Chapter 3
Beyond Comparing Learning Technologies: Experiencing Flow in Virtual Reality

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3.1 Introduction

Virtual Reality (VR) is an advanced technology that simulates realistic environments by combining a high degree of control with ecological validity (Bohil et al., 2011). It is becoming increasingly popular. VR applications used for teaching and learning purposes are also gaining importance (e.g., Fowler, 2015). VR is said to promote the acquisition of procedural skills, for example, in skilled trades (e.g., Radianti et al., 2020), but also affective skills, such as perspective-taking or prosocial behavior (e.g., Martingano et al., 2021). Here, VR refers to 360-degree videos or three-dimensional worlds that allow experiences involving sounds and moving images via multiple channels and interactive interfaces (Obrist et al., 2017). Users have vicarious experiences through simulated worlds that include three types of functions: immersion, interaction, and imagination (Burdea & Coiffet, 2003). Multiple kinds of VR systems have been studied, such as desktop monitors, projection screens, and head-mounted displays (HMDs). Thus, the term VR is often used as a collective term for heterogeneous technologies and is not used distinctively. It may mean 360° pictures viewed on tablets, or 360° movies viewed through cardboard goggles. In addition, the term encompasses environments in which HMDs, which enclose ears and eyes, paired with data suits and controllers, enable interaction in entirely computer-generated spaces. What they all have in common is the understanding of a computer-generated and realistic real-time representation that individuals virtually enter, experience multisensory, and in which they interact via artificial and natural user interfaces (Radianti et al., 2020; Zinn, 2019).

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A distinctive subdivision of VR technologies is often challenging. Many studies, therefore, focus on the comparison of such technologies regarding the intended learning outcomes. Their goal is usually to find out with which technology learning is better or worse. The implication is that the technology itself could directly influence learning. However, in such media comparison studies, which are often viewed critically (e.g., Clark & Mayer, 2016), the instructional design behind the educational technology is neglected. It is not the technology that leads to better or worse learning, rather it is the interaction of many factors, of which the technology is just one. In many previous studies on learning with VR applications, learning outcomes are the subject of research. Latent processes taking place within the VR experience have rarely been considered. These include the experience of presence (e.g., Mikropoulos, 2006), cognitive load (e.g., Parong & Mayer, 2021), or flow (e.g., Rutrecht et al., 2021). It can be assumed that such learning process variables can significantly explain the effects of VR technologies on learning outcomes. Thus, instead of a simple media comparison, the present study focuses on the experience of flow in VR. From a theoretical perspective, this study contributes to a better understanding of the cognitive psychological processes involved in learning in VR. From a practical perspective, this study highlights those processes that need to be enhanced for successful learning in VR.

The study design considers both, the direct effects on learning outcomes through VR technologies as well as the indirect effects mediated by the learning process variable flow can be investigated. Therefore, we used a VR environment, which is accessible via two different technologies (HMD and laptop) and which is a virtual replication of the Anne Frank Museum in Amsterdam.

The article is divided into the parts theoretical background, methodology, results, and discussion. In the first part, VR as a technology and the learning process variable flow are described. In the second part, the methodological approach including a description of the sample, procedure, measurement instruments, and data analysis is explained. In the third part, results are presented. Part four serves to interpret the results. Finally, the implications of the work are discussed.

3.2 Theoretical Background

3.2.1 Virtual Reality

VR has often been defined in terms of its technological features. Greenbaum (1992) wrote "*Virtual Reality is an alternate world filled with computer-generated images that respond to human movements. These simulated environments are usually visited with the aid of an expensive data suit which features stereophonic video goggles and fiber-optic data gloves.*" (p. 58). While even today, depending on the discipline, educational technologies are often characterized and judged based on their hardware conditions, research in educational psychology attempts to define the technology more on the basis of its underlying cognitive processes (e.g., Bente et al., 2002). A definition by Biocca and Delaney (1995) addresses both: "*VR is the sum of the hardware and software systems that seek to perfect an all-inclusive, sensory illusion of being present in another environment.*" (p. 63). Nevertheless, the characterization of VR based on its technological characteristics is common and also relevant to the present study. Currently, three-dimensional environments exist that are presented via two-dimensional screens and are based on devices such as monitors, mice, joysticks, keyboards, microphones, and speakers (Burdea & Coiffet, 2003). Such VR environments are often classified as non-immersive (Cummings & Bailenson, 2016; Schroeder, 2010). Stereoscopic displays visually convey depth information, creating a spatial impression. However, many stimuli from the real environment are still perceived. Auditory content is presented via headphones or speakers. Navigation and interaction with virtual artifacts are done via mouse, joystick, or keyboard (Lee et al., 2010). When referring to laptop technology in the following part of this paper, the latter description is always meant. Immersive VR environments, on the other hand, are often associated with the use of HMDs. In the following text, this technology will be linked with the abbreviation HMD. HMDs fill the entire field of vision and largely block out environmental stimuli from the reality. Auditory VR content is conveyed via integrated headphones. The displays present an image to each eye from a slightly different viewing angle. This mimics natural human visual perception, creating the stereoscopic impression of a computer-generated virtual world. The sensors of the HMDs consider head movements and enable perspective changes and movements in space. This is often combined with data gloves, body suits, and controllers, whose functionalities are used to navigate, select, and interact (Allmendinger, 2010; Andreas et al., 2010). Of course, a division in HMD and laptop VR is limited, but sufficient in the context of the present study. Nevertheless, other VR technologies such as CAVEs (e.g., Buttussi & Chittaro, 2017) exist and VR technologies undergo ongoing development activities. As described above, HMD and laptop VR differ in terms of their technological features. Besides the visible differences, there are latent factors happening during a VR experience that differ depending on the kind of technology. These factors are correlates of human information processing and thus modify the experiences in VR. Hence, investigating such processes enables us to describe the experiential quality of VR learning in more detail. Among others, the experience of flow (e.g., Rutrecht et al., 2021) has been shown to be promising for learning in VR.

3.2.2 *Flow Experience*

Csikszentmihalyi proposed Flow Theory in 1975 (Csikszentmihalyi, 1975). Flow means a mental state when concentrating on an activity completely, with a high level of excitement and fulfillment. When someone experiences the state of flow, receptions of environmental stimulus become limited. Uncorrelated stimuli from the environment are filtered out. Meanwhile, the person loses self-perceptions. Instead, the person only responds to the target and feedback and has feelings of control over the environment (Nakamura & Csikszentmihalyi, 2009). Furthermore, the course of the action becomes automated, and the action is usually performed faster and more effectively. Another characteristic of flow is the loss of the sense of time (Rutrecht et al., 2021). For the measurement of flow experience, Rheinberg et al. (2003) consider flow as a multidimensional construct consisting mainly of the facets (1) smooth automated flow and (2) absorbedness. Meant are the flow of action chains and the complete absorption in an activity. Based on these facets, Rheinberg et al. (2003) developed a questionnaire.

In educational psychology, the experience of flow is also classified as a performance-relevant component of learning motivation and described as increasing motivation (Engeser et al., 2005). Accordingly, flow is a positive emotion in the form of intrinsic reward (Sherry, 2004; Voiskounsky et al., 2004). The experience of flow is also dependent on the fit between the individual and the task. According to this, flow can only occur if the acting person is neither under- nor over-challenged (Nakamura & Csikszentmihalyi, 2009).

With the development of technology and the internet, many researchers have used Flow Theory to investigate experiences and interactions with e-learning, computer games, and mobile devices (Ozkara et al., 2017; Pelet et al., 2017; Shim et al., 2015; Su et al., 2016). When engaging in e-learning, for example, a state of flow can increase the enjoyment of the learning experience. Consequently, a learner will seek the same learning experience in the future, activating an intrinsic motivation to learn. Flow extends to subjective feelings involving desirable positive affective states (Webster et al., 1993). Considering flow and simulated environments, VR experiences that are vivid and real should enhance flow feelings. The concept of flow has been studied in VR research and found to predict user behavior (Bodzin et al., 2021; Kunz & Santomier, 2019; Rutrecht et al., 2021; Tai et al., 2022). In a study by Bodzin et al. (2021), students explored their city's river watershed in VR. They reported that they had significantly experienced more flow and learned more. A comparison group was not implemented. In another study by Tai et al. (2022), again no control group was used. 143 engineering students were trained in VR regarding the care of car body parts. Procedural skills recorded in a post hoc test could be significantly explained by experiencing flow in the VR environment. Another study by Rutrecht et al. (2021) examined 100 subjects playing a performance-based rhythm game under an HMD or on a desktop. The game outcome could be significantly explained by the experience of flow. However, the groups did not differ with respect to flow. Overall, there is still little empirical research on the relationship between experiencing flow in VR and learning outcomes. Hence, the present experimental study aims to contribute to the understanding of the role of flow in VR by comparing two different VR technologies.

3.2.3 *Research Aim and Hypotheses*

Many studies in the field of educational technology are driven by the need to prove or disprove the effectiveness of certain technologies. Nevertheless, so-called media comparison studies are often criticized (Clark & Mayer, 2016; Reeves, 2006). Parong and Mayer (2018) refer to the comparison of two media methods as an "*apples-to-oranges type of comparison*" (p. 789), as underlying instructional methods and further correlating factors are neglected. Therefore, in this study, a research design is used that considers two VR technologies and one learning process. As a basis for this study, the Cognitive Affective Model of Immersive Learning (CAMIL) by Makransky and Petersen (2021), the Educational Framework for immersive Learning (EFiL) by Dengel and Mägdefrau (2020), and the Meaningful immersive VR Learning (M-iVR-L) model by Mulders et al. (2020) were used. These three recent models, especially the CAMIL, are the basis for the research design and the experimental study presented in this paper. Figure 3.1 illustrates the research design on which the experimental study is built.

Our study intends to investigate to what extent VR technologies are suitable to significantly support students' learning. Using the example of the historically relevant VR environment *Anne Frank VR House*, the in VR recreated hiding place of Anne Frank, a girl of Jewish heritage during the Second World War, in Amsterdam, cognitive (i.e., declarative knowledge) and affective (i.e., perspective-taking in Anne Frank) parameters of learning and the evaluation of the VR application (i.e., satisfaction, recommendation) are analyzed. VR is said to promote in particular the acquisition of affective skills such as perspective-taking or prosocial behavior (e.g., Martingano et al., 2021). Therefore, we assume that HMD-based VR is more conducive for perspective-taking, whereas, for declarative knowledge, we do not expect any differences between the technologies. Due to the novelty effect (e.g., Miguel-Alonso et al., 2023), we assume that the HMD-based VR will be rated better by the students than the laptop-based VR.

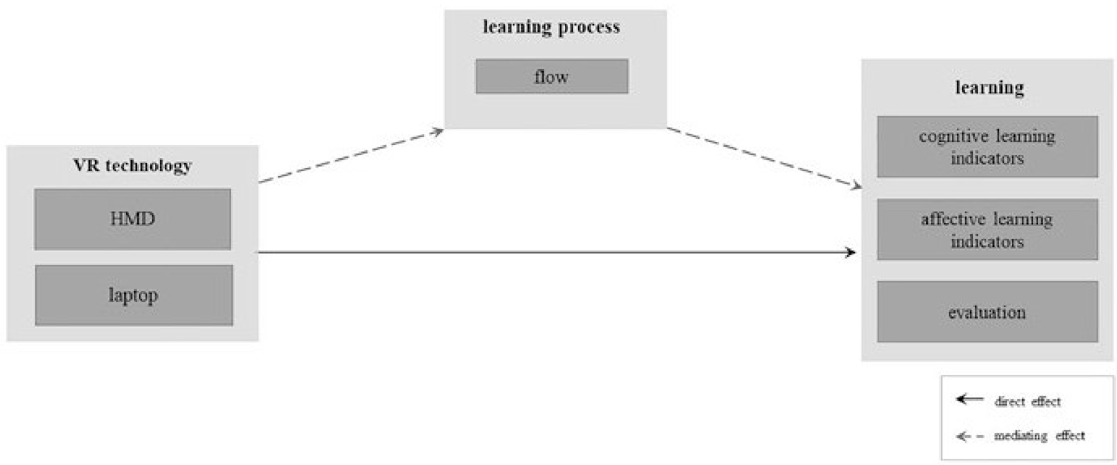

Fig. 3.1 Research design

A special focus of the study will be on the learning process variable flow. The research design that is visualized in Fig. 3.1 aims at a more appropriate representation of the complex interaction structures of learning-relevant variables and thus mediating relationships. Both, direct effects, and indirect effects become measurable. By controlling for the additional variable flow, confounding can be avoided, of course not fully, but at least to some extent. If influencing variables that correlate with the independent variables, in this case, VR technology, and dependent variables, in this case learning indicators, are not controlled, so-called spurious effects can arise. The estimation of the correlations between the independent and dependent variables is biased if relevant factors are not controlled. Thus, correlations are systematically over- or underestimated. The interpretation of causality between independent variables and dependent variables is compromised. Studies that have been exclusively devoted to the comparison of two forms of media presentation have often failed to control for person-specific variables (e.g., experience of flow) and, thus for differences within the sample concerning these variables. This is particularly problematic when the study is not a randomized experiment, in which person-specific variables are assumed to be balanced out due to random assignment to experimental conditions (Eid et al., 2010). If, as the research design underlying this paper suggests, additional variables are integrated that appear to be related to the independent and dependent variables, on the one hand confounding and thus biased results are tried to be avoided, at the same time, additional variance in the dependent variables can be systematically elucidated (Buchner, 2023; Mulders, 2023). Furthermore, this study tries to emphasize that the choice for or against particular VR technologies should not be made based on their technical capabilities, but rather based on what learning processes the user should experience in VR.

The following hypotheses will be tested:

1. Effect of technology on learning: Learning outcomes differ depending on technology.
   (a) with respect to affective and evaluative learning indicators: HMD > laptop
   (b) with respect to cognitive learning indicators: HMD = laptop
2. Mediating effect by flow: More flow is experienced in the HMD conditions than in the laptop conditions. The more flow is experienced, the more beneficial for the learning outcomes.

3.3 Methods

3.3.1 Anne Frank VR House

The VR environment is the freely available *Anne Frank VR House*, jointly developed by the *Anne Frank Foundation* and *Force Field VR*. The application allows insights into the hiding place of 13-year-old Anne Frank, her sister, her parents, and

Fig. 3.2 The room of Anne Frank and Fritz Pfeffer

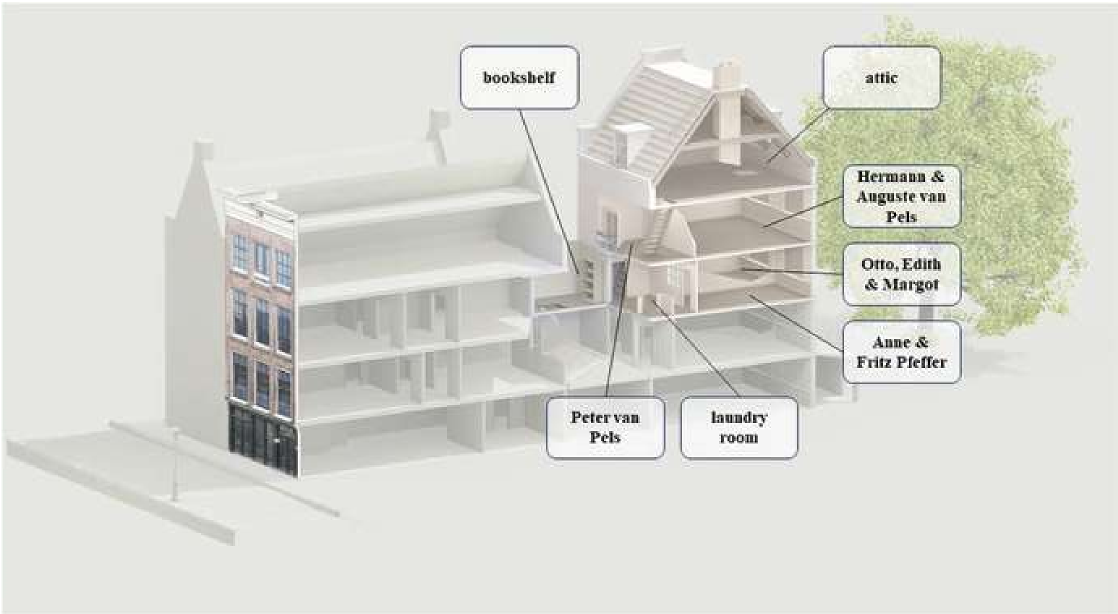

Fig. 3.3 Overview of the hiding place

four other people. The hiding place was in the back of a company building on Prinsengracht 263 in Amsterdam. The VR environment shows the living conditions of the eight people of Jewish origin in the period from 1942 to 1944. All eight rooms are reproduced in detail. No persons are depicted. Additional information about life in hiding and the history of those in hiding is included. The information is presented verbally by a female voice-over. There is no corresponding virtual agent for the voice. Insights are provided by Figs. 3.2 and 3.3.

The *Anne Frank VR House* can be explored by two VR technologies. On the one hand, HMDs and two linked controllers can be used. Teleportation and head movements make it possible to discover the hiding place room by room. On the other hand, the virtual hiding place can be explored by various devices with 2D screens

Fig. 3.4 The two VR technologies

(e.g., tablets, laptops) by accessing the 360° web application with equivalent content. Here, the field of view is changed either by the mouse cursor or by the touch function. Figure 3.4 shows the differences between the two technology forms.

3.3.2 Procedure

The study was conducted between May and December 2021. The single-scenario study included a pre-questionnaire, a VR experience, and a post-questionnaire (see Fig. 3.5). The VR experience itself took an average of 30 minutes. The experience differed between students in terms of the technology that was used (HMD, here *Meta Quest 2* vs. laptop, here *Dell Latitude 3510*). The online-questionnaire batteries included instruments on sociodemographic variables, evaluation, cognitive and affective learning outcomes, and the learning process variable flow.

3.3.3 Measurement Instruments

In addition to sociodemographic variables (gender, age, grade level), learning outcomes were collected at various levels. To measure cognitive learning, the subjects were asked to answer ten short knowledge questions (e.g., "*What did Anne's diary look like?*"). A maximum of two points per question was reachable, resulting in a maximum point value of 20. The internal consistency of the knowledge test is $\alpha = 0.71$. In addition to cognitive learning objectives, affective learning was also

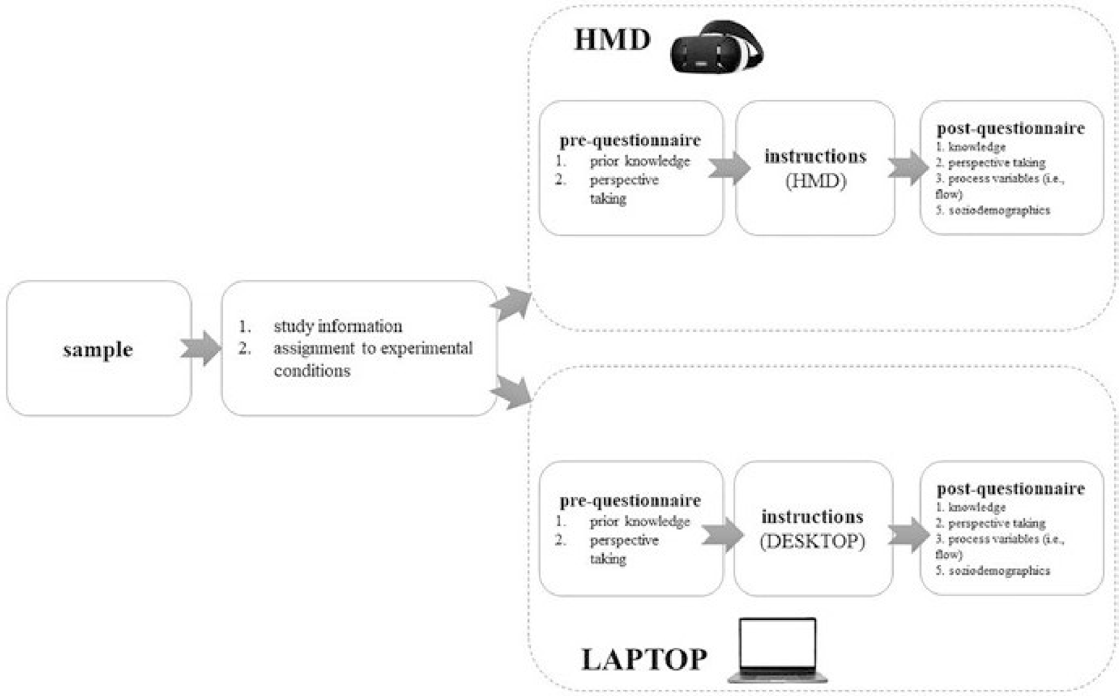

Fig. 3.5 Study process

considered. As an affective goal, perspective-taking in Anne Frank was set. Perspective-taking is understood as the ability to empathize with another person's feelings, which is considered as an essential prerequisite for the emergence of empathy or compassion (Dimitrova et al., 2014). To test the extent of perspective-taking, students were asked to indicate how well they could empathize with Anne's life situation in the hiding place. A ten-point scale from 1 ("*not at all*") to 10 ("*very well*") was used as the response format. Students had to answer this question before and after the VR experience. In addition, the students were asked to evaluate the VR experience. To do so, they should indicate their level of satisfaction ("*I am satisfied with the virtual learning experience.*") as well as their tendency to recommend it ("*I would recommend the virtual hiding to other students.*") on a scale of 1 ("*strongly disagree*") to 5 ("*strongly agree*").

To measure the experience of flow, the Flow Short Scale (FKS; Rheinberg et al., 2003) was used. The instrument consists of the two dimensions of smooth automated flow (example: "*I was completely absorbed in what I was doing*.") and absorbedness (example: "*I had no trouble concentrating*.") and a total of ten items. The questionnaire has a seven-point scale as a response format from 1 ("*strongly disagree*") to 4 ("*partly agree*") to 7 ("*strongly agree*"). Rheinberg et al. (2003) listed values from comparative studies. A mean of $M = 5.16$ ($SD = 0.93$) was found for graffiti spraying and a mean of $M = 4.57$ ($SD = 1.13$) for solving a statistics task. Rheinberg et al. (2003) reported a Cronbach's alpha of $\alpha = 0.90$, and the internal consistency in the present study was $\alpha = 81$.

3.3.4 *Data Analysis*

In addition to simple descriptive statistical analyses, a multivariate analysis of variance (MANOVA) and post hoc ANOVAs were conducted with technology as the independent variable and the various learning indicators as the dependent variables. To explore the mediating effects of the learning process variable flow, mediation analyses were conducted. Therefore, the SPSS macro PROCESS (Hayes, 2017) was installed.

3.4 Results

The presentation of the statistical analyses is divided into three main sections. First, the descriptive statistics of the variables collected are reported. In the next step, the testing of hypotheses one is adequately presented in the context of a MANOVA. Finally, to answer hypothesis two, t-tests for independent samples, correlations, and mediation analyses are presented.

3.4.1 *Descriptive Characteristics of the Sample*

One hundred thirty-two subjects (65 female, 63 male, 4 diverse) were surveyed. The sample of this study consists of students aged 12–17 years ($M = 13.84$, $SD = 0.92$). Students had to attend the eighth or ninth grade of a middle school in Germany to participate. Seventy-four students participated in the study via an HMD and 58 via a laptop. Table 3.1 shows the measurement points, sample sizes, means, standard deviations, and Cronbach's alphas as a measurement of internal consistency for each scale or item.

To assess the increase in perspective-taking from the first to the second measurement point, a new variable was calculated that allows a pre-post comparison. The variable calculation involved subtracting the pre from the post value. Across the

Table 3.1 Descriptive characteristic values of all scales used in the study

Variable	MP	*N*	*M*	*SD*	α
Knowledge test	Post	132	10.89	4.36	0.71
Perspective-taking	Pre	132	4.77	2.40	–
	Post	132	6.67	2.13	–
Satisfaction	Post	124	4.31	0.91	–
Recommendation	Post	124	4.33	0.93	–
Flow: smooth automated flow	Post	128	5.18	1.36	0.68
Flow: absorbedness	Post	128	5.37	1.38	0.85

Annotations: *MP* measurement point, *N* sample size, *M* mean, *SD* standard deviation, α Cronbach's alpha experimental conditions, there is an increase in perspective-taking in Anne Frank from the first to the second measurement, although the variation among students is quite large ($M = 1.90$, $SD = 2.37$). In the knowledge test, the students received on average slightly more than half of the maximum 20 points that could be achieved. However, the high variation indicates very different performances among the students. Regarding the evaluation of the VR application, high means and low variation were found averaged across the experimental conditions. Only a few outliers were not satisfied and would not recommend the VR application to others. Compared to the values reported by Rheinberg et al. (2003) for activities such as graffiti spraying, the experience of flow in the present study can be classified as very high. Absorbedness, in particular, reached very high values.

3.4.2 *Effects of VR Technology*

To address hypothesis 1, a one-way MANOVA was conducted with technology as the independent variable and knowledge test, perspective-taking (pre-post), and evaluation as dependent variables. The MANOVA showed statistically significant differences between HMD-based and laptop-based VR ($F(4119) = 14.96$, $p < .001$, $\eta^2 = 0.34$, Wilk's $\Lambda = 0.67$) for the combined dependent variables. Thus, the factor technology can explain 39% of the total variance. Multi-factorial ANOVAs were then calculated for each of the four dependent variables. The Bonferroni correction was used to decrease the risk of a type I error when calculating multiple statistical tests. Table 3.2 shows the results of the ANOVAs.

Further follow-up analyses showed that students in the HMD condition rated the application higher, and were better able to empathize with Anne Frank. In more detail, students in the HMD condition were significantly more satisfied (10% variance explanation) and would be more likely to recommend the application to classmates (11% variance explanation). It can be assumed that this finding is also partly due to the novelty effect (e.g., Miguel-Alonso et al., 2023). This effect was certainly more pronounced among students in the HMD condition than in the laptop condition. Nevertheless, learning with HMDs seems to have been more emotionally engaging and motivating for the students. According to recent assumptions of motivation theories (e.g., Renninger & Hidi, 2015), multimedia learning environments

Table 3.2 Results of ANOVAs for the independent variable technology

Variable	*F*	*df*	*p*	η^2
Knowledge test	32.36	1122	0.00	0.21
Perspective-taking (pre-post)	3.80	1122	0.05	0.03
Satisfaction	13.36	1122	0.00	0.10
Recommendation	15.17	1122	0.00	0.11

Annotations: *F* test statistic, *df* degrees of freedom, *p* probability, η^2 effect size partial eta^2

trigger, when they are perceived as appealing, a high initial situational interest, which in turn can have a positive effect on subsequent learning processes. Based on these results, sub hypothesis 1a can be accepted. Regarding sub hypothesis 1b, other follow-up analyses revealed unexpected group differences: Results of the laptop group are significantly better than those of the HMD group. This difference was highly significant. The difference between the two groups is approximately one standard deviation unit. This means that, on average, the students in the laptop condition solved two more knowledge questions correctly than students in the HMD condition. The significant difference between the two groups could be explained by the fact that cognitive capacities that were tied up by many environmental details and by the high interactivity of the HMD technology were free in the laptop condition, and the focus could be placed on the acquisition of expertise (Makransky et al., 2019; Parong & Mayer, 2021).

3.4.3 Mediating Effects of Flow

To address hypothesis 2, mediation analyses were performed. It was hypothesized that experiencing flow can systematically explain the direct effects of VR technology on the learning outcomes we found in the MANOVA (see Fig. 3.1). According to Baron and Kenny (1986), four assumptions for the existence of a mediation must be fulfilled: First, between the independent variable and the dependent variable, there is a direct relationship (path c). This path is also called the total effect. Second, the independent variable must correlate with the mediator (path a). Third, the mediator and the dependent variable must be connected (path b). Fourth, in full mediation, the direct path between independent and dependent variable loses its significance (path c’). If the fourth step is not fulfilled, it is referred to as partial mediation. In this study, it has been assumed that the latent learning process flow (mediator variable) significantly explains the relationships between technology (independent variable) and learning indicators (dependent variables).

The first assumption of Baron and Kenny (1986), namely the direct relationship between technology and the various learning indicators (path c), has already been sufficiently verified by the MANOVA and the subsequent ANOVAs in Sect. 3.4.2. The main effect of technology for the combined dependent variables was significant.

To test the second assumption (path a), the relationships between technology and the learning process variable flow were investigated. For this purpose, multiple t-tests for independent samples were carried out. Here, the method tests whether there are differences in the feeling of flow regarding the stages of technology (HMD vs. laptop). The results of the t-tests are shown in Table 3.3. A positive mean difference indicates that students in the HMD condition achieved higher values than students in the laptop condition.

Table 3.3 Results of the multiple t-tests for independent samples for flow at the stages of technology

Mediator	*MD*	*SD*	*df*	*t*	*p*	*d*
Smooth automated flow	1.17	0.23	103	5.17	0.00	0.95
Absorbedness	1.75	0.19	126	9.18	0.00	1.64

Annotations: *MD* mean difference, *SD* standard deviation, *t* test statistic, *df* degrees of freedom, *p* probability, *d* effect size d

Table 3.4 Spearman rank correlations between learning process variables and learning indicators

Mediator	Perspective taking	Knowledge test	Satisfaction	Recommendation
Smooth automated flow	0.16	0.22**	0.47**	0.36**
Absorbedness	0.11	0.23**	0.41**	0.36**

Annotations: significance level $*p < 0.05$, $**p < 0.01$

Regarding the learning processes, statistically highly significant differences could be found between the HMD group and the laptop group. Students in the HMD condition experienced more flow. This applies to both subscales.

To test the third assumption of Baron and Kenny (path b), descriptive correlation analyses were used. The correlative relationships were determined due to a lack of normal distribution with the nonparametric Spearman Rank Correlation. The results of the correlation analyses are shown in Table 3.4. Several statistically significant correlations could be determined. Thus, the experience of flow seems to be related to increased satisfaction, greater tendency to recommend, and better performance in the knowledge test.

In the following, the fourth assumption of Baron and Kenny and thus the mediation assumptions are checked inferential statistically. In the mediation model, technology was included as an independent variable, the two subscales of flow as mediator variables, and satisfaction, recommendation, and the knowledge test as dependent variables. Eight mediation analyses were calculated. In four of these, we found statistically significant indirect effects mediated by flow, but mainly for the evaluative indicators. A significant mediation could be found, among others, for the mediator flow (subscale: automated process) and the dependent variable satisfaction. Within the analysis, a total effect of technology on satisfaction was found ($c = -0.58$**). The total effect means that students in the laptop group were significantly more dissatisfied than those in the HMD group. After the mediator was included in the model, technology significantly predicted the mediator flow ($a = -.1.19$***). Students in the laptop condition experienced significantly less flow than students in the HMD condition. Flow, in turn, predicted satisfaction ($b = 0.29$***). When students experienced more flow, they were also more satisfied. Path c`, the direct effect of technology on satisfaction, did not become significant ($c$` $= -0.23$). Thus, a total mediation could be detected. After the mediator flow (subscale: automated process) was integrated into the analysis, the correlation

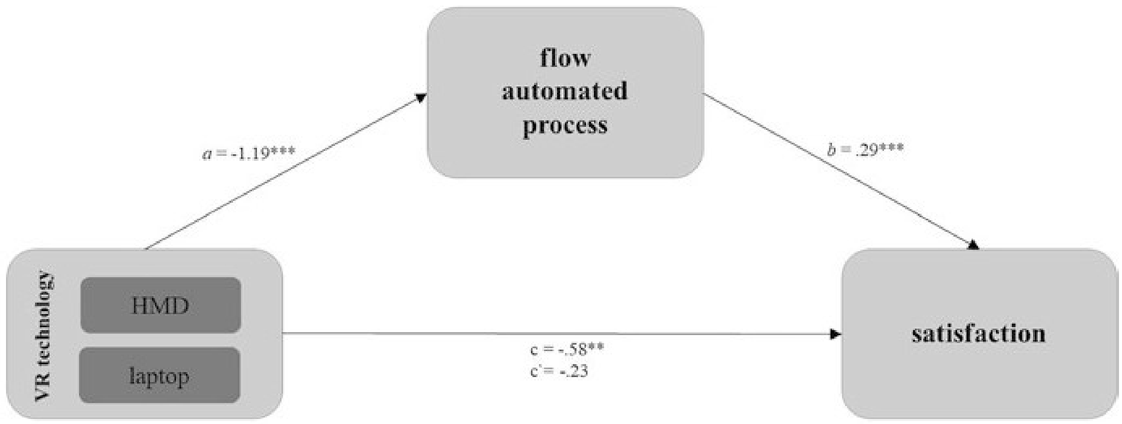

Fig. 3.6 Example of a total mediation

between technology and satisfaction loses its statistical significance. Consequently, there is no direct correlation between technology and satisfaction, but there is an indirect correlation, which can be completely explained by flow (indirect effect $ab_{flow\_auto\_process} = -0.28$, 95% CI [−0.525, −0.070]). The confidence interval does not enclose the value zero. The indirect effect is estimated to be significant. For an illustration of the causal relationships, see Fig. 3.6. The correlations are similar to the other significant mediation analyses and are therefore not listed separately again.

3.5 Discussion

In this study, the *Anne Frank VR House* was empirically investigated. Across the experimental conditions (HMD vs. laptop), it was found that the VR application can generally address cognitive and affective learning objectives and is rated extremely positively by middle school students. In this respect, the application seems to be suitable for purposes of teaching and learning. Nevertheless, this study is not able to decide which VR technology, here HMD or laptop, seems superior for presenting VR content. Unsurprisingly, significantly better student ratings were found for HMD compared to laptop. However, the use of HMDs also proved to be beneficial for affective learning objectives (i.e., perspective-taking). For cognitive learning objectives, it was even the other way around: Students on laptops answered significantly more knowledge questions correctly. Therefore, a decision for or against a VR technology should always be a case-by-case decision made by a teacher based on the intended learning objectives.

Equally important as main effects were mediation effects. Indirect effects mediated by the experience of flow can significantly explain the effects of VR technologies on learning outcomes. In some cases, the direct effect disappeared with the addition of the mediator and only the indirect effect mediated by flow proved to be statistically significant. At this point, it becomes obvious why latent process variables should be systematically controlled in empirical studies. Otherwise, statistically significant direct effects are seemingly interpreted as significant or are overestimated systematically, although an underlying learning process is responsible for the correlation. Accordingly, complex interaction structures are more suitable for representing and investigating learning in VR. Unfortunately, most of the significant mediation effects concern the evaluation of the VR application and not the affective or cognitive learning indicators. Hence, it seems of importance that follow-up studies also consider latent learning processes in VR. This is not limited to VR. Latent learning processes also play a crucial role in learning scenarios that make use of Augmented Reality or interactive videos, for example. Consequently, other educational technologies could be explored in qualitative and quantitative studies using the proposed research design. This approach goes beyond traditional approaches of media comparison studies, which are considered critical in the literature (Clark & Mayer, 2016; Mulders, 2023). In addition, the research design makes it possible to uncover causal and correlational relationships through mediating learning process variables and thus help to avoid confounding.

Additionally, the study provides initial evidence for the underlying theoretical models (Dengel & Mägdefrau, 2020; Makransky & Petersen, 2021; Mulders et al., 2020). However, many of the constructs listed in these models (e.g., agency) have remained untouched and provide high potential for future research.

Moreover, from a researcher's perspective, the role of virtual agents as postulated in the iSTAR framework (Huang et al., 2023), could be further examined. In the *Anne Frank VR House*, a disembodied voice presented information about the life of Anne. It would be interesting in future studies to manipulate the extent of collaboration between users and agents with and without a body and investigate their influences on learning parameters.

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