it is possible to create an experience that is somewhere in between off-the-job and on-the-job learning. While using (hand-held) controllers, the learner is provided the possibility to experience the safety of off-the-job learning, while also being able to experience the unpredictability of on-the-job learning (Seo, 2019). Additionally, because it is a digital simulation, it is possible to have multiple people train at the same time.

Because of these benefits, the use of IVR simulations in educational settings has been increasing over the last years (Chen et al., 2020; Majchrzak et al., 2022; Radianti et al., 2020). First, the end-user is offered the possibility to repeatedly practice learning (Brewer, 2011). Second, IVR simulations can be used to practice situations which take place in high-risk environments, such as highway construction workers (Roofigari-Esfahan et al., 2022). Third, IVR is computer based, thus various data can be gathered, such as completion time (Khan et al, 2018; Şuşnea, 2013). Fourth, IVR offers the possibility to practice certain irregularities that are hard to recreate, such as fires within certain buildings (Seo, 2019). In conclusion, technological developments within IVR offers the education provided by simulations and on-the-job coaching with the added benefit of safety and irregularities of the real world.

In recent years, academic interest into applying IVR for learning has increased and the field is slowly maturing. Radianti et al. (2020) mapped the various VR trainings that have been investigated in research studies. Their main conclusions were that research thus far has been focusing on technological design, and that VR applications were mainly experimental and learning theories were often not considered. The lack of consideration of learning theories is quite problematic, since if learning theories were to be considered, the educational effects of IVR simulation trainings could drastically improve (Radianti et al, 2020).

This limited consideration of learning theories leads to the purpose for this research. Ideally, there should be a set of guidelines for the development of IVR simulations for education. Educational science is a mature field of research and provides insights into the best practices to make learning as effective as possible. Thus, it is a missed opportunity that little attention has been given to educational science regarding the development of IVR simulations for education.

IVR simulation seem to be the perfect solution for all the mentioned challenges, however it must be used carefully. As Frederiksen et al. (2020) pointed out, a learner receives a lot of information whilst using IVR simulations. Suddenly, all their senses are exposed to the learning materials, whereas in more traditional, lecture-based methods, the learner can easily look away. Providing all this information could have a negative effect on the learning process and could lead to hampering the learning effect, rather than improving it. Therefore, it is currently unclear what educational design elements lead to the success of an IVR simulation. And if it even does. Due to the limited knowledge that we currently have on this topic, it is impossible to determine if IVR simulations in itself contribute to learning.

However, multimedia educational design has been developed to ensure that the learner does not get overwhelmed by learning materials that provide information via multiple channels, for example the visual and auditory channels (Mayer, 2014a). Moreover, digital simulations have been used in education for quite some time. A digital simulation is different from IVR simulations because these can be provided via all sorts of technologies, such as a personal computer. Thus, by combining knowledge that already exists about MM educational design and the design of simulations for education, insights could be gathered into what design principles should be used to develop IVR simulations that have the potential to be beneficial for education. Especially when discussing educating professionals. When educational science is incorporated in IVR simulations for education, this could combine the benefits of off-the-job and on-the-job training by being a less resource intensive training with real world irregularities.

Study 1: Multimedia Educational Design of the Education of Adults

Theoretical Framework

Multimedia Learning

Thompson and Paivio (1994) developed the cognitive theory based on the *dual-channel assumption*. That theory assumes that humans can process information through two channels: the visual and auditory channel. That is the origin of multimedia (MM) educational design.

MM educational design was created to fully utilize the dual-channel assumption by ensuring that the visual and auditory channels optimally support each other. This form of educational design adheres to the cognitive theory of MM learning (Mayer, 2014a). An example of this utilization is seen in the very common lecture-based instructions. A lecturer is audibly sharing information, whilst visually supported by a slide deck that is presented on a large screen.

In order to retain information from the mentioned lectures, humans need to use their cognition to process information into their long-term memory. In human memory theories that process is referred to as cognitive processing. The cognitive processing happens whilst information is in the very limited working memory (Baddeley, 1992).

One must be careful with providing learners with information to process, since they have finite cognitive capacity (Sweller & Chandler, 1994). When a part of that capacity is used, that is called cognitive load (CL). To learn, learners always use some CL for cognitive processing, this requires the ability to focus on the educational materials. Anything that hinders that focus could negatively affect the cognitive processing, since that hinder takes up some of the limited cognitive capacity available.

Therefore, the cognitive theory of MM learning does not only consider learning through the visual and auditory channel, but it also takes into account the limited capacity of the working memory and CL. By adhering to these developed guidelines, it is possible to optimally use the learner’s ability to learn (Mayer, 2014a). These guidelines can be used in order to: 1) reduce extraneous processing; 2) manage essential processing; and 3) foster generative processing. These three main reasons will be further explained below.

Multimedia Educational Design to Reduce Extraneous Processing

The first reason for using MM educational design is to reduce extraneous processing. Which is all information that must be processed, which is irrelevant to understanding the materials. Extraneous processing takes up some of that precious CL. To understand how extraneous processing can take up CL, it must first be understood what element interactivity is. The level of element interactivity can be explained by the number of elements that must be understood at once to learn the material that is taught (Sweller, 2010). Low element interactivity also means that low CL is elicited to process the information.

At first instance, the degree of element interactivity refers to the degree of difficulty. However, element interactivity can also refer to filtering through the material to arrive at the information that is vital for understanding. This part of the theory focusses on the latter. Having to filter through unnecessary information to come to the essence is referred to as extraneous load (Mayer, 2014a). Extraneous load could be imposed by images, colours on a background or even an accent in the voice of the lecturer. According to Mayer and Fiorella (2014), there are five design principles that can be used to reduce the unnecessary extraneous load that is sometimes imposed on learners.

First, there is the *coherence principle*, which details that learners should only be subjected to the information that is needed to understand the lesson. In order to adhere to that, carefully examine if all the included figures and statements are necessary to understand the lesson.

Secondly, the *signalling principle* takes a learner by the hand by providing cues for processing the information. This can be done by showing the order in which information has to be organized, or by highlighting the most important words in a text.

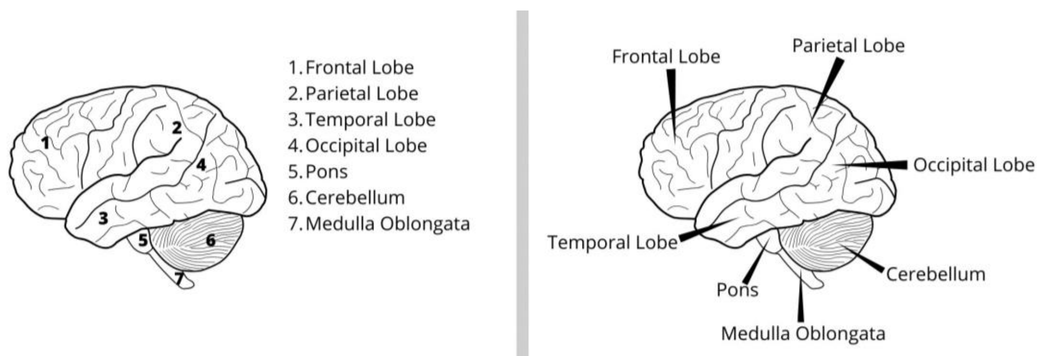
Third, the *redundancy principle* aims to ensure that the visual and auditory channel support each other. The learner should receive information either via narration or via printed words, not both.

Fourth, the *spatial contiguity* principle aims to reduce the amount of searching that needs to be done by the learner. This design principle encourages to place printed words next to their corresponding part of a graphic (Mayer & Fiorella, 2014). An example is displayed in Figure 1.

And finally, the fifth principle is *temporal contiguity*. This design principle is closely related to the spatial contiguity principle and is again aimed at optimal use of the visual and auditory channel. However, temporal contiguity mostly relates to the timing of the audio and visual message. These should, ideally, be presented at the same time and otherwise very close together. Otherwise, the learner must hold information in memory.

Figure 1

Example of the Application of the Spatial Contiguity Principle.



Multimedia Educational Design to Manage Essential Processing

Essential processes are slightly different to extraneous processes. Essential processes focus on element interactivity as well, but it focusses on the difficulty of the material. Essential information needs to be processed, but, due to high element interactivity, is difficult and dense. Hence, as a rule, more CL is needed to process the information. The presented information is all relevant, but when presented with too much new information that can require too much cognitive processing at once (Butcher, 2014). To help manage essential processing that is required by learners, three principles can be applied.

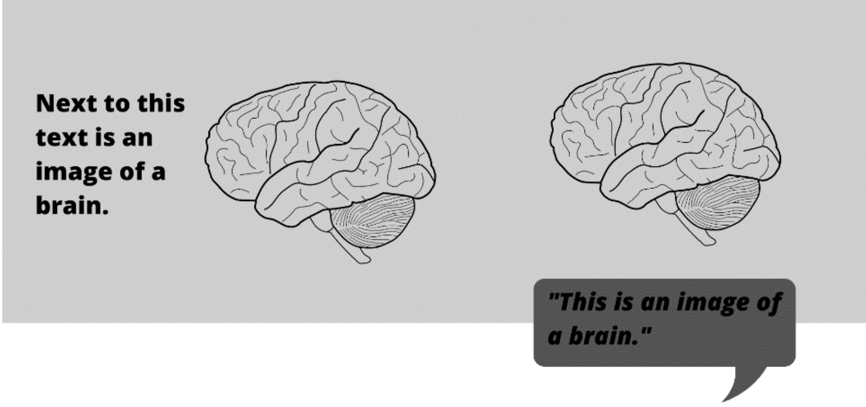
First, the *segmenting principle* provides the learner with the freedom to determine at what pace the information is presented to them, instead of presenting a bulk of information that needs to be processed at one given moment.

Second, the *pre-training principle* encourages educators to provide the learner with parts of the information beforehand, such as key terms or basic principles. Then, when those materials are discussed, not everything is new and therefore easier to process.

Lastly, the *modality principle* can be used to offload some of the essential processing that is used over either the visual or auditory channel. By offloading this information from one of the channels, this principle is the only principle that could effectively expand working memory (Low & Sweller, 2014). An example of this can be replacing printed word by a narration with the same information, see Figure 2.

Figure 2

Example of the Application of the Modality Principle.



Multimedia Educational Design to Foster Generative Processing

Learning is complete when information is processed from the short-term memory to the long-term memory, or, in other words, when a permanent alteration is made to the long-term memory. This permanent alteration can be achieved through making sense of the presented information and is highly dependent on the learner's motivation to learn (Butcher, 2014). Making sense of the material can be done through establishing relationships with previous knowledge and associations of the presented material (Stull & Mayer, 2007). Also referred to as generative processing. Generative processing can be supported in various ways, as long as it focusses on building the relationship between previous knowledge and new information it can be considered supporting. However, there are four principles that have been investigated in depth.

First, the use of *social cues* to foster generative processing. Activation of the social response leads to an increase in active cognitive processing. This social response activates the cooperation principle within humans, meaning that a listener has implicitly agreed to try to make sense of the information they receive (Mayer, 2014b). Essentially, using social cues activates the learner in trying to make sense of the educational materials. An example is using personalization, by focussing on addressing the learner in a conversational style, rather than formally written.

Second, the *guided discovery principle* stems from the fact that learners learn better when information is generated by the learner, instead of simply received. This is also referred to as the 'generation effect' (Bertsch et al., 2007). An example of this is providing learners with a fading worked example. A worked example is providing a learner with a fully worked out solution, including which steps to take to get to the solution. A fading worked example means that the learner is provided with less and less information about how to reach the solution, until, in the end, the learner had to complete all the steps themselves. This provides learners with understanding of how to apply certain rules to come to a solution, before they must solve problems based on these rules themselves (Renkl, 2005).

Third, to support generative processing, instructional materials could use the self-explanation principle. This quite simply asks the learner to explain provided material in their own words after having read or seen it. By doing so, the learner engages in reflecting, relating to existing knowledge and potentially repair faulty knowledge. An example of self-explanation is encouraging a learner to identify the different parts of the brains and their functions (Wylie & Chi, 2014).

Finally, to encourage learners to really integrate new knowledge into their long-term memory, educational materials could use the drawing principle. This principle also closely interacts with the generation effect. This principle encourages learners to draw while reading a text, by doing so learners are creating a picture that represents relationships among elements that are explained in the text (Leutner & Schmeck, 2014). By using this principle, text is translated into visual connections.

In summary, there are three categories of interventions that can be implemented in order to help the learner to learn as best as possible. An overview of those categories, strategies and an example are presented in Table 1. Irrelevant information should be reduced to a minimum, the learner should be guided towards through all the relevant information, and it should be attempted to motivate the learner to engage in learning. While all that is happening, educational designers must stay aware of the fact that learners have two channels that need to be optimally used to yield the highest learning effect.

Table 1

Overview of the Multimedia Principles

Aim	Strategy	Example/description
Reduce extraneous processing	Coherence	Only use information that helps the learner understand the educational message.
	Signalling	Guide the learner's attention to the most important part in the educational message.
	Redundancy	Only use narration with graphics in the educational message, do not add on-screen text.
	Spatial contiguity	Place images and text that belong together close together to prevent the learner from searching.
	Temporal contiguity	Narration and corresponding graphics are presented at the same time to the learner.
Managing essential processing	Segmenting	Provide the learner with the autonomy to decide the pace of the educational message.
	Pre-training	Provide the learner with elements of difficult materials to study before delving into details.
	Modality	Present some information over the visual channel and some information over the auditory channel.
Foster generative processing	Social cues	Activate a social response in the learner by aligning educational content with social interactions.
	Guided discovery	Provide the learner with steps towards independently solving a problem.
	Self-explanation	Require the learner to rephrase the learned materials in their own words.
	Drawing	Require the learner to draw the connections between the elements that were explained in text.

Skill Learning

Various professions can only be executed when people are able to apply their knowledge and execute skills. These skills go beyond simply memorizing certain movements, one must know why it is done in that way, how it is done and if there are risks involved (Burgess et al., 2020).

In order to ensure that the presented information is on a correct level of difficulty, researchers have investigated what individuals should be able to do with the presented information. That hierarchy of knowledge is displayed in Bloom's taxonomy. Before someone is able to apply their knowledge, it is vital that they first are able to remember and understand the needed information. This is also theorized in the cumulative hierarchy of Bloom's taxonomy; one needs to master the simpler categories, before continuing to the more complex one (Kratwohl, 2002). When addressing skills in this thesis, we refer to everything from the '3.0 Apply' and higher, as displayed in Figure 3.

Figure 3

Overview of the Cognitive Process Dimension of the Revised Taxonomy adopted from Kratwohl (2002).

1.0 Remember – Retrieving relevant knowledge from long-term memory.
- ***1.1 Recognizing***
- ***1.2 Recalling***

2.0 Understand – Determining the meaning of instructional messages, including oral, written, and graphic communication.
- ***2.1 Interpreting***
- ***2.2 Exemplifying***
- ***2.3 Classifying***
- ***2.4 Summarizing***
- ***2.5 Inferring***
- ***2.6 Comparing***
- ***2.7 Explaining***

3.0 Apply – Carrying out or using a procedure in a given situation.
- ***3.1 Executing***
- ***3.2 Implementing***

4.0 Analyze – Breaking material into its constituent parts and detecting how the parts relate to one another and to an overall structure or purpose.
- ***4.1 Differentiating***
- ***4.2 Organizing***
- ***4.3 Attributing***

5.0 Evaluate – Making judgments based on criteria and standards.
- ***5.1 Checking***
- ***5.2 Critiquing***

6.0 Create – Putting elements together to form a novel, coherent whole or make an original product.
- ***6.1 Generating***
- ***6.2 Planning***
- ***6.3 Producing***

Standard lecture-based lessons can explain parts of these procedural skills, but the execution of the skills cannot be learned by only sitting and listening. In order to successfully teach procedural skills one can use methods such as the Halsted method, or Peyton's four step approach (Le et al., 2022).

The Halsted method is often described as “see one-do one-teach one”, since it asks the learner to observe a procedure, then they should be able to execute a procedure and the last and final step consist of instructing a fellow learner how to do it (Le et al., 2022).

The training method as designed by Peyton breaks down procedural skills in smaller steps and encourages learners to walk through these phases by following four steps. Therefore, this method is often referred to as Peyton’s four step approach (Burgess et al, 2020; Le et al, 2022). First, a learner must observe the procedure, then the teacher will explain the procedure by explaining the different phases. In the third step, the teacher is still executing the procedure, but the learner is supporting and in the final step the learner individually executes the procedure.

These two methods share an important characteristic: seeing and doing. In order to master a procedural skill, learners must be shown what they must learn, and they must be able to practice it. In the medical industry this is often adhered to by letting learners participate in a skills lab, in which they can safely practice procedures on mannequins with fellow learners (Nikendei et al, 2014). These mannequins can be seen as a simulation of when these students have to interact with patients. However, whilst practicing with peers, there is not always a teacher present. Therefore, there is a chance that students accidentally learn the procedure wrongly (Guerrero et al, 2022). Furthermore, it must be acknowledged that not all disciplines can incorporate a skills lab. This is especially true for occupations that are reliant upon costly specialized equipment. Digital simulations could resolve both matters, it is technically possible to simulate the equipment and simulations can have built-in fail saves to ensure that information is learned correctly.

This thesis contributes to the fast knowledge base about the design of educational materials by answering the following questions:

RQ1 What MM principles that reduce extraneous processing have been found to contribute to effective skill learning amongst adults?

RQ2 What MM principles that manage essential processing have been found to contribute to effective skill learning amongst adults?

RQ3 What MM principles to foster generative processing have been found to contribute to effective skill learning amongst adults?

MM design principles have been thoroughly researched, but not yet in through the lens of a review on the topic of learning effects. Moreover, MM design research often investigates traditional educational settings, such as schools. Therefore, the population that is often investigated are school going children or young adults. Unfortunately, this means that there is little knowledge about what MM principles work for adults.

Method

Research Design

In order to find answers to the proposed research questions, a systematic literature review was conducted. An attempt was made to discover what multimedia (MM) educational design principles could be used to maximise learning effects among adults. By using a systematic literature review as methodology, it is possible to discover empirically proven practices in MM educational design for adults. This ultimately led to an overview of practices that could be used as a guideline to develop educational materials that reach the highest learning effect. This study compiled a sample out of the different experimental groups that were investigated in the analysed studies, since some studies investigated multiple principles at once.

Inclusion Criteria

This study adhered to seven strict inclusion criteria, if a study did not fulfil one of the described criteria, it was deleted out of the data gathering. The eligibility criteria for the literature review were that the study (1) was conducted with adult participants; (2) requires from the participants to apply knowledge or above, as described in the revision of Bloom's taxonomy (Kratwohl, 2002); (3) describes effect size or presents results that makes it possible to calculate effect size; (4) setting is generalizable to other industries; (5) had full text available in Dutch or English; (6) was peer reviewed.

Literature Search

In order to execute a systematic literature review, it was first determined what the scope and the keywords were going to be. To ensure that no important synonyms were forgotten, a thesaurus, experts and a scoping search were used.

The following terms were used to conduct a scoping search: 1) "educational design", 2) "skills training", 3) "multimedia learning", 4) "vocational education". This search resulted in the refinement of most terms and the exclusion of the third and fourth search term, in order to acquire the most relevant results. In the end, this resulted into the following search string:

> ("multimedia principles" OR "split-attention" OR modality OR redundancy OR signaling OR cueing OR coherence OR contiguity OR segmenting OR "pre-training" OR personalization OR personalisation OR voice OR image OR embodiment)
>
> AND skill*
>
> AND (learn* OR educat* OR teach* OR instruct*)
>
> AND ("working memory" OR "cognitive load")
>
> AND (effect OR "effect size")
>
> NOT (autism OR child* OR meta OR read* OR social OR writ* OR therapy)

The search string was then used to search relevant databases. Scopus, Web of Science, ERIC and PsychInfo were selected, due to their incorporation of educational sciences. Other databases were considered but were excluded due to saturation or irrelevance.

Identification of Studies

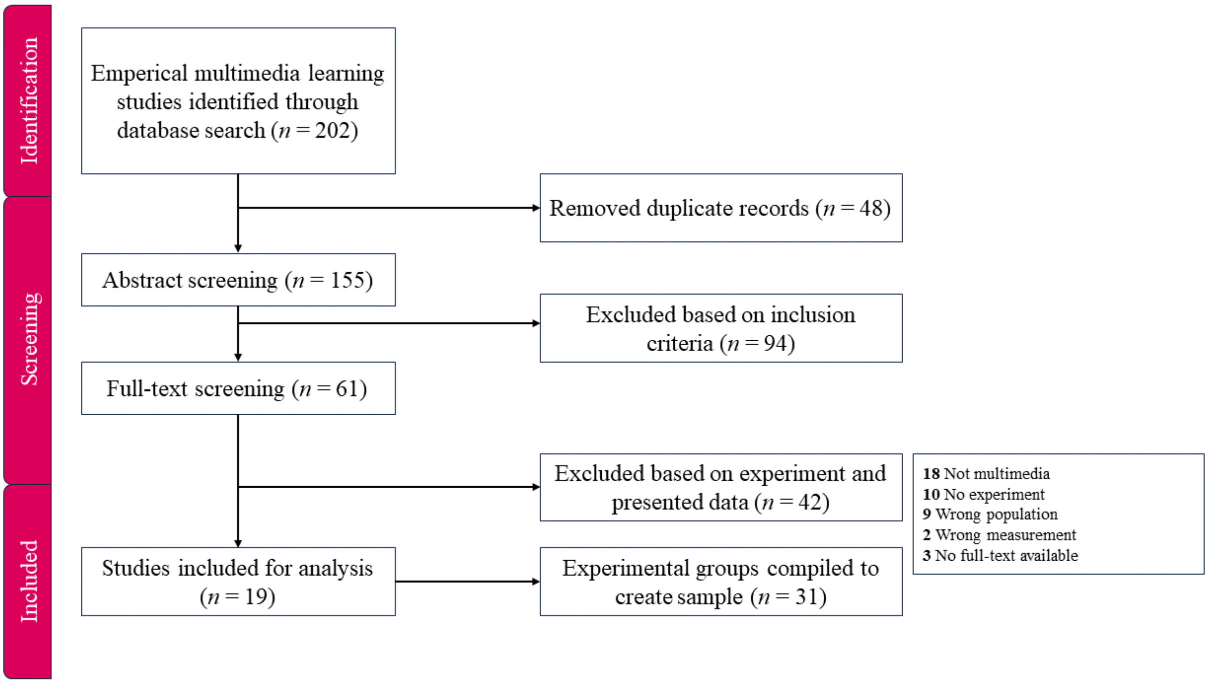
In this thesis the articles that were be used in the results were be determined by following the steps as defined in Preferred Reporting Items for Systematic reviews and Meta-Analyses, or PRISMA (Moher, 2009). First, any duplicates were be removed from the results. Second, the results were be screened based on the abstract, any articles that do not contribute to the goal of this research were be eliminated. Reasons for removal at this stage included the focus on rehabilitation of motor senses, neurosciences, language learning and musical training.

Third, a full text analysis was conducted. This resulted in the exclusion of studies because of full text availability, unclear description of the educational design or because measurements only measured memorization and not transfer.

Other important considerations in the identification process were the use of empirical data and if the study was original research. The latter was decided upon, since this Study needed a detailed description of the experimental design, materials, and sample. This decision prevented therefore that studies were included multiple times. The articles that remained after the fourth stage, were subjected to data extraction. The criteria for the identification of studies were not open to interpretation, thus this was completed by the author. The criteria were first be checked by experts. These experts are an associate professor and an information officer at a research university. This resulted in a total of 19 articles, which all investigated at least one group, thus leading to a sample of n = 31. An overview of this process can be found in Figure 5.

Figure 4

Review Process of Study 1



Data Extraction

In order to extract relevant data from the results a data extraction form was created. In this document the relevant articles were standardized into terms that are applicable for the research questions. The data extraction form used in this study can be found in Appendix 1 (available upon request), it includes sample size, sample characteristics, such as education level and field, topic of educational material, type of intervention, classification of intervention, effect of the intervention, cognitive load (CL) measurement, CL mean and CL scale.

The classification of intervention refers to a standardization of all the intervention that were used. Sometimes authors used different words for the same design choices in the intervention. Therefore, based on the explanation given in the theoretical framework, all the studies were categorized into their designated MM principles as described in Table 1 in the Theoretical Framework.

In order to systematically gather the data, the selected articles were read carefully, whilst highlighting the information that was relevant for the data extraction sheet. Consequently, that information was imported into an excel spreadsheet. Moreover, the effect sizes were always reported as Cohen's d. When the effect size was reported in a different scale, the method developed by Lakens (2013) was used to translate the information to Cohen's d.

Code Book

Before any data was extracted from the articles in the final phase, a codebook was created. Essentially, the codebook served as a guide to systematically gather information from the articles. Table 2 presents the codebook that was used in this Study.

Table 2

Codebook with Explanation of Data Input for Study 1

Identifiers	First author	Fully written out last name of the first author of the chosen article.
	Year	The year in which the article was published.
Methodological characteristics	Sample size	Total number of participants in study
	Sample characteristics	Highest level of education, field of education and age.
	Topic of educational material	Short description of what the topic was of the educational material.
	Type of intervention group	Short description of the intervention of which the effect is measured in the article. Differentiated by control and experimental group.
	Classification of intervention	The intervention is classified into one of the MM principles as described in Table 1 of the Theoretical Framework.
Results	Effect of the intervention	Description of effect size in Cohen's d.
	CL measurement	Description of what instrument was used to measure cognitive load.
	CL mean	The mean of the cognitive load measurement.
	CL scale	How many points the Likert scale had.
	CL percentage	How much percentage the CL was, so it can be compared over studies.

Data Analysis

By utilizing the data entered in the extraction form, the educational design methods under study were recorded. The systematic literature review was completed via a qualitative research approach. A deductive approach of coding the studied articles was chosen, that information was then captured within the data extraction form. Important to note is the fact that the data was gathered on group level, instead of study level. Some studies had multiple experimental groups, which slightly differed in intervention, but all were relevant for this study.

First, it was determined if the studied design choices were effective or not. This was done by examining effect sizes. The effects that were specifically searched for were the difference between pre- and post-test of the control and experimental group, more specifically the observed learning gains.

These effect sizes were displayed in Cohen's *d*-measurement, of which any results between 0.20 and 1.30 and up indicate a positive effect, whereas -0.20 and -1.30 indicate a negative effect.

Results between -0.20 and 0.20 indicate that there was too little of an effect to seriously consider. These results were displayed as such. Moreover, the CL data was also considered an important factor for determining the effectiveness of design choices. Since, if an MM design showed a positive effect, but the group also reported a very high CL-level, that choice might not be the most suitable for there IVR simulation design, due to the high risk of cognitive overload.

Additionally, the information about the sample and experiment set up were considered. The alignment between the educational background and the educational contents were discussed, as well as what type of participants were most frequently used in these experiments. This information led to certain nuances under which circumstances the MM educational design principles were effective.

Results

This section of the thesis presents the results, focussing on how multimedia design affects the learning effect of an adult population. The first part will examine the characteristics of the studied samples, the second part will examine the used cognitive load measurement instruments. This choice was made because the other parts of the results use that information to set apart the results.

The remaining part of this chapter has been organized around the different research questions. Therefore, there will be a part dedicated to; 1) reduce extraneous processing, 2) manage essential processing, and; 3) fostering cognitive processing. Each part then focusses on the cognitive load and the learning effects that were reported for the different groups. Finally, each part will end with a description of the educational materials as were provided in the individual papers.

MM principles were studied in a variety of ways. In order to be able to use the included studies, the assumption was made that all educational materials adhered to the coherence principle, none of the studies specifically reported on that. The coherence principle is applied when educational material only presents information that contributes to the learning goal. Out of all the possible multimedia principles that could be studied, the segmenting principle was most often investigated (n = 11). The segmenting principle boils down to separating information into smaller parts to guide the learner through the most important information.

Other principles that were often investigated were the signalling principle in six studies and six experimental groups, followed by the self-explanation- and worked-example principles, which were both investigated in four studies and four experimental groups. Finally, after applying all the exclusion criteria. there were two MM principles that did not make it into the data extraction phase, those are pre-training and social cues. See Appendix 1 for a full overview of all the included studies and the tested interventions (available upon request).

Sample Characteristics

The dataset that will be analysed in this section consisted of a sample of n = 31. The 19 studies that were considered, totalled up to 31 different experimental groups in which various MM principles were investigated. In Appendix 1 an overview is presented of all the characteristics of the considered samples (available upon request).

What stands out is the fact that most studies observed either University or College students. In total, there were only three included articles that studied a different population; 1) football players (Khacharem, 2017); 2) basketball players (Khacharem et al., 2020); and 3) the elderly (Van Gerven et al., 2003). The latter did originally compare the results of the elderly to youngsters, but due to the nature of this study that comparison was not included here.

It is also noticeable that there are a few studies that were conducted with very small samples. For example, the study conducted by Hsu et al. (2012) included a total of 42 participants, but those participants were later divided into four groups. Meaning that each group had 10-11 participants.

Lastly, even though all participants were novices to the presented material, some studies had participants whose discipline aligned with the topic of the educational material, whereas others did not. The experiment conducted by Agostinho et al. (2013) investigated how teacher students learned material related to educational science, and Hsu et al. (2012) investigated how students enrolled in a programming course responded to a programming class. On the other hand, the water jug problem that was presented by Van Gerven et al. (2003) was completely new material for the elderly participants, similar to the construction tasks as presented by Wong et al. (2015) and Yuliver-Gavish et al. (2023).

Cognitive Load Measurement Instruments

If studies investigated the cognitive load of the learners, this was always done via a self-reporting instrument. However, the instruments varied. The mental effort scale by Paas (1992) was used most often (n = 10). The three studies who did not use that mental effort scale used all different instruments. In the next paragraphs all CL measurement instruments are explained, as well as the scales that were used.

First, I will provide an explanation of the mental effort scale by Paas (1992). This instrument is a self-assessment scale in which the participant is asked how much mental effort they had to invest. The participant has to rate their mental effort on a scale from one (very, very low mental effort) to nine (very, very high mental effort). The scale is tested to have a test reliability of $\alpha = .90$. Thus, indicating that this scale is very reliable.

Secondly, the extraneous load scale by Kalyuga et al. (1998) will be explained, this instrument was used in the included study of Ciernak et al. (2009). The scale by Kalyuga et al. (1998) is an adaptation of the cognitive load measurement scale as developed by Paas (1992). The only difference between these two scales is that the scale by Paas (1992) consists of a range from one to nine, whereas the scale by Kalyuga et al. (1998) consists of a range of one (extremely easy) to seven (extremely difficult). The final scale that was used by Ciernak et al. (2009) made a slight adaptation to the self-assessment question. Kalyuga et al. (1998) asked participants to estimate how easy or difficult the subject material was to understand, whereas Ciernak et al. (2009) asked participants how difficult it was to learn with the materials, their scale consisted of a range from one (not at all) to six (extremely). They explain their choice by aiming the scale to focus on the materials and not so much on the content.

Then, the study into worked examples by Jung et al. (2016) reported on extraneous cognitive load by asking their participants if it was difficult to learn with the used materials (Ryu

& Yim, 2009 as cited in Jung et al., 2016). Their participants had to provide a rating on a scale of one (extremely easy) to seven (extremely difficult).

Finally, Scheiter et al. (2016) used a modified version of the NASA-TLX as developed by Hart and Staveland (1988). The NASA-TLX is a scale developed for the rating of workload and it consist out of six subscales; mental demand, physical demand, temporal demand, performance, effort and frustration level. In the study by Scheiter et al. (2016) they used part of the NASA-TLX by including three subscales. These subscales asked the participants to rate how much mental and physical activity were required, how hard they had to work to understand the contents of the learning environment and how much effort the participant had to invest to navigate the learning environment. The participants were asked to provide a rating that ranged from 0 (very low cognitive load) to 100 (very high cognitive load).

In summary, different methods were used to identify the experienced CL by the participants. Their approaches might be different, but they essentially measure the same.

Multimedia Educational Design to Reduce Extraneous Processing

Cognitive Load & Learning Effect

The MM interventions that aim to reduce extraneous processing were investigated in varying ways. An overview is displayed in Table 3. The signalling principle was investigated most often. The signalling principle aims to reduce CL by pointing out the most relevant information through, for example, highlighting it. All studies that investigated this principle reported significant positive learning effects. The highest study reported a very large effect of $d = 2.22$ (Kacharem, 2020). However, in only three of the five interventions did the experimental group report a lower CL than the control group (Jung, 2016; De Koning, 2010; Khacharem, 2017). These differences were relatively small, see for example the study by Bolkan (2019), the experimental group reported a CL of 33.14%, whereas the control group reported a CL of 28.71%.

The redundancy principle was investigated twice, of which only one Kacharem (2020) showed a significant, very large effect ($d = 3.41$). However, the CL measurement was very similar between the experimental (45.56%) and the control group (44.44%), even slightly higher for the experimental group. Which is interesting, because the redundancy principle is aimed at reducing CL by ensuring that the visual and auditory channel support each other. Thus, in theory the control group should receive a treatment in which this is less the case and should have experienced a higher CL. This will be further evaluated in the part about the educational materials.

Even though in the study by Jung (2016) it did not lead to an increase in learning effect, there is a large reduction in the experienced CL. The experimental group experienced a CL impact of 88.86%, compared to 95% of the control group.

Lastly, the spatial contiguity principle was investigated two times. This principle aims to reduce CL by placing information together and thus requesting less searching of the learner. Both times it was studied, a significant learning effect was discovered. In the study conducted by Agostinho (2013) this was a large effect (*d* = 1.00) and a slight increase in the experienced cognitive load of the experimental group was reported (81.11%, compared to 80.00% of the control group). In the article by Ciernak (2009) a medium effect was observed (*d* = .68) and a slight decrease in the experienced cognitive load of the experimental group (81.11%, compared to 80.00% of the control group).

In sum, even though all but one of the included studies reported an increased learning effect by applying these MM principles, only half of the included studies reported a decrease in the experienced CL by the experimental group. This begs for further investigation of other elements of these studies, since the primary reason for the investigated MM principles to exist is to reduce CL.

Table 3

Effect Sizes of the Different MM Interventions to Reduce Extraneous Processing

MM intervention	Cohen's d	CL % (control)
Signalling		
Animation with concise narration and verbal labels (Jung, 2016)	1.69[L]	67.14% (95.00%)
Powerpoint with animations on the slides (Bolkan, 2019)	0.28[S]	33.14% (28.71%)
Visual cueing and instructional explanations (De Koning, 2010)	0.59[M]	48.00% (58.77%)
Circle signal (Khacharem, 2017)	1.35[L]	55.22% (68.56%)
Up to three materials per page were highlighted (Ring, 2022)	0.21[S]	75.00% (74.33%)
Arrow symbols of tactical instruction (Khacharem, 2020)	2.22[L]	45.56% (44.44%)
Redundancy		
Animation with narration and concise text (Jung, 2016)	0	88.86% (95.00%)
Oral explanation and arrow symbols of tactical instruction (Khacharem, 2020)	3.41[L]	45.56% (44.44%)
Spatial contiguity		
Integrated format (Ciernak, 2009)	0.68[M]	46.43% (53.85%)
Static integrated condition (Agostinho, 2013)	1.00[L]	81.11% (80.00%)

Note. Large effect size is indicated with [L], medium effect size is indicated with [M] and small effect size is indicated with [S].

Educational Materials

In Table 4 an overview of the tested MM principles to reduce extraneous processing, along with an explanation of the instructional materials, can be found. A first observation that can be made is that the topics and experiments greatly vary. In this part we briefly highlight some of the interventions to provide some more information about the effects and CL measures that were previously presented.

One thing that must be noted, is that all educational design was done in a way that the participant could work on it individually. There were no lecture-based instructional materials that tested the MM principles to reduce extraneous processing. An example of instructional material that could be used individually, is that of De Koning (2010). They provide a video to their experimental groups in which the discussed part would light up. The control group did not receive guidance in viewing the animation by lighting up certain elements, however the CL was very similar in the experimental group and the control group.

In the study conducted by Jung (2016) the participants received too much information, according to the redundancy principle. The participants received auditory information, as well as some concise textual explanations below the video that showed the replacement of the car tyre. And even though, the CL was lower compared to the control group, the experimental group was measured to not have a learning effect. Additionally, the control group had to process a lot of information, because they received a more extensive narration than the experimental group.

Finally, in the spatial contiguity principle, participants in the study by Ciernak (2009) received information about the functioning of the nephron, an important part for the functioning of the kidney. In their educational materials, the experimental group was shown an image with text next to the part that it was explaining, whereas the control group received the same image, but the text listed to the side. With the help of corresponding numbers, they could identify what explanation belonged where. This experimental group did not only report a medium learning effect, but they also reported on a lower CL compared to their control group.

Table 4

MM principles to reduce extraneous processing that were tested and the corresponding instructional material

Intervention description	MM intervention	Explanation
Signalling	Animation with concise narration and verbal labels (Jung, 2016)	The participants received a video with instructions on how to replace a car tire. They had the possibility to use ‘play’ and ‘pause’ buttons. While the narration continued, verbal labels appeared when the speaker presented the information. **Control group:** received the same video, but the narration was more extensive and there were no verbal labels.
	Powerpoint with animations on the slides (Bolkan, 2019)	The information about persuasion was provided via voice-over and content on the Powerpoint slides, the content would only appear once the speaker presented the information. For example, one bullet point at a time. **Control group:** received the same information, but the slides did not have any animations, so all the information was presented at once.
	Visual cueing and instructional explanations (De Koning, 2010)	The information about the cardiovascular system was presented while a voice-over explained its workings. The learner could not control the video and it would start again after it ended. The cueing was done by decreasing the luminance of all the elements, except the one being explained. **Control group:** received the same information without cueing.
	Circle signal (Khacharem, 2017)	Learners were presented with an overview of a football gameplay diagram. When the narration was addressing a certain part of that diagram, a red circle appeared around that part. **Control group:** received the same presentation, but without the red circle.
	Up to three materials per page were highlighted (Ring, 2022)	The economic principle of supply and demand was explained in 7 pages of text. The words that explained important elements in a graph were highlighted in a colour that corresponds with the graph. **Control group:** received the same information without anything highlighted.
	Arrow symbols of tactical instruction (Khacharem, 2020)	The learner’s received tactical instructions for a basketball game via a diagram with arrows. The displayed arrows all had their own individual meaning that was explained beforehand. The game was progressively displayed. **Control group:** received the same diagram, but without the arrows and with verbal narration.
Redundancy	Animation with narration and concise text (Jung, 2016)	The participants received a narrated video with instructions on how to replace a car tire. They had the possibility to use ‘play’ and ‘pause’ buttons. Additionally, there were concise textual explanations at the bottom of the screen. **Control group:** received the same video, but the narration was more extensive and there was no concise text.
	Oral explanation and arrow symbols of tactical instruction (Khacharem, 2020)	The learner’s received tactical instructions for a basketball game via a diagram with arrows. The displayed arrows all had their own individual meaning that was explained beforehand. Additionally, a narration explained what could be seen, on top of the arrows that already explained that. **Control group:** received the same diagram, but without the arrows and with verbal narration.

Intervention description	MM intervention	Explanation
Spatial contiguity	Integrated format (Ciernak, 2009)	Learners received verbal information about the physiological functioning of the nephron. The verbal information corresponded with a graphic in which the textual labels were presented next to the part of the image that it described. **Control group:** received the same information and graphic, but the text was listed next to the image and connected to the right part of the image with numbers.
	Static integrated condition (Agostinho, 2013)	The learners received a diagram and text about the cognitive theory of multimedia learning. The text was integrated into the graph, by displayed it close to the part of the diagram that was explained. **Control group:** received the same information, but the text was listed next to the graph.

Multimedia Educational Design to Manage Essential Processing

Cognitive Load & Learning Effect

Only two of the MM design principles that can be used to manage essential processing were investigated, these are the segmenting and the modality principle. The pre-training principle was not found in the studied articles. What stands out, is the fact that of the ten investigated groups in the segmenting principle, only six were reported to have significant learning effects. A full overview of all the results regarding the segmenting and modality principle can be found in Table 5.

First, the results related to the segmenting principle shall be presented. This principle aims to decrease the CL by providing small chunks of information to guide the processing. In total six studies investigated this principle. Out of the eleven experimental groups that were included, for only five a significant positive learning effect was reported. Interestingly, the single screen experimental group in the study by Hsu (2012) even reported a medium negative learning effect. However, the CL was lower for the experimental group (32.71%) than for the control group (36.24%). In that same study they also observed a different experimental group in a dual screen condition and even though the learning effect was not significant, the CL was even lower at 24.05%. Finally, out of the five experimental groups that reported a significant positive learning effect, only four also measured CL (Kester 2004; Khacharem, 2017). Interestingly, all those four experimental groups reported a lower CL than their control group. The highest difference can be found in the study by Khacharem (2017) in which the experimental group reported 50.11% on the CL scale, whereas the control group reported 68.56%. Moreover, that same study also found a very large significant learning effect (d = 1.61).

Secondly, the modality principle was investigated in three studies. Briefly explained, the modality principle entails offloading CL by using a different channel to provide necessary information, for example through narrating an image, instead of providing information that should be read next to an image. Something that immediately stands out is that all the included studies reported a significant learning effect and a decrease in CL by the experimental group. For example, van Gerven (2003) reported a large significant learning effect (d = .84) and a lower CL for the experimental group (22.33%) than that of the control group (44.89%).

Table 5

Effect sizes of the different MM interventions to manage essential processing

MM intervention	Cohen's d	CL % (control)
Segmenting		
Single screen with progressive instructions (Hsu, 2012)	-0.79[M]	32.71% (36.24%)
Dual screen with progressive instructions (Hsu, 2012)	n.s.	24.05% (36.24%)
Pictures only, static visualization for each component (Scheiter, 2006)	0.19	57.00% (52.10%)
36 step-by-step instructions in 2 segments (Yuliver-Gavish, 2023)	0.45[S][a]	n.d.
36 step-by-step instructions in 9 segments (Yuliver-Gavish, 2023)	n.s.	n.d.
15 step-by-step image instructions for physical LEGO building (Wong, 2015)	n.s.	88.11% (77.44%)
15 step-by-step image instructions for virtual LEGO building (Wong, 2015)	n.s.	82.22% (85.89%)
Procedural before task, supportive during task (Kester, 2004)	1.29[L]	43.22% (52.67%)
Supportive before task, procedural during task (Kester, 2004)	0.20[S]	45.67% (52.67%)
Procedural during task, supportive during task (Kester, 2004)	0.21[S]	45.89% (52.67%)
Segmented, orally narrated (Khacharem, 2017)	1.61[L]	50.11% (68.56%)
Modality		
Multimedia based worked example (van Gerven, 2003)	0.84[L]	22.33% (44.89%)
Animation with concise narration (Jung, 2016)	0.66[M]	85.14% (95.00%)
Visual illustration of database with oral explanation (Neto, 2015)	0.43[S]	62.60% (68.40%)

Note. Large effect size is indicated with [L], medium effect size is indicated with [M] and small effect size is indicated with [S].

[a]) Higher number of mean errors

Educational Materials

The groups that were subjected to the segmenting principle, all received information in smaller chunks, compared to their control group. Moreover, the groups in the modality conditions received instructional materials in which visual information was supported by auditory explanation. Refer to Table 6 for a full overview of the tested MM principles for managing essential processing and explanations of the instructional materials.

The groups in the segmenting condition were subjected to interventions varying from lectures, to videos, to images. The groups studied by Yuliver-Gavish (2023) received step-by-step images for the 71 steps they had to take to come to a final product. Separating that information into smaller chunks could help decrease their CL, but when using the information, they were required to recall information that was only needed much later in the process. For example, one moment they were working on the first four steps, and the other they had to work on steps 50 to 54. When considering the goal, this makes sense, the participants would have to be able to step in at any moment in the process.

The study by Kester (2006) did not only provide information in segments, but also labelled the information as being procedural or supportive. The participants had to learn how to use a Chi-square test, they would either receive all the information beforehand (control group) or would receive a part of the information beforehand and a part during the task or all the information during the task. It seems to have resulted in the desired effect, the CL was lower for all three the experimental groups than for the control group and receiving procedural information beforehand and supportive during the task even resulted in a very large learning effect ($d = 1.29$).

The results related to the modality principle had to ensure that the visual information was supported by auditory information. Two of the three included studies also reported that participants had control over the timing of the presented information. For example, the study conducted by Neto (2015), their participants received a self-paced visualization of a basic database concept. The narration made the visualization adhere to the modality principle, whereas the control group had to read on-screen text as well as view the visualization. Interestingly, this only led to a small learning effect ($d = 0.43$) and the CL was also not that different between the experimental group (62.60%) and the control group (68.40%).

Table 6

MM principles to manage essential processing that were tested and the corresponding instructional material

Intervention description	MM intervention	Explanation
Segmenting	Single screen with progressive instructions (Hsu, 2012)	On one screen, the instructional information was showed by using animations within PowerPoint. Thus, only the information that was relevant in that moment was shown. The presentation was carefully switched between demonstrating the instructional material and using the programming software. **Control group:** received the same information on one screen, but the PowerPoint did not use animation.
	Dual screen with progressive instructions (Hsu, 2012)	On one screen, the instructional information was showed by using animations within PowerPoint. Thus, only the information that was relevant in that moment was shown. On the second screen, the programming software was shown, which corresponds with the given instructions. **Control group:** received the same information on one screen, but the PowerPoint did not use animation.
	Pictures only, static visualization for each component (Scheiter, 2006)	The learners received instructions on how to calculate a probability of outcomes, this was done via example-based learning. The instructions were provided via worked examples and the learner could choose to display a static visualization of the worked example for each component of the example. **Control group:** received the same example, but only in text.
	After pressing play, the descriptions were dynamically visualized (Scheiter, 2006)	The learners received instructions on how to calculate a probability of outcomes, this was done via example-based learning. The instructions were provided via worked examples and the learner could choose to display a dynamic visualization of the worked example for each component of the example. **Control group:** received the same example, but only in text.
	71 step-by-step instructions in 2 segments (Yuliver-Gavish, 2023)	A brick-assembly task was simulated via a 3D application. The application demonstrated a model that could be seen and manipulated from all directions. The participants had to put together a truck within this application. The 71 steps were split in two groups of 35 and 36 steps and were demonstrated via images and text. In the experiment the participants were first asked to complete four steps in segment one, then four steps in segment two, they kept going back and forth until all 71 steps were completed. **Control group:** received the same information, but in one segment. They were also required to follow the order of the one segment.

Intervention description	MM intervention	Explanation
Segmenting	71 step-by-step instructions in 9 segments (Yuliver-Gavish, 2023)	A brick-assembly task was simulated via a 3D application. The application demonstrated a model that could be seen and manipulated from all directions. The participants had to put together a truck within this application. The 71 steps were split in 9 groups of 7 steps and were demonstrated via images and text. In the experiment the participants were first asked to complete four steps in one segment and were then randomly moved to another segment to also complete four steps. This continued until all 71 steps were completed. **Control group:** received the same information, but in one segment. They were also required to follow the order of the one segment.
	15 step-by-step image instructions for physical LEGO building (Wong, 2015)	The participants received 15 images that displayed the placement of a LEGO brick. The images were numbered to indicate sequence. They had to then use physical LEGO bricks to build the shown construction. **Control group:** received the same information, but via an animation that lasted 92 seconds, without any control over the pacing.
	15 step-by-step image instructions for virtual LEGO building (Wong, 2015)	The participants received 15 images that displayed the placement of a LEGO brick. The images were numbered to indicate sequence. They had to then use digital LEGO bricks to build the shown construction. **Control group:** received the same information, but via an animation that lasted 92 seconds, without any control over the pacing.
	Procedural before task, supportive during task (Kester, 2004)	The participants received instructions on how and when to use a Chi-square test. Procedural information about the exact form of the formula and definitions of the elements in the formula were displayed before the participants started their task. Supportive information about testing in general and circumstances under which one would use a Chi-square test were demonstrated during the task. **Control group:** received the same information, but all that information was provided before they had to complete a task.
	Supportive before task, procedural during task (Kester, 2004)	The participants received instructions on how and when to use a Chi-square test. Supportive information about testing in general and circumstances under which one would use a Chi-square test were demonstrated before the task. Procedural information about the exact form of the formula and definitions of the elements in the formula were displayed during the task. **Control group:** received the same information, but all that information was provided before they had to complete a task.
	Procedural during task, supportive during task (Kester, 2004)	The participants received instructions on how and when to use a Chi-square test. Supportive information about testing in general and circumstances under which one would use a Chi-square test were demonstrated while participants were executing the task. Procedural information about the exact form of the formula and definitions of the elements in the formula were also displayed during the task. **Control group:** received the same information, but all that information was provided before they had to complete a task.

Intervention description	MM intervention	Explanation
Segmenting	Segmented orally narrated (Khacharem, 2017)	The participants viewed a system-paced segmented evolution of a football game. As the information was orally explained, it also appeared on the screen. **Control group:** received the same presentation, but the entire evolution was shown from the start.
Modality	Multimedia based worked example (van Gerven, 2003)	The participants learned about the water jug problem, and the solution was presented through showing the initial state, intermediate state and the goal. A narration explained the displayed visualization. **Control group:** received instructions on solving the water jug problem, but they only received the initial state and had to reach the goal independently.
	Animation with concise narration (Jung, 2016)	The participants received a video with instructions on how to replace a car tire. They had the possibility to use 'play' and 'pause' buttons. Whilst the video displayed the instruction, a narration explained at the moment that it was shown, what was demonstrated. **Control group:** received the same video, but the narration was more extensive.
	Visual illustration of database with oral explanation (Neto, 2015)	The participants received a self-paced, computer-based lesson that explained a visual illustration of a basic database concept. A narration explained the displayed visualization. **Control group:** received the same self-pace, computer-based lesson, but there was on-screen text instead of a narration.

Multimedia Educational Design to Foster Cognitive Processing

Cognitive Load & Learning Effect

Lastly, there were seven studies that investigated the use of MM design principles to foster cognitive processing, and these were only represented by the self-explanation and worked example principles. In total eight experimental groups were included. A full overview can be found in Table 7.

Firstly, the results related to the self-explanation principle shall be discussed. The self-explanation principle is a learning activity which requires the learner to integrate information by encouraging learners to reflect whilst learning. An example is showing a diagram and asking the learner to explain what the diagram means. Interestingly, only the experimental group in the study of De Koning (2010) reported a significant learning effect (d = .59). Additionally, when it comes to CL, only this experimental group reported a lower CL (53.67%) than that of the control group (58.77%). The other included studies either yielded a learning effect that was not significant (Agostinho, 2013) or too small to be considered an effect (Ring, 2022; Ong, 2015). Moreover, CL was either very similar between control group and experimental group (Agostinho, 2013) or worse (Ring, 2022) or not reported (Ong, 2015).

Secondly, more insight will be provided into the results regarding the worked-example principle. A worked example is a problem with the correct solution, depending on the context it could even include a demonstration of the steps that need to be taken to arrive at the correct solution. Three studies that were included investigated this principle; those studies totalled four experimental groups. Only two groups reported a large significant learning effect (Hsu, 2012; Van Gerven, 2003). In the study by Van Gerven (2003) the experimental group reported both a large learning effect (d = .63) and a lower CL (28.67%) than the control group (44.89%). However, the single screen group in the study by Hsu (2012) reported a large significant negative learning effect (d = -1.53) and that same group also reported experiencing a higher CL (39.07%) than the control group (36.24%). These are notable results, since the worked example should provide learners with a path to learning. Therefore, further investigation should point out if there are reasons for these results based on the control group conditions or the educational materials.

Table 7

Effect Sizes of the Different MM Principles to Foster Cognitive Processing

MM intervention	Cohen's d	CL % (control)
Self-explanation		
Adaptive diagram (Agostinho, 2013)	n.s.	80.33% (80.00%)
Visual cueing and self-explanation (De Koning, 2010)	0.59[M]	53.67% (58.77%)
Active signalling (Ring, 2022)	0.10	76.22% (74.33%)
Self-instruction module (Ong, 2015)	0.18	n.d.
Worked example		
Single screen worked example (Hsu, 2012)	-1.35[L]	39.07% (36.24%)
Dual-screen worked example (Hsu, 2012)	n.s.	23.29% (36.24%)
Unimodal worked example (Van Gerven, 2003)	0.63[L]	28.67% (44.89%)

Note. Large effect size is indicated with [L], medium effect size is indicated with [M] and small effect size is indicated with [S].

Educational Materials

Finally, the educational design choices of the intervention materials in the groups that were subjected to MM design principles which should foster cognitive processing, of which a full overview is displayed in Table 8. As described earlier, MM design principles to foster cognitive processing are relatively new and engage the learner by having them actively participate in the materials. Thus, one thing that can immediately be noted is that the participants are not only receiving information, as can be seen in the self-explanation group under study of De Koning (2010). In this group the participants were asked to self-explain out loud. However, the intervention seemed to help the learning effect, since there was a medium effect size (d =.59). Moreover, the CL was nearly similar between the experimental group (53.67%) and the control group (58.77%).

Another group that stands out is the dual-screen worked example group in the study of Hsu (2012). Their study consisted of an experiment with two beamers of which one would present content information and the other would present a worked example of the final product. All the while a lecturer was explaining the content. The authors explained that for their purpose, learning a programming language, this was a suitable solution. While using a single screen one must constantly switch between the content information and the worked example. Although the learning effect was deemed insignificant, there was a difference in CL between the experimental group (23.29%) and the control group (36.24%). Moreover, one could also consider the single screen worked example to be the control group (39.07%) for CL, in which case the experimental group had an even bigger advantage.

Table 8

Advanced MM principles that were tested and the corresponding instructional material

Intervention description	MM intervention	Explanation
Self-explanation	Adaptive diagram (Agostinho, 2013)	The learners received a diagram and text about the cognitive theory of multimedia learning. The text was placed in boxes and displayed at the bottom of the screen. The learner was asked to move the boxes to the part of the diagram that it described. **Control group:** received the same information, but the text was listed next to the graph and the text could not be moved.
	Visual cueing and self-explanation (De Koning, 2010)	The explanation about the cardiovascular system was presented without textual information. The learner could not control the video and it would start again after it ended. The learners had to explain out loud the functioning of the different parts of the system. The cueing was done by decreasing the luminance of all the elements, except the one being explained. **Control group:** received the same animation, but with textual information and without cueing.
	Active signalling (Ring, 2022)	The economic principle of supply and demand was explained in 7 pages of text. The learner was asked to highlight the most relevant information that corresponds with the graph. **Control group:** received the same information without the prompt to highlight anything.
	Self-instruction module (Ong, 2015)	The participants learned about Excel through a self-instruction module that was designed based on the cognitive load theory. **Control group:** received the same information, but through the conventional module.
Worked example	Single screen worked example (Hsu, 2012)	On one screen, the instructional information was showed by using animations within PowerPoint. Thus, only the information that was relevant in that moment was shown. The presentation was carefully switched between demonstrating the instructional material and using the programming software. Additionally, the programming software was often interchanged with a worked example of the final product. **Control group:** received the same information on one screen, but the PowerPoint did not use animation. There was no demonstration of the final product.
	Dual-screen worked example (Hsu, 2012)	On one screen, the instructional information was showed by using animations within PowerPoint. Thus, only the information that was relevant in that moment was shown. On the second screen, the programming software was shown, which corresponds with the given instructions. Additionally, the programming software was often interchanged with a worked example of the final product. **Control group:** received the same information on one screen, but the PowerPoint did not use animation. There was no demonstration of the final product.

Intervention description	MM intervention	Explanation
	Unimodal worked example (Van Gerven, 2003)	The participants learned about the water jug problem, and the solution was presented through showing the initial state, intermediate state and the goal. An explanatory text was imposed on the images. **Control group:** received instructions on solving the water jug problem, but they only received the initial state and had to reach the goal independently.

Discussion Study 1

The goal of this first study was to investigate multimedia educational principles for adults. In order to find out what principles work most effectively articles that reported on experiments with the different principles were analysed. Comparisons were made based on the learning effect and the reported cognitive load.

What MM Principles That Reduce Extraneous Processing Have Been Found to Contribute to Effective Skill Learning Amongst Adults?

All the MM principles to reduce extraneous processing reported significant positive learning gains in at least one of the included experimental groups. This is especially true for the signalling principle. However, it must be noted that the increase in learning effect often went together with a similar or higher level of CL compared to the control group. Which is not entirely as expected, because when subjected to educational design that takes CL into consideration, the results should lead to a lower CL.

However, there might be a different explanation for this. That explanation can be found in the fact that the majority of the results showed an increased learning effect. As explained by Sweller & Chandler (1994), in order to learn, learners use their cognitive capacity to process that information. Thus, in order to learn more in the same time span, more of that cognition capacity is used to process that information. This is for example true for De Koning (2010), the information that is provided to their participants has, what Sweller (1994) calls, high element interactivity. Simply put, high element interactivity addresses the fact that to fully understand the materials, there are multiple elements that must be learned and understood at once, because the first element is needed to understand the second and vice versa. One can reduce the extraneous CL, but the intrinsic CL will remain high because of the high element interactivity. Moreover, in the study conducted by De Koning (2010), there is a high likelihood that the extraneous CL that is reduced by the intervention, is then used as intrinsic CL and thus resulted in higher learning effects, but similar CL measurements.

Nonetheless, the studies by Jung (2016) and Ciernak (2009) have similar results, even though they investigated different MM principles. Both studies have a higher learning effect and equal CL. These studies used the same CL measurement instrument and asked participants to answer the question: “How difficult was it for you to learn with the material?”. Moreover, they had additional questions that asked specifically about the different types of CL: 1) “How difficult was the learning content for you?”, and 2) "How much did you concentrate during learning?”. So essentially, in both groups the participants learning from the materials that adhered to the signalling principle experienced *more* difficulty to learn with the materials, than the group that learned with materials that did not adhere to said principle. There is one thing that stands out when looking at the description of the materials. Both experimental groups received a video with concise narration and textual signals. In the study by Jung (2016) these were labels placed closely to the part that was being discussed and in the study by Ciernak (2006) the received a graphic in which names of different parts were placed next to their corresponding part. To some extent, both studies violate the redundancy principle. Since, they receive the information written and via narration (Mayer & Fiorella, 2014).

Out of the three investigated MM design principles, the signalling principle yielded the most overwhelmingly positive results. Out of the observed six groups, all of them caused a learning effect and in three groups this also led to a decrease in experienced CL. More importantly, out of those three groups that experienced a lower CL, two groups showed a large learning effect and one a medium learning effect. So based on the presented results, one could conclude that signalling is a highly effective MM design principle.

The redundancy- and spatial contiguity principle were less overwhelmingly positive, but still showed promising results. Out of the two times that the redundancy principle was investigated, one experimental group displayed a large learning effect and a CL that was very similar to that of the control group. The other experimental group did not display a learning effect, but they did report experiencing a lower CL.

The spatial contiguity principle was also investigated in two groups and both groups reported a learning effect, out of which one group reported a similar CL compared to their control group, whereas the other group reported a lower CL.

In summary, the signalling principle seems to be the most effective principle to reduce extraneous processing. This is reinforced by the fact that Jung (2016) had one group in subjected to the signalling principle and one group to the redundancy principle. The signalling principle outperformed the redundancy principle by demonstrating a very large learning effect and reporting a much lower CL. The signalling principle is closely followed by the spatial contiguity principle in reducing extraneous processing. Finally, the redundancy principle presented the least positive results. However, all of these interventions had positive outcomes, so all should be considered when designing an IVR educational simulation for adults.

What MM Principles That Manage Essential Processing Have Been Found to Contribute to Effective Skill Learning Amongst Adults?

The results among the interventions to manage essential processing were positive in a majority of cases. Not every included study reported a significant result or included CL measurement, but the significant reported CL was lower than that of the control group and those interventions also reported a significant learning effect.

Firstly, it is noticeable that most studied groups were categorized in the segmenting principle. This can be explained by the fact that studies usually included two or more experimental groups when investigating the segmenting principle, because the topic was usually related to the optimal timing our number of the segments than whether or not it works. For example, Kester (2004) investigated three experimental groups which all received information at different points in time. Since they were all compared to the same control group, they were all included in this study.

Regarding the results of the segmenting principle, it is interesting to note that Hsu (2012) reported a negative learning effect alongside a lowered CL level. Which could be linked to the Cognitive Load Theory by Sweller (1994). The content of the experiment by Hsu (2012) was about learning a programming language. Languages are known for being complicated because of the high element interactivity. Therefore, segmentation of this information could lead to more work from the individual to integrate those separate chunks of information into one coherent schema. Additionally, it is worth noting that four of the included groups had a non-significant learning effect, out of which one reported a higher CL than the control group and one provided no data on that. Therefore, the segmenting principle should carefully be applied, for example only among people with some prior knowledge. A meta-analysis conducted by Rey et al. (2019) concluded that segmenting is more effective for learners with high prior knowledge compared to those with zero or low prior knowledge. Their explanation for this result is the fact that learners with prior knowledge have pre-existing knowledge that can guide them through the segments, therefore fewer CL is needed to process the information presented in these segments, since not everything is new (Rey et al., 2019).

However, when looking at the segmenting that was done in the study by Kester (2004), the results seem more positive. In their study, low prior knowledge learners were exposed to different segments of information at different moments in time. It seems that splitting information in chunks by providing some information before executing a task and some during, is an effective approach. All groups showed a learning effect and a decrease in CL compared to the control group, who received all information beforehand. In this experiment the groups learned about conducting a Chi-Square test. There was one group that outperformed the others, that was the *'procedural before task, supportive during task'* – group. After receiving information about the formula and definitions of its elements, the group was then presented with information about testing in general and the appropriate circumstances for using the test during their task. They had the highest learning effect and the lowest CL compared to the other experimental groups and the control group.

Moreover, due to the differences that were reported relating to the segmenting principle, this might be an indication that segmenting is not as effective as it was made out to be, at least not as how it was done in the presented studies. An important part of the segmenting principle is the fact that the learner is in charge, in the presented studies this was not the case. Even though all experiments presented the information in smaller chunks, the learner was still a passive receiver.

The modality principle has a more overwhelming positive result. Similar to the MM principles to reduce extraneous processing, it seems that the freed up cognitive capacity from presenting the information in this way lead to higher learning effects. However, it must be noted that the *animation with concise narration*-group from the study by Jung (2016) still reported a very high CL, even though it was lower than the control group. This also begs the question what the balance between CL and learning effect should be.

These findings suggest that the modality principle could effectively be used in IVR educational simulations for adults, but that the segmenting principle must be used with caution. The latter seems to be less effective with low prior-knowledge learners. Whereas low prior knowledge and timing seem to be better aligned based on the study by Kester (2004). In which segmenting based on the timing of information seems an effective approach, especially when procedural information is presented beforehand and supportive information while executing the task.

What MM Principles to Foster Cognitive Processing Have Been Found to Contribute to Effective Skill Learning Amongst Adults?

The MM principles that foster cognitive processing were studied less than the previously investigated MM principles. They also lead to much more mixed results. For example, out of the four included groups in the self-explanation principle, only De Koning (2010) showed a significant learning effect. In the other three groups, Agostinho (2013) reported non-significant results and both Ring (2022) and Ong (2015) reported no effect. The results for the worked example principle were similarly conflicting. All three included studies reported almost opposite results. Dual-screen by Hsu (2012) reported a nonsignificant learning effect, Van Gerven (2003) reported a large positive effect, and Hsu (2012) reported a large negative effect. Similarly, the CL results were also opposites, dual-screen by Hsu (2012) and Van Gerven (2003) reported lower CL than the control groups and single screen by Hsu (2012) reported a higher CL than the control group.

First, the non-significant result provided by the study of Ring (2022) is explained in their discussion by the fact that it can be due to the use of graphs, instead of images. The authors provide evidence from Acaturk et al. (2008) who even demonstrated that signals aimed at text-picture integration could decrease learning when applied to text-graph integration, but Richter et al. (2021) found contradicting evidence. Their study found positive knowledge gains for both picture and graph integration.

When addressing the results presented in the study by Ong (2015), it must be noted that there was limited explanation of the educational design. The authors developed a module in line with the self-instructional principle and CL theory, however, there is no explanation about what the module exactly looks like. This will be further discussed in the limitation section of this thesis, but we cannot discuss these findings without that being noted. An important limitation of self-explanation is that a lot of learners will not self-explain without prompting. Moreover, the quality of the self-explanation is a condition for effective learning from self-explanation (Chi et al., 1989; Roy & Chi, 2005). This could very well explain the fact that the control and experimental group had similar performance levels.

The relatively negative results within the worked example condition could be explained by the passive form of the described worked examples. Within the two groups by Hsu (2012), the participants were sat in a traditional classroom setting, whilst receiving a worked example on-screen. The experimental groups received a worked example of the final product they were expected to create, whereas the control group did not. So, the control group had to use the knowledge they received to create something they had never seen before, whereas the experimental group could lean on a recollection of the example, thus creating fewer connections, as was also proposed by Richey & Nokes-Malach (2015). Interestingly, the worked example in the study by Van Gerven (2003) showed almost a complete contrary result. Showing that there is some truth to using worked examples.

In sum, the evidence provided in this study is inconclusive on the use of self-explanation and worked example principles. Therefore, until there is more knowledge related to the advantages of MM principles to foster cognitive processing, the use of it within IVR educational simulations for adults cannot be recommended.

Study 2: Simulation Design for the Education of Adults

Study 1 provided more insight into MM educational design, but in order to explore the proper educational design for IVR simulations, we should also consider simulation design. Both studies are systematic literature reviews, but the studies each have their own focus. In the end, this should lead to a more comprehensive idea about what is known regarding IVR simulation design.

Theoretical Framework

Simulation Learning

In the previous study it was shared that learning a skill involves seeing and doing, as well as the possibility to repeat and practice. Simulations offer exactly that and learners can practice until they themselves feel confident in their ability (McGaghie et al., 2006; Ziv et al., 2003). However, in order to maximize learning in simulations there are several guidelines that must be adhered.

Isenberg et al. (2005), notes several key factors for achieving effective learning through simulations. These factors are applicable for low- and high-tech simulations, and there are seven factors. The factors encompass various aspects such as integrating feedback within the simulation, embedding it into the curriculum and providing practice opportunities with increasing difficulty. Tailoring the simulation to accommodate individual learning preferences, introducing elements of variation, and establishing clearly defined, measurable learning outcomes are also vital components. Moreover, a crucial requirement is that the simulation accurately mirrors real-world practice. A skills lab in the medical community is an example of a simulation; a safe and protected environment in which close-to-real-life situations are presented for learners to practice, such as a mannequin (Nikendei et al., 2014). Also referred to as low-tech simulations. This thesis focusses on high-tech simulations, henceforth referred to as digital simulations.

Digital simulations offer even greater possibilities than low-tech simulations. Because next to simulating what we can do in reality, digital simulation provide the opportunity to simulate scenarios that can only exist in a digital world. For example, by simulating evacuation routes in underground mines (Adjiski et al., 2015). Fire creates stressful situations; however, it is not possible to practice evacuating with real fire, therefore digital simulations can be a perfect solution. Moreover, digital simulations provide the possibility to collaborate without distance restraints, to share and reuse models, customize for a very specific situation and a place where learners can learn independent of time, place, and equipment (Byrne et al., 2010).

In the last decade, high-tech simulations have been on the rise. These simulations can roughly be divided in two categories:

1) Exploratory simulations (Wagner, 2013). The purpose of these simulations is to provide learners with the opportunity to explore phenomena which they otherwise could not. An

example of such a simulation can be found in the study by Riess & Mischo (2010). They investigated how students could best learn about the importance of biodiversity. In their simulation, students create a forest by planting trees, and it is simulated how the forest develops over the course of 15 years. The second part is exploratory, because the students can only observe.

2) Participatory simulations (Wagner, 2013). The purpose of these simulations is to provide learners the possibility to partake in a situation and execute actions. An example is a neonatal resuscitation simulator, in which the participant receives a scenario and needs to make choices based on that. While the learner is acting upon their decision, the situation of the baby constantly changes (Ghoman et al., 2021).

Moreover, since everything that is needed to use a high-tech simulation is a computer and a monitor, it is also a very cost-effective solution. Learners can endlessly repeat situations to improve their abilities without needing to use additional equipment.

Learning with simulations seems to be a promising way of learning all sorts of knowledge. Consequently, it is important to discover in what way simulations can be best presented to optimize the learning effect. Because, as pointed out by van Merriënboer et al. (2003) the richness that is a simulation can potentially be overwhelming to learners. As discussed earlier, if there is too much extraneous processing involved, this could hamper the learning process.

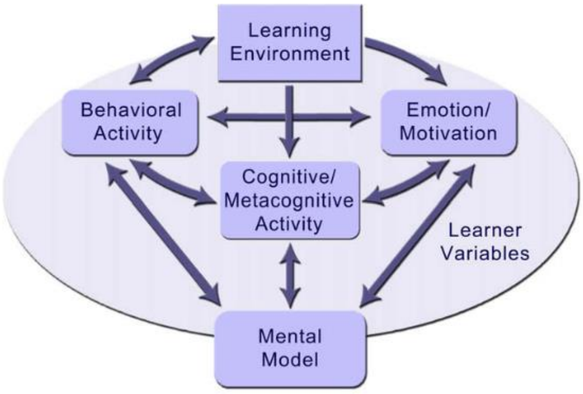
One of the MM design principles that is recommended to be used in simulation is signalling or worked examples (Rutten et al., 2012). Especially in the design of simulations it is important to consider how to present the relevant information, because it strongly affects how the learner will be able to perceive and reflect upon the material, before storing it in their long-term memory (Plass & Schwartz, 2014).

Additional to receiving information, learners are expected to perform certain actions whilst in a simulation. Whether it be manipulating objects to explore concepts or actively participating in situations, this demands a high level of CL (Domagk et al., 2010). What must be noted is that most of the findings related to learning in digital simulations are related to learning science and math and the context in which the studies are situated are often schools (Plass & Schwartz, 2014).

The INTERACT model as designed by Domagk et al. (2010) provides insight into what exactly the reasons are for attempting to overcome all the design challenges that simulations form. This model proposes a system of linked elements that comprise interactivity. Interactivity is an important concept when discussing simulations, especially when addressing participatory simulations. The INTERACT model was developed to visualize all the different elements that need to be considered when addressing interactivity. See Figure 4 for the complete model.

Figure 5

INTERACT model of cognitive, social, and affective learning activities adopted from



An important element is the fact that being able to interact with learning materials leads to deeper learning (Bransford et al., 1999; Domagk et al., 2010). The INTERACT model aims to explain interaction by addressing the interdependent relations between the learning environment, motivation and emotion, behavioural activities, cognitive and metacognitive activities, learner variables and the learner's previous knowledge (Domagk et al., 2010). In essence, in order to successfully use interaction of simulations as an advantage for learning, all the mentioned elements of the INTERACT model should be present.

IVR Simulation Skill Learning

High-tech simulations have been around for quite some time, for example in aviation (Robertson et al., 1993). However, because of technological advancements, simulations have become more accessible for other industries. These Immersive Virtual Reality simulations often use a standardized head mounted display (HMD) and controllers. There are various applications for these IVR simulations, for example handling complaints in customer service settings (Fujita et al., 2019).

Because of the technology that is offered, it is now possible for learners to feel as if they are present within the digital simulation. In the customer service application, the learner is offered a close to real-life situation in which they can practice their complaint handling skills. This resulted in learners feeling more comfortable during their final roleplay (Fujita, 2019). This form of feeling present is often referred to as psychological immersion.

If done correctly, immersion could lead to a fully interactive simulation as described in the INTERACT model. This means that the learning environment evokes a social, behavioural, and cognitive response within the learner (Domagk et al., 2010). All those elements combined should enhance skill learning and this can be achieved through a well-constructed IVR simulation training.

Another application of IVR is fire extinguisher training, in which the trainees use a special fire extinguisher to practice the use of the instrument (Saghafian et al., 2020). In the experiment with the fire extinguisher, it was discovered that realism is an important factor of IVR training. Importantly, these insights were provided by only the end-users of the IVR training.

In the road construction sector, there is an immediate need for a more accessible way to learn about safety at the construction site, due to high numbers of accidents and even deaths. Therefore, Roofigari-Esfahan et al. (2022) developed an IVR simulation in which the entire group can take part. Instead of using one HMD per person, the group of trainees can enter a cyclorama environment in which the 360-degree immersive projection will be displayed. An experienced construction safety instructor evaluated the designed scenario, and their evaluation deemed the scenario as beneficial for learning the required skills (Roofigari-Esfahan et al., 2022).

A final application of IVR simulation that could illustrate the effects of IVR simulation training was conducted in the welding sector. The team of Sakata and Mizuno (2019) developed a tool that felt like a welding tool and virtually also looked like one. Then, with a very small sample of four, of which two users took part in the IVR simulation training to perform welding, they experimented the effectiveness. Afterwards the four participants were asked to weld. There was a noticeable difference between the body language and the execution of the participants who did execute the training and those who did not. The first group bended forward and delivered nicer work, whereas the second group leant back as to protect themselves from the welding beam (Sakata & Mizuno, 2019).

In summary, the few listed examples show great promises for the application of IVR simulation. However, currently, the biggest obstacle is the fact that most of these examples do not actively implement educational design into their research into IVR simulation, if they did these were not described in the materials section of their methodology. Therefore, more information needs to be gathered into what these IVR simulations should present to the learner before we start addressing these interventions as successful.

Currently, there is limited consideration for measuring the actual learning outcomes of IVR simulations, versus their traditional counterparts. Therefore, this research aims to contribute to the knowledge base about simulations by answering the following research question:

RQ4 What simulation design characteristics have been found to contribute to effective skill learning amongst adults?

Method

Research Design

In this study a different systematic literature review was conducted, than in Study 1. In this study the aim is to investigate simulation design and placement in order to support learning. A systematic literature review was chosen to discover the best practices in simulation design. This method led to insight in the current knowledge of educational simulation design for adults. The methodology for this Study is very similar to that of Study 1, the main difference is the topic of interest. Whereas Study 1 focussed on MM design principles, this Study focusses on digital simulation design for the education of adults.

Inclusion Criteria

In total, seven inclusion criteria were considered. In order for a study to be included in this review it must (1) describe the place of the simulation in the overall learning programme; (2) have been conducted with adult participants; (3) have been shaped around a digital or computer interactive simulation; (4) have a setting that is generalizable to other industries; (5) have full text available in Dutch or English; (6) have been peer-reviewed; (7) have been published after 2010. The year 2010 is the cut-off point because of the fact that simulations that were tested before that year have a high chance of being too different from what current technology could provide.

Literature Search

Similar to Study 1, it was first determined what the scope and the keywords were going to be. This Study also used a thesaurus, experts and a scoping search were used.

The procedure for the literature search started with a scoping search. In that search the following key words were used: 1) "virtual reality design", 2) "simulation design", 3) "3d simulation", 4) "computer simulation". This led to a refinement in which only simulation was considered, due to the broadest possible scope, resulting in the following search string:

"Digital simulation"

AND design

AND (educat* OR teach* OR train* OR instruction*)

NOT (disorder OR child* OR therapy OR attitude* OR system*)

Corresponding with the approach in Study 1, this systematic literature review used the same databases that incorporates educational sciences: Scopus, Web of Science, ERIC and PsychInfo.

Identification of Studies

This Study also adhered to the steps as defined in PRISMA (Moher, 2009). Thus, first duplicates will be removed, second, the abstract of the included studies were screened. Exclusion reasons at this stage were mainly centred around the type of simulation. This led, for example, to the exclusion of simulations to predict future climates, to discover if constructions can withstand forces and simulations of temperature changes.

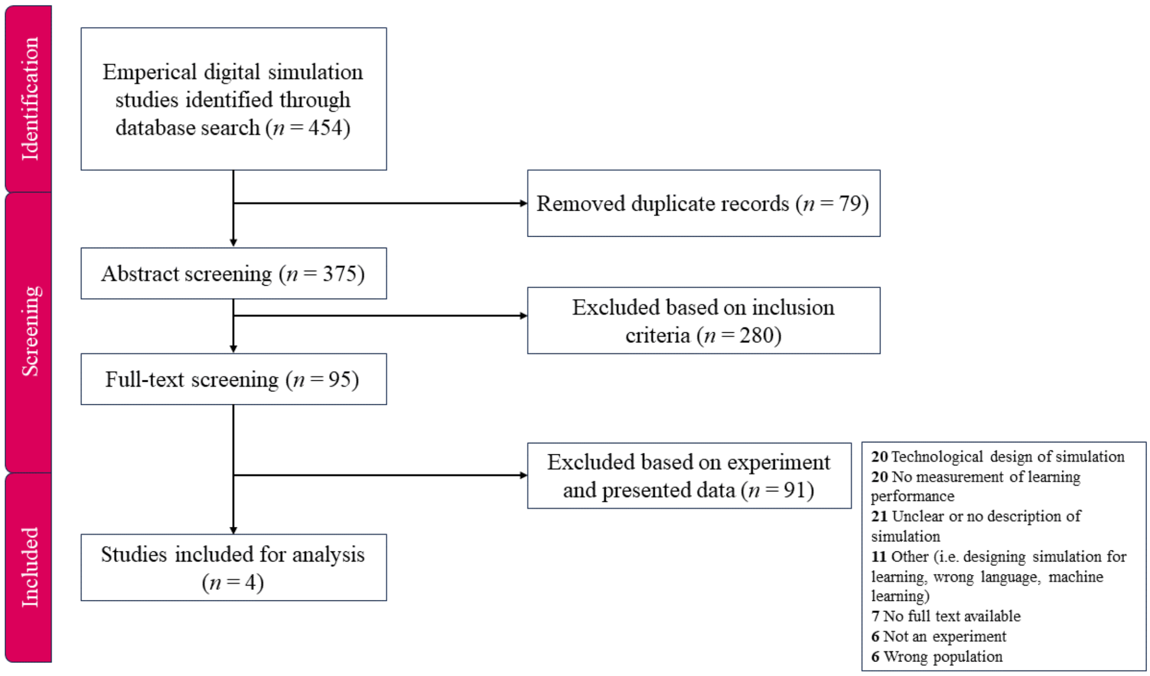
Third, the studies that were still included at this point were subjected to a full text analysis. At this stage, articles were excluded due to the fact that they focussed on the technological design of the simulation and not on the learning effects, because they did not measure learning performance or because it turned out to not be an experiment.

The identification process also required empirical data and original research had to be presented. This last part is important, because a thorough description was needed of the sample, experimental design and especially the materials. This simultaneously had the effect that no studies were considered more than once.

Finally, as in Study 1, the articles that remained after the fourth stage, were used in the data extraction phase. The criteria for the identification of studies were not open to interpretation, thus this was completed by one author. The criteria were first be checked by experts. An overview of this process can be found in Figure 6.

Figure 6

Review Process of Study 2



Data Extraction

Parallel to Study 1, this study also required the creation of a data extraction form. In this document the relevant information was summarized into brief descriptions that could be used to answer the research question. The data extraction form can be found in Appendix 2 (available upon request). The collected data included the sample size, sample characteristics, topic of educational material, topic of simulation, level of immersiveness, type of simulation, summary of the playthrough, design choices, reasons for design choices and the learning effects that were measured.

The type of simulation is classified based on the information that was provided by the authors in their method and connected to the Theory presented in this study; a participant explores, participated, or does both in the simulation. The reason for the design choices needs to be explained to be able to provide that as input for guidelines.

Code Book

The data extraction form was be filled by the help of a pre-determined codebook. The codebook defined the variables and data elements that were needed for the analysis. Table 9 which is displayed on the next page, presents the codebook for the conducted literature in this Study. The codebook served as a standardized tool to summarize the information that was found in the included articles.

Table 9

Codebook With Explanation of Data Input for Study 2

Identifiers	First author	Fully written out last name of the first author of the chosen article.
	Year	The year in which the article was published.
Methodological characteristics	Sample size	Total number of participants in study
	Sample characteristics	Highest level of education, field of education and age.
	Topic of educational material	Short description of what the topic was of the educational material in which the simulation was placed.
	Topic of simulation	Short description of what should be learned through the simulation.
Results	Learning goal	The learning goal that was stated for the participants.
	Topic of the simulation	The theme that was addressed by the simulation.
	Level of immersiveness	- Desktop - VR with standard remote - VR with gloves - VR with additional tools
	Type of simulation	- Explanatory - Participatory - Both explanatory and participatory
	Summary of playthrough	An explanation of what the participant encounters in chronological order when using the simulation.
	Design choices made	An explanation of educational design choices in the simulation.
	Reason for design choice	An explanation of the reasoning of the made design choices.
	Learning effects measured	How the learning effects were measured and how the participants scored.

Data Analysis

Similar to Study 1, this Study also utilized the data entered in the extraction form and recorded the simulation design choices and their reasoning that were under study. This review was completed via a qualitative research approach. A deductive approach of coding the studied articles was chosen, with the code book as the input for codes. The provided information was then captured within the data extraction form.

In this study the effectiveness of the design choices were considered on based on the reported learning result and explanation for choices. Additionally, the information about the sample and experiment set up were considered. This resulted in certain nuances based on the alignment between the educational background and provided simulation.

Results

The dataset consisted of a total of four studies that fulfilled all the inclusion criteria. Therefore, all the included studies shall be qualitatively discussed. A full overview of the study and simulation characteristics can be found in Table 10. In Appendix 2, an overview can be found of the full description of the simulation, as presented in the materials section of the study (available upon request).

There are a few characteristics that immediately stand out. First and foremost, all results were simulations that took place on a desktop. Secondly, the participants of these studies had to go through the simulation individually. And lastly, all participants were university students.

These results will provide an answer to the following RQ: What simulation design characteristics have been found to contribute to effective skill learning amongst adults?

Simulation Design

The study of Park (2011) addressed a very specific problem, the spatial visualization of patterns among design students. In a video that lasted between 85 and 128 seconds, the students had the possibility to see how clothing patterns form around a model. This video was shown to the experimental group right after the explanation on patternmaking, the control group either received a physical demonstration of a pattern on a mannequin or they received only a lecture. The authors chose to show the students the simulation right after the lecture, since that is when they would otherwise receive a demonstration. The simulation was intended to be supplemental to the lecture. Compared to the lecture, the students in the 3D group performed better, but compared to the physical demonstration, the students in the 3D group performed equally, or slightly worse.

Secondly, the study by Jagger (2016) the participants participated in a gamified simulation, which took them through a story about a manager who was faced with ethical decision-making. After they participated in the simulation, they were asked to self-assess their knowledge increase related to knowledge, real-world ethical dilemmas and ethical decision making. For all three elements, more than 60% answered positively, the highest score being for increase in learning about real-world ethical dilemmas at 69%. In the simulation game students had to approach ethical dilemmas from various perspectives, this was prompted in-simulation via clues in the shape of philosophical books appearing on desks or by the appearance of a stakeholder map of the fictional company. The clues correspond to the topics that occur in the simulation. They aim to have the participants experience the consequences of their actions and ethical choices by also showing how this affects other characters in the simulation.

Third, the study of Nadolny (2013) investigated a simulation game in the context of understanding the scientific and ethical implications of genetical modification (GMO). The simulation moderately correlated with increased knowledge on GMO and that moderately correlated with the in-game reporting on ethical issues. Before starting the simulation, the participants received a detailed instruction package which included information on login procedures, background information, a task list and assignment instructions. The main reason for this choice was to alleviate the steep learning curve from the instructor because they did not need to know all the technical information needed to operate within the simulation. The instructor did have access to a handbook which offered contextual information, theory, and vocabulary for leading a classroom discussion afterwards. Moreover, the authors also chose a web-based simulation, since that offers the flexibility to adapt to various courses and curricula and supports both individual and group work. Lastly, the virtual activities were supplemental to the existing curriculum and required he students to work on it two to five hours outside of class.

In the fourth and final simulation that is presented here, Widiasih (2022) aimed to increase the knowledge of IV catheterization for fluid therapy of undergraduate nursing students. Their participants participated in a simulation that is designed to be an alternative learning medium. The knowledge of both the control group (pre-test: $M = 7.76$, $SD = 2.95$; post-test: $M = 9.67$, $SD = 3.13$) and the experimental group increased (pre-test: $M = 9.80$, $SD = 3.04$; post-test: $M = 12.26$, $SD = 4.11$). The difference between groups was tested to be significant. Moreover, the researchers also tested for satisfaction, which was also significantly different. The experimental group ($M = 23.00$, $SD = 2.32$) scored higher than the control group ($M = 21.70$, $SD = 2.68$). Before the participants could use the simulator, they received a lecture on DHF and IV catheterization. Afterwards, the participants could use the simulator for three weeks. They had physical sessions in which they used the simulator. The simulator provided the possibility to use seven components: reading material, a pre-test, case studies, analysis of nursing plans, 3D simulation of nursing skills, a post-test, and a self-evaluation.

Table 10

Overview of Sample Characteristics in Combination with Learning Goal, Level of Immersion, Type and Learning effects

Author	Characteristics	Learning goal	Immersive	Type	Learning effects
Park, 2011	Design majors in an introductory patternmaking course; 56.5% freshman, 34.8% sophomore, 4.3% junior and 4.3% senior	Enhance spatial visualization in patternmaking of two sleeve variations and one skirt type.	Desktop	Exploratory	Spatial visualization score, max is 5. Petal: 3D (M = 3.04, SD = 1.35), lecture (M = 2.07, SD = 1.44), demonstration (M = 3.75, SD = 1.19). Bishop, n.s. Godet: 3D (M = 4.43, SD = .79); lecture (M = 3.74, SD = 1.57); demonstration (M = 4.48, SD = .73).
Jagger, 2016	Undergraduate business students	Increased understanding of business ethics.	Desktop	Participatory	64% felt they had acquired new knowledge that would be useful for them, 69% felt the game environment aided their ability to relate their learning to real-world ethical dilemmas and 62 % felt the game useful in making ethical decisions.
Nadolny, 2013	University students (both undergraduate and graduate) in science, engineering and computer science	Increased understanding of (ethical) considerations of genetically modified salmon.	Desktop	Participatory	Science of GMO: there was a moderate correlation (.453, $p < .05$) with M = 3.19 (out of 4), SD = .81; moderate correlation with reporting on ethical issues: (.505, $p < .05$).
Widiasih. 2022	Third year undergraduate nursing students	Increase understanding of IV catheterization for fluid therapy.	Desktop	Botch exploratory and participatory	Increase in knowledge: the intervention group (M = 2.46), the control group (M = 1.91). Satisfaction: 23.00 + 2.32 in the intervention group and 21.7 + 2.68 in the control group. Difference $p < .05$

Discussion Study 2

This second study aimed to address the simulation design considerations for adults. In the investigation studies were considered that explained their chosen design and reported learning outcomes. Eventually, that information should lead to recommendations regarding effective design choices. In order to come to that conclusion, the following research question had to be answered:

RQ4 What simulation design characteristics have been found to contribute to effective skill learning amongst adults?

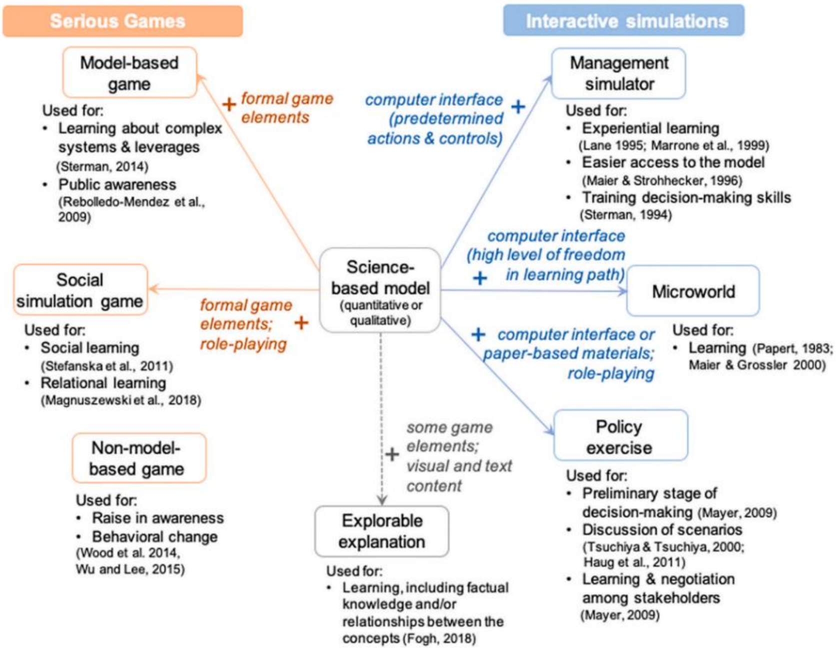
First and foremost, it is important to note the number of simulations that entered the data extraction phase was only four. Therefore, the results discussed here are anecdotal. However, this led to at least one definite conclusion: there is currently too little empirical research into how simulations affect skill learning in adults to conclude whether they are beneficial. There is little explanation about the design and the learning considerations in the investigated simulations.

In the selection of included studies, there was one study that included a purely exploratory simulation and the other three had elements that allowed the learners to participate in the simulations. One thing that all three of the participatory simulations had in common is the fact that all included elements of gamification. Both the studies by Jagger (2016) and Nadolny (2013) had elements of quests, in which participants had to gather information to essentially solve a puzzle, for example to reach the verdict about what is ethical and what is not. These elements of gamification make it difficult to assess the effectiveness of these simulations. On the one hand it could be the simulation that causes the increased learning and on the other hand it could also be the elements of gamification. Moreover, the study by Widiasih (2022) included for example avatars and it tracked the score of the participants.

Bakhanova et al. (2020) also explored the interrelationships between serious games, simulations and gamification. They even state in their research that there is no consensus whether simulations are ‘serious games’ or ‘interactive simulations’. Interestingly, both comply with the definition of a game. As defined by Salen and Zimmerman (2003, p. 80): “a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome.” Game-like applications were summarized by the authors in Figure 7.

Figure 7

Application of Game-like Elements Adopted from Bakhanova et al. (2020)



As can be seen in Figure 7, simulations exist in both the serious game spectrum, as well as the interactive simulation spectrum. This incorporation of gamification explains part of the success of simulations. Ultimately, games are designed to keep people interested and engaged (Bakhanova et al., 2020). However, on a more critical note, it must be mentioned that not too long ago, a critical review by Dichev and Dicheva (2017) concluded that the success of gamification is a "specific combination of game elements, gamified activity, academic subject, and age group" (p. 20).

In conclusion, even though all of the considered simulations were effective, it is important to note that is unclear which elements caused this effect. Based on the present results it is not possible to distinguish between the gamification elements and the simulation elements. And until more research is conducted into the workings of simulations and gamification, future educational simulations should be implemented carefully. The current simulations could function greatly for keeping the target audience interested and engaged, which is very important. However, when discussing educational effectiveness, they should be used cautiously. Until further research is conducted it is recommended to use more traditional educational interventions to rely on to evoke learning.

General Discussion

In this thesis two studies were conducted. The first study focused on the current insights into the learning effects of different multimedia design principles within education for adults. The second study delved into the current knowledge about effective digital simulation design for the education of adults.

The two studies both investigated different applications of educational interventions. Study 1 focussed on the use of multimedia interventions, whereas Study 2 focussed on the use of simulations for education. Both studies predominantly took place within universities. However, where Study 1 led to specific recommendations where the presented insights could be used or further explored, Study 2 provided less insights. The main finding that Study 2 provided is the fact that there is very little knowledge on the appropriate design of educational simulations for adults.

In this thesis the learning among adults was the centre of attention. An important contribution from this thesis to the existing literature base is an overview of effective MM design principles for adult learning. Moreover, this thesis also contributed by providing a first insight into the design of educational simulations for an adult population and its effectiveness to evoke learning. Additionally, this thesis also presents an identification of the gaps in the current literature on the topics of MM and simulation design for adult learning. In both the conducted studies, the most used sample were adult university students. This begs the question, to what extent the presented results are generalizable to the targeted professional population, that did not continue their studies towards university degrees. In the Netherlands, only 38% of adults, aged between 25 and 64 years have tertiary education, similar to the average of the OECD which is 36% (OECD, 2019). Therefore, results related to learning that are yielded from experiments with university students, must be carefully applied into practice. Research has pointed out that due to a variety of elements, outcomes with student populations should be carefully applied to the general population. Elements that influence this are the values that persons hold, personality characteristics, moreover, there appears to be a great difference between student populations in different countries (Hanel & Vione, 2016). Furthermore, investigations into different skills such as numeracy and literacy pointed out that compared to the rest of the population, university students display a far more advanced level of literacy and numeracy skills (Wild et al., 2022). Thus, concluding that the presented results may be used for university students, but cannot be applied to the more general population.

In summary, various skills and preferences have influence on how an intervention is experienced. Even though it is true that the literacy and numeracy skills of the participants suited the provided educational content, this cannot be said for the rest of the general population. Therefore, an argument can be made that the considered interventions work for university students, but it cannot be said with certainty that these results can and should be applied to the general population.

General Limitations

Readers should consider the several limitations of this thesis when reviewing the findings. The limitations can roughly be categorized into three categories: 1) sample characteristics, 2) heterogeneity in interventions and study design, and 3). quality of reporting.

One of the most important limitations of this literature review has to do with the sample characteristics that were included. The group that was most often studied were university or college students. They are adults and to some extent these findings are generalizable, but there is also another group in society that has not attended university and has different academic skills. There are various elements that influence academic skills and achievement in individuals, for example the extent to which children are exposed to these abilities, which are often dependent on their socio-economic situation (Stipek & Ryan, 1997). Then, of course, the extent to which people attend formal education in their life. The survey of adult skills (OECD, 2019) investigates proficiency in literacy and numeracy skills amongst adults in 40 countries and then cross checks these scores with elements such as socio-economic status and followed formal education. In which literacy is defined as "Literacy is the ability to identify, understand, interpret, create, communicate, and compute, using printed and written materials associated with varying contexts. Literacy involves a continuum of learning in enabling individuals to achieve their goals, to develop their knowledge and potential, and to participate fully in their community and wider society." (OECD, n.d.). There are large differences to be seen there, with a statistically significant difference of over 60 points in literacy between the lowest level of education and the highest level of education in the Netherlands. Moreover, in that same report, the OECD presented results that on average, adults after the age of 30 scored lower on literacy and numeracy skills, than the adults that were younger than 30. Thus, the results and learning effect presented in this thesis should not be considered generalizable to all groups of the population, when such a specific age group, with such specific literacy and numeracy skills are investigated.

Secondly, due to the diverse interest in educational science from all angles of the educational spectrum, there is a strong heterogeneity among interventions. In this entire thesis, there are only four groups that were subjected to an intervention that were somewhat similar. Those were the interventions in Study 1 by Khacharem (2017) and Khacharem et al. (2020). In both studies, the sample consisted of novice and (more) expert athletes and both studies addressed the understanding of a sport graph. All the other studies were only similar in that they fulfilled the inclusion criteria. The participants were adults and had to learn complicated knowledge. However, it must be noted that the studies included in this thesis for comparison, were originally not designed to be compared. Thus, it must be considered that the differences in effects are only true when comparing the specific setting of one study to the other. There are many variables that influence the extent to which an individual is provided an opportunity to learn, such as time exposed to material, time between material and test and who presents the material; the researcher or a teacher (Chin, 1998; Boer et al., 2014). Thus, because there are multiple groups within the same principle that reported positive effects, there is some certainty that there is truth to one effect being more influential in gaining a higher learning gain, than the other.

Thirdly, a literature review heavily depends on the content provided by the original authors of the studies. This literature review faced that same dependability which led to sometimes-difficult interpretations of the results, this is especially true for the study investigating simulation design. After the first exclusion criteria were considered for these studies, the final one related to quality of reporting. Which meant that in the final stage it was examined to what extent the simulation design choices were discussed in terms of choices and reasoning for choices. Ideally, all studies included a description of choices and their reasoning, unfortunately, it became apparent that only few studies describe their design choices, let alone the reasoning. Thus, in the end the four studies that were included, did fulfil the criteria of a thorough description, but the argumentation for the choices that were made were missing. To gain better understanding of what interventions work, more detailed descriptions of the materials should be provided. A very good example of a detailed description is that of the intervention by Nadolny (2013). Next to explaining the simulation, they also provide an explanation about the additional materials received by the participants. Moreover, in their paper they also included screenshots of the simulation. This ensures that the reader gains an understanding of what can be seen by the participants. One of the reasons that could explain this phenomenon is the fact publishers give a character limit to authors writing journal articles. Which means authors have to make tough choices. However, for the repeatability and transparency of research it is incredibly important to provide more details related to the design of the educational materials.

Theoretical Implications

This study set out to compile a list of educational and simulation design choices that can establish a base for the design of IVR educational simulations for adults. The main reason is the limited consideration in learning theories in IVR educational simulations up until now (Radianti et al., 2020). This thesis contributes to that goal by compiling what is known about the design of simulations for educational purposes. As well as what is known about multimedia educational design. The present studies are the first that combine educational design and simulation design to uncover what we currently know about its effects on learning among adults.

Secondly, this thesis unveils the diversity among educational and digital simulation interventions and the experiment in which their successes are tested. Therefore, it is very hard to conclude why one intervention was more successful in yielding learning effect that the other. This is true for both studies. In Study 1, this can be seen in the signalling principle. Both Jung (2016) and Khacharem (2017) investigated the signalling principle, but where one applied it to learning how to change a car tire (Jung, 2016), the other applied it to understanding a sports graphic (Khacharem, 2017). These results support the idea that some of the educational interventions are wildly applicable.

However, the same diversification can be seen in Study 2, in which this poses a bigger challenge. In the presented results it is hard to discover what exactly caused the success of, for example, the experiment conducted by Nadoly (2013). In this experiment a social simulation game was tested (Bakhanova et al., 2020). There were a variety of elements that were more closely related to gamification than to simulation, for example, the use of avatars. Moreover, there are other variables that could also impact the presented results. Such as the time spent within the simulation, the order in which information was presented or even because of the gamified elements that were present. These insights are highly relevant if IVR simulations should one day be deemed an effective educational tool, currently, it is even too early to deem digital simulations effective for learning among adults. The first insights are highly valuable, but they also expose the weaknesses in these studies. For example, the different studies measure their success in all sorts of different way and providing no insight into the learning effect. One thing that the two of three studies that investigated a participatory simulation had in common, was the fact that they only observed the group that was exposed to the simulation. This only reveals information that is applicable to that particular simulation, these insights cannot be generalized and that is not only because of the chosen methodology, but also because of how the design of these simulations was described.

Therefore, the third theoretical implication is that this thesis raises questions about the knowledge that we have regarding effective design of both digital simulations and education for adults. The current thesis implies that especially related to how a simulation should be most effectively designed, there is little knowledge. At the beginning of this thesis the promising insight related to simulation were presented, however, these results mainly related to low-tech simulations or to a younger audience. An important implication that is presented in this thesis is that most of what is currently known to be successful within educational science related to research that was conducted within schools, with a young audience. However, as these results present, especially within the first study into effective multimedia design, is that successful results among youngsters does not automatically mean success among an adult population. An example of these results relates to the worked example principles investigated by Hsu (2012) and Van Gerven (2003). The results presented in this thesis were opposing each other, but Renkl (2005) addressed how successful it is in guiding young novice learners. The results of this thesis challenge the notion that when something is successful for youngsters this is also true for adults.

Practical Implications

IVR simulation training seems a promising tool since it combines the safety of a training situation with the irregularities in real life (Seo, 2019). Therefore, in order to provide learners with an authentic learning experience, it is important that the optimal use of this tool is explored. However, currently, from the perspective of this study there is too little knowledge on responsible use of this tool for all audiences. The results presented here, provide important insights into which variables all influence how multimedia educational messages are perceived by the learner. Therefore, the current practical implications should only be considered for audiences with relatively high literacy an numeracy skills of student-age.

Firstly, when considering the fact that an IVR simulation training is a multimedia educational tool, it should adhere to the following design principles.

1.) Multimedia educational design to reduce extraneous processing

Whilst designing an IVR simulation, the designer should ensure that the learner is properly guided through the educational materials. In the design process special attention should be given to the signalling principle, this was the most overwhelmingly positive out of all the interventions. A well-designed educational message should therefore signal to elements that are the most important to understand, should put elements and words that belong together closely together and should be a combination of providing information via the visual and auditory channel.

2.) Multimedia educational design to manage essential processing

When providing a learner with an educational tool, the aim must be to ensure that the learner learns as pleasantly as possible. To reduce the difficulty level the materials can be designed to reduce essential processing. Important is that the modality principle is used, for example by showing a visual of the material, whilst a narration explains what the learner sees. However, when using the segmenting principle, this must be done carefully. Providing information at different points in time was the most beneficial for learners. Therefore, an effective educational tool offloads the density of the material by providing some information via the visual channel and some via the auditory channel and the segments are presented to the learner at the appropriate moments in time.

3.) Multimedia educational design to foster cognitive processing

When an educational designer is considering applying design principles to foster cognitive processing, this should be done with caution. These interventions were proven successful among young audiences, but in the present study they yielded contradicting results. Therefore, until further research is conducted with these principles, it is strongly advisable that practitioners do not use either the worked example or the self-explanation principles in their educational materials. The results in this study showed that these could also negatively affect the learning process.

Future Research

First and foremost, the lack of simulations in Study 2 shines light on how little the scientific community knows regarding appropriate digital simulation design for an adult audience. Therefore, it is strongly recommended that educational design researchers further investigate if and how digital simulations contribute to learning among adults. In the development of these investigations, the information provided in this thesis could be used to combine MM design with simulations. In the design of the interventions the differences between simulations and gamification should be considered. In order to guide the design of these two, the overview by Bakhova et al. (2020) can be used as a guide. Moreover, it is interesting to consider age as well, since it appears that the success of gamification comes from a combination of multiple factors in which academic subject and age group are only two (Dichev & Dicheva, 2017).

Second, this thesis addressed a vital issue that is currently the norm within the educational science community. It is common, almost standard, to investigate students pursuing a tertiary degree, which even though valuable, cannot be applied to the entire population. In recent years it became more apparent how important it is to have a life full of learning, commonly referred to as lifelong learning. This is vital to ensure financial stability, employment security and emotional well-being in light of the 21^{st} century (Autor, 2013; Brockmann et al., 2008; Merriam & Kee, 2014). However, due to the common focus on university students within the educational science community, there is very little knowledge about what can be done to yield learning effects among a population with less advanced literacy and numeracy skills and different ages. In order to effectively build the bridge between theory and practice, the academic community has a responsibility to investigate interventions that are broadly applicable across the entire society.

Finally, this thesis will repeat the recommendation given by Karasek et al. (2020). Future research endeavours into IVR simulations should focus on the educational aspects. This advice is twofold, first it should be investigated if the earlier described MM interventions lead to similar learning effects when incorporated in an IVR simulation training. Second, it should be investigated whether IVR simulation training in general lead to an increased learning effect compared to more traditional educational methods.

Conclusion

Effective educational design within simulations is vital to prevent cognitive overload in learners. Digital simulations are promising because of the availability of technology. However, very little is known about the optimal balance between education, gamification, and simulation in order to lead to the desired learning outcomes. This study highlighted how little evidence there is to advice practitioners on the design of IVR simulation training for adults' skill development. The comprehensive nature of this study revealed that there are a multitude of areas that need further research before we can provide sound insight to advance IVR simulation training in becoming a sturdy educational tool. In general, the conducted studies make a meaningful contribution to advancing our knowledge related to multimedia educational- and simulation design for adults. It highlights the importance of diversifying our sample of choice to promote generating research results that are applicable to a greater part of society.

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