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Usability of Gamified Knowledge Learning in VR and Desktop-3D

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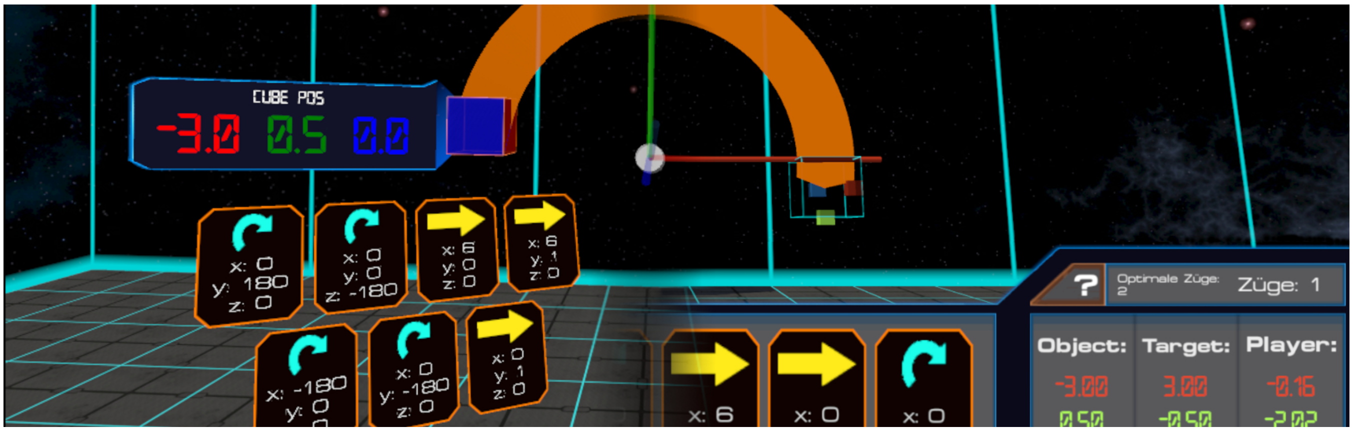

Figure 1: *GEtiT VR* (l) and *GEtiT* (r) challenge players to apply ATs to solve spatial puzzles.

ABSTRACT

Affine Transformations (ATs) often escape an intuitive approach due to their high complexity. Therefore, we developed GEtiT that directly encodes ATs in its game mechanics and scales the knowledge's level of abstraction. This results in an intuitive application as well as audiovisual presentation of ATs and hence in a knowledge learning. We also developed a specific Virtual Reality (VR) version to explore the effects of immersive VR on the learning outcomes. This paper presents our approach of directly encoding abstract knowledge in game mechanics, the conceptual design of GEtiT and its technical implementation. Both versions are compared in regard to their usability in a user study. The results show that both GEtiT versions induce a high degree of flow and elicit a good intuitive use. They validate the effectiveness of the design and the resulting knowledge application requirements. Participants favored GEtiT VR thus showing a potentially higher learning quality when using VR.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; **Empirical studies in HCI**; • **Applied computing** → **Interactive learning environments**;

KEYWORDS

Gamification, Knowledge Learning, Serious Games Design

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1 INTRODUCTION

Affine Transformations (ATs) are a crucial knowledge for many engineering areas such as robotics [21], 3D computer graphics [19], and Virtual Reality (VR) and Augmented Reality (AR) development. Learning and practicing ATs often leads to a high degree of frustration. ATs cannot easily be demonstrated or visualized due to their high complexity. AT operations, i.e., a translation, rotation, scaling, shearing or reflection, in $\mathbb{R}^3$ are commonly expressed as 4×4 matrices. Students struggle when trying to comprehend how the theoretically grounded mathematical aspects result in a transformation of an object. Using the homogeneous representation as 4×4 matrices, arbitrary matrices, each potentially representing an AT, can be multiplied together to combine transformations. This multiplication is order dependent. For instance, a rotation followed by a translation potentially has a different outcome than a translation followed by a rotation.

Therefore, we developed the *Gamified Training Environment for Affine Transformations (GEtiT)*[1] (see Figure 1) that requires the knowledge's *repetitive application* during the gameplay [50]. GEtiT challenges users with spatial puzzles that require the application of AT operations. When solving these puzzles, GEtiT provides learners with *immediate feedback* about the correctness of their actions. Thus, the gameplay results in an audiovisual demonstration of the underlying principles. Also, the serious game *moderates* the *level of abstraction* of ATs by implementing four different difficulty levels. Each difficulty encodes an adjusted subset of the knowledge. Hence, students learn the learning content in an intuitive and comprehensible way. Overall, GEtiT aims at a training transfer of the AT learning content. Training transfer is the application of knowledge trained in one context to a different context [16]. GEtiT's desktop version already demonstrated its educational effectiveness by yielding a similar learning outcome to a traditional method [52].

A *higher visual immersion* leads to a *higher presence* and *higher performance* [73] in the case of a virtual training simulation [77]. Presence also has a mediating effect on the learning outcome. It increases the intrinsic motivation and enjoyment of learners thus improving the perceived learning quality and satisfaction [41]. Therefore, we also developed a specific *GEtiT VR* version to potentially increase GEtiT's learning outcome and learning quality [48]. GEtiT VR implements the same core game mechanics as GEtiT but utilizes *Head Mounted Display (HMD) VR* to visualize the gameplay.

Our contribution: This paper's contribution is twofold. 1) *Conceptual presentation* of a serious game targeting a transfer-oriented learning of ATs in desktop-3D and HMD-VR. 2) *Usability and joy of use* evaluation of the two systems. The study's results show a *higher enjoyment* when using GEtiT VR suggesting that using VR enhances the learning quality. The user study *validates the design* and shows that the audiovisual presentation and the application requirement of ATs is effective. Also, the results reveal that both GEtiT versions induce a *high degree of flow* and elicit a *good intuitive use*. However, the user study also indicates the importance of researching selection-based text-input techniques for VR. Overall, this paper contributes to the on-going research of analyzing the educational potentials of VR technology.

[1]Get GEtiT: http://www.hci.uni-wuerzburg.de/projects/getit/

The paper begins with an analysis of the related work, provides a brief overview of GEtiT's design and gameplay. Then, we describe our research method and present as well as discuss the results of a user study. This paper is concluded with a brief summary and an outlook for future research.

2 RELATED WORK

Acquiring and mastering knowledge or gaining expertise with its explicit application requires a high amount of deliberate practice [17]. Thus, repetitive knowledge training is a very effective learning method [7]. It achieves a knowledge automatization, deepening, and training transfer [15, 45]. Creating similar requirements with the targeted context facilitates a transfer-oriented knowledge training [12, 54, 76]. Computer games have the potential to simulate, demonstrate, and require any knowledge [56]. Hence, they are ideal environments for a transfer-oriented knowledge learning.

Game-Based Knowledge Learning

Each computer game encodes specific knowledge that is learned, practiced, and mastered during the gameplay [13, 27]. Research has shown that computer games are useful to train complex sets of skills [49], such as skills of laparoscopic surgery [65], communication [58, 68], collaboration [59, 63] and leadership [61, 71]. Also, they fulfill the conditions for optimal learning [17]. Computer games *keep players motivated* even when the content goes beyond the usual entertainment purpose [2] due to their flow-inducing aspects [11]. Flow is the central construct that mainly influences enjoyment and performance of gaming action [83] and hence knowledge learning. A well-designed video game continuously provides new challenges that increase in their difficulty to match a player's knowledge gain [43]. In this way, players *periodically repeat* [22] *preexisting knowledge* that is acquired during a game's gameplay, e.g., during a tutorial phase. Lastly, players receive *immediate feedback* about their progress towards solving a challenges and the correctness of their actions [10]. Serious games [14] combine these aspects of entertainment and learning with pedagogical elements [8] for a targeted knowledge learning.

A computer game consists of a series of game mechanics. Game mechanics are the rules of a computer game. They define what is possible inside a particular game environment by encoding the underlying principles as their internal rules. Thus, they create a game's virtual environment [1] and allow players to interact [70] with it. The interaction between individual game mechanics creates a game's gameplay.

The internal rules of a game mechanic can also consist of rules derived from a specific learning content thus achieving a *gamified knowledge encoding* [53]. Game mechanics then create *learning affordances* for the encoded knowledge by requiring its application and demonstrating the underlying principles [12, 34]. Executing these game mechanics takes place on a player's skill-based or rule-based level of human performance [60]. This leads to a compilation of situation specific *mental models* [40, 55]. Mental models are complex constructs that allow for a visualization and simulation of familiar situations [32, 79] and for the analysis of unfamiliar problems [69], e.g., a training transfer. By *moderating* the level of abstraction, i.e., adjusting the encoded knowledge rules in their complexity, an intuitive knowledge learning is achieved [53]. Thus, encoding the AT learning content in game mechanics realizes an effective transfer-oriented knowledge training.

The first learning effectiveness study of GEtiT already validated this approach [52]. Here, participants either played GEtiT or practiced the AT knowledge using paper-based assignments. At the end of the study, a paper-based exam was written and revealed a successful training-transfer from the serious game to the exam. Also, the *gamified knowledge encoding* was used to identify orbital mechanics knowledge rules encoded in Kerbal Space Program [78] and to predict its learning effect. In the study, participants played the game and showed a significant knowledge gain as well as effective training-transfer [51]. Thus, the gamified knowledge encoding also allows for a prediction of the learning outcome. In sum, knowledge learning using game mechanics is effective.

Educational Use of 3D Environments and VR

Learning of ATs requires an environment that visually demonstrates 3D geometrical problems. 3D action-based computer games train a player's spatial abilities such as the mental rotation skill [9], spatial visual attention [25], spatial resolution of vision [26], and spatial navigation [33]. This is crucial as a training of spatial abilities improves 3D geometry thinking [57]. Vice-versa, learning descriptive geometry assists the development of spatial abilities [24]. Thus, by visually demonstrating the AT knowledge in a 3D environment, the learning of it is facilitated.

VR technology visually immerses a user in a 3D environment allowing for such a presentation of 3D geometry. Visual immersion is achieved with system properties reducing sensory inputs from the real world and replacing them with digital information, e.g., by wearing an HMD [74]. Users then experience the effects of AT operations in a more natural and immersive way [44, 66]. This supports the compilation of mental models for the learning content [84]. Also, a higher visual immersion and a thus resulting higher presence leads to a higher performance in case of a training scenario [77]. Spatial presence describes the subjective sensation of being in a real place, e.g., inside the virtual environment, despite physically being in a different environment [72]. Presence has a mediating effect on the learning outcome as it affects a student's intrinsic motivation and enjoyment thus increasing the perceived learning quality and satisfaction [41]. Overall, VR technology increases a student's motivation as well as engagement, provides an immersive experience, and allows for a constructivist approach of learning [20, 42]. For instance, it can simulate complex machinery thus enabling learners to experience them in a normal classroom without requiring the actual hardware [64].

Therefore, designing a specific GEtiT VR version leads to a presentation of the learning content in a more natural way. This potentially allows for an easier compilation of mental models, a better understanding, and an improved learning effect. Also, it increases a learner's motivation and satisfaction when practicing the application of ATs.

Virtual Geometry Learning

Virtual learning of geometry was already approached with other projects. *Construct3D* represents an AR application that allows students to collaboratively create and manipulate geometrical objects [35, 36]. Similarly, *Mathland* provides a Mixed Reality learning platform that augments the real world with mathematical concepts [38]. Mathland allows learners to observe their environment thus achieving a constructionist mathematical learning. In contrast to the present system, both applications are not gamified training environments that target a highly motivating knowledge learning.

3 GETIT

Aside from encoding the AT knowledge, GEtiT needs to fulfill three additional requirements to achieve an effective knowledge learning:

(1) Different sets of knowledge rules that are scaled in their complexity need to be encoded in GEtiT's game mechanics to moderate the learning content's level of abstraction.

(2) The interaction of the game mechanics needs to provide feedback that not only informs the learners about the correctness and their learning progress, but also visualizes and demonstrates the effects of an AT operation.

(3) Finally, well designed and clear learning exercises need to be provided to motivate and to require learners to apply their knowledge.

Performance of an Affine Transformation Operation

To fulfill these requirements, GEtiT needs two central elements: an *input* game mechanic allowing for the configuration of a 4×4 transformation matrix and a *manipulable object* game mechanic that changes the state of the object based on the applied transformation. Thus, the object provides learners with an immediate feedback about the correctness and the effects of their inputs. Aside from immediately being transformed, the object also casts a trail indicating the path on which it translated through the game world. This path provides learners with a visual feedback about the additional

Figure 2: On expert difficulty, the direct value configuration screen has the structure of a 4×4 transformation matrix.

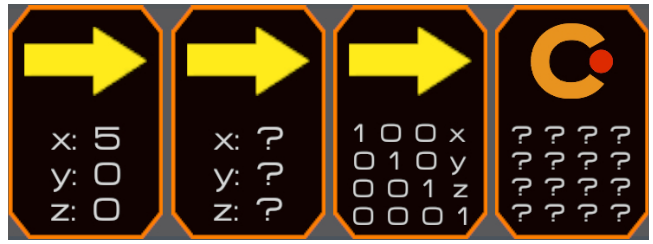

Figure 3: The AT cards change based on the selected difficulty rating: easy, medium, hard and expert.

effects of an AT operation, e.g., the object's translation when a rotation operation is applied while the object is not located in the level's origin.

Configuring and applying an AT in GEtiT is implemented with the players' ability to select, configure, and play cards of which each represents an individual mathematical operation. By activating an *AT card*, a *direct value configuration screen* (see Figure 2) representing an empty 4×4 transformation matrix that must be completed with self-obtained computational results is shown. Once an AT card's configuration is confirmed, the object immediately gets transformed according to the entered values. By providing these two game mechanics, GEtiT directly encodes the AT knowledge, requires its application, and provides immediate visual feedback. This direct AT knowledge encoding also represents the highest, i.e., *expert*, difficulty.

The AT cards moderate the knowledge's level of abstraction by encoding a specific simplified but more intuitive and comprehensible subsets of the total AT knowledge rules. GEtiT features *four different difficulty levels*, i.e., easy, medium, hard and expert, of which each achieves a different degree of the moderation. In particular, from easy to hard difficulty, each AT card only represents one specific AT type which is indicated by a symbol displayed on the cards. From easy to medium difficulty, the AT cards are even reduced to a transformation vector representation (see Figure 3). On *easy* difficulty, each card is predefined and hence a learner merely has to activate a card to transform the object according to the values displayed on it. On *medium* difficulty, the vector AT cards are undefined thus requiring users to enter self-obtained computational results in a vector direct value configuration screen. On *hard* difficulty, each AT card represents a transformation matrix and, upon activation, opens a direct value configuration screen which only provides access to matrix fields relevant to the selected transformation type. As a result, the difficulty levels not only scale the level of abstraction, but also reflect a learner's level of expertise with the explicit application of the AT knowledge. By periodically increasing the difficulty of the exercises, gaming flow is induced that further increases a learner's motivation to tackle the challenges [43].

GEtiT displays the available AT cards as clickable elements at the bottom of the player's User Interface (UI) that open the direct value configuration screen. GEtiT VR (see Figure 4), to achieve a diegetic UI design [67], gives the cards a physical property, displays them on a moveable card holder and integrates the direct value configuration screen directly into them. In contrast to GEtiT that is played with mouse and keyboard, GEtiT VR implements the HTC Vive controllers as input devices. They are used to realize a within arm's reach *selection and manipulation* interaction technique [4, 39]. A user selects an AT card by merely touching it with one controller. Using the controller's trackpad initiates the configuration process. After selecting a desired field on the card, the direct value configuration screen is shown. It is controlled using the second controller allowing for a selection and confirmation of inputs. Finally, a player activates a card by pulling the first controller's trigger button. As the controllers are part of the virtual environment, their realization is diegetic which increases GEtiT VR's naturalness and the experienced presence [44, 66]. The moveable card holder enables players to place it at a position from which they can simultaneously see the available cards and the object. This facilitates the process of analyzing the spatial puzzles and applying the correct AT operation.

Providing Clear Learning Exercises

GEtiT's learning exercises are created in form of an *escape scenario* [56]. Exercises challenge players with spatial puzzle tasks requiring the transformation of the object in such a way that it matches a level's victory conditions, i.e., a switch. Each puzzle consists of a sealed room featuring a closed exit, i.e., a portal, potential obstacles blocking the object's translation path, a half-transparent object displaying the victory conditions, the manipulable object, and a level-specific selection of AT cards. Internally, GEtiT compares the state of the

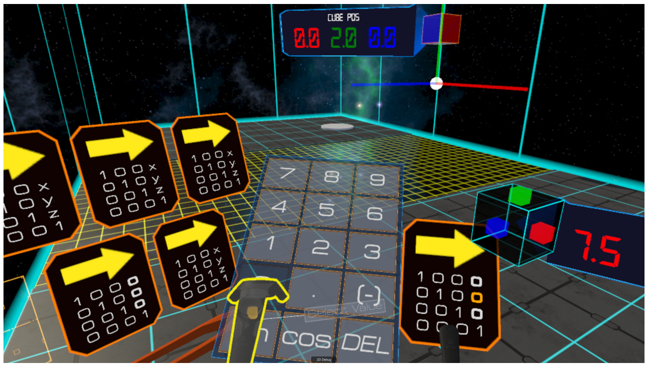

Figure 4: *GEtiT VR* allows for a direct value input via a diegetic input interface.

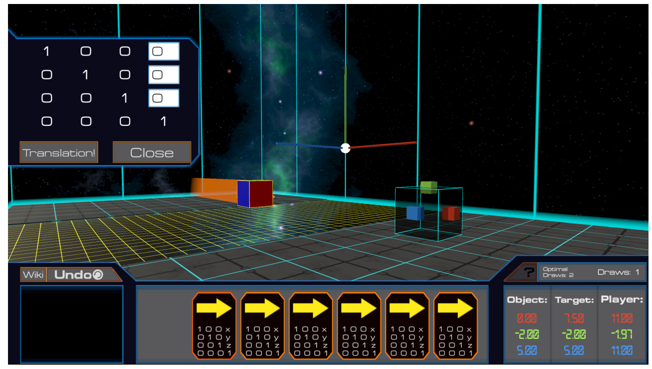

Figure 5: Players cannot walk on the yellow grid between the two platforms. They are challenged to utilize the object as a stepping stone to cross the gap.

manipulable object with the level's victory conditions and, once they are met, activates the portal. Then, players may leave the room and proceed to the next exercise.

The level design also creates additional challenges by placing the exit portal at unreachable places. This requires players to utilize the object as a stepping stone to overleap gaps (see Figure 5) or as a lift to get on top of a high obstacle. Thus, the application of the AT knowledge can become meaningful to players. It is no longer just a complex learning content but a means to solve puzzles and to ultimately beat the game. Overall, GEtiT provides 108 different spatial puzzles (27 per difficulty level).

An achievement and a point system got implemented to increase the game's motivational aspects. The point system bases on a performance rating system that challenges players to solve a level with a minimum amount of cards. Beating a level with the minimum or small deviation from the minimum rewards users with a performance dependent amount of points symbolized by stars. The points provide users with feedback about their progress towards the completion of the game, i.e., stars earned for a particular level are displayed in the level selection menu. Achievements are unlocked by solving levels in a perfect way, completing all levels of a particular transformation type or finding a hidden easter-egg.

Each level can freely be explored and, although a timer indicating the time spent in a particular level is shown, solved without a time constraint. GEtiT is played from a first-person perspective and implements the traditional first-person controls, e.g., WASD, to achieve a movement and view control using the keyboard and mouse. GEtiT VR implements the HTC Vive's room-scale VR technology thus allowing players to walk and to look around using the HMD. However, as GEtiT's levels are larger than the tracking area, the intuitive and easy *Point & Teleport* technique [5, 6] is implemented as a second interaction technique to perform a locomotion inside of the virtual environment.

Enhancing Usability

A player needs to be aware of the object's, target's, and origin's position as well as the direction of the level's three axes to successfully solve a level using ATs. In GEtiT, the object's and target's positions are directly displayed in the UI and are always visible independent of a player's view. As GEtiT VR requires a diegetic UI to avoid breaking a user's presence, the position indications are implemented as labels that are attached to the object and to the target, respectively. The position labels always face towards the player, are scaled up or down depending on the player's distance to them, and shine through obstacles to ensure a good visibility from any position inside of a particular level. The origin and a level's three axes are displayed in form of a white ball that features three differently colored bars symbolizing the axes.

To reduce the frustrating effects of giving a wrong input, an undo function is implemented that reverts the game to the status before the last AT card was used. However, players can only go one step back and are not able to revert the entire history of their gameplay.

GEtiT provides a small built-in AT wiki that informs about the theoretically grounded mathematical aspects to keep learners immersed when they need to look up further information to determine a spatial puzzle's correct solution. The wiki is implemented with a 2D interface overlay that is activated via the main UI. As static UI elements would reduce the naturalness and experienced presence of GEtiT VR [44, 66], a special menu in form of a futuristic playing room was implemented. It features a control console, a game console, and two wiki screens. This playing room also allows players to load and enter a level and to change the game's settings. While the control console provides access to the game's settings and the option to switch through the wiki slides, the game console allows learners to load and to enter levels. Levels are represented by cubes stored in shelfs that

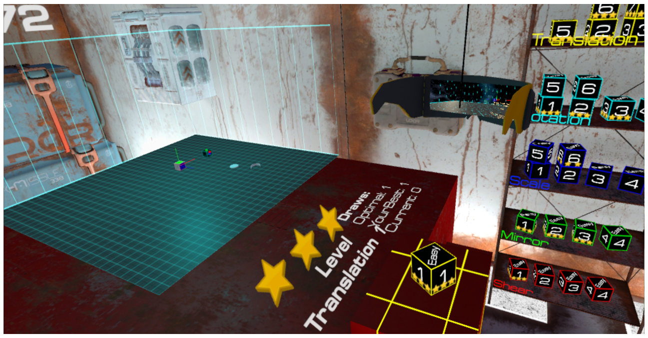

Figure 6: *GEtiT VR* uses an HMD metaphor to allow for a transition between the playing room and a level. On the right hand side, level cubes representing each individual level are shown.

are ordered by the targeted transformation type and difficulty level. By grabbing a cube and placing it on the game console, a level gets loaded. The game console is connected to a virtual HMD (see Figure 6) that can be grabbed with one of the controllers and put on with a gesture one would perform to put on glasses [47]. Subsequently, the player is teleported into the loaded level and can start or continue to solve the presented spatial puzzle. By taking off the virtual HMD, players return to the playing room to check the wiki or to load a different level.

Finally, GEtiT displays a summary screen when a level was successfully solved to provide additional immediate feedback. The victory screens informs learners about the amount of cards used, the level's minimum amount, the stars achieved based on their performance, the time needed, and the composite mathematical equation of the used AT operations. This screen also provides the options to continue to the next challenge, to retry the current challenge or to return to the level selection menu. Thus, the summary screen allows players to analyze their performance and to develop an in-depth understanding of the AT's theoretically grounded mathematical aspects [10]. This summary screen is implemented as a 2D UI overlay in GEtiT that is displayed once a player has entered a portal. In contrast, GEtiT VR teleports the player into a summary virtual environment featuring the relevant information in form of diegetic interface elements and providing the options to restart or continue in form of two labeled portals.

Achieving Optimal Knowledge Learning

Both GEtiT versions require preexisting knowledge during the gameplay and motivate learners to tackle the learning exercises by using reward game mechanics. By moderating the level of abstraction and implementing the resulting four difficulty levels, both games achieve a periodical repetition of the learning content. Furthermore, clear game goals, immediate feedback and a constant stream of new challenges induce gaming flow. Flow influences a player's performance of gaming action and leads to an increased learning performance. After starting a level and analyzing the presented spatial puzzle, learners are required to apply their AT knowledge to escape the room. For this purpose, they utilize the AT cards representing individual mathematical operations to transform the object in such a way that it matches the victory conditions (see Figure 7). At the same time, GEtiT provides immediate feedback to inform learners about the correctness of their self-obtained solutions and the effects of the used AT operation.

4 TECHNOLOGY

GEtiT and GEtiT VR are developed with *unity* in the version 5.5.2p1 [80] for PC and Mac. The gameplay is rendered to the connected main monitor and, in the case of GEtiT VR, to the HTC Vive HMD. The VR implementation of GEtiT VR is achieved using the *SteamVR Plugin* [82] in the version 1.2.0 which already provided functions for the point & teleport locomotion, controller-based system interaction, controller tooltips, and overall player controller. The playing room's furniture is freely available on the *unity asset store* [81] or part of the *unity standard assets.*

5 METHOD

The study was designed to evaluate and to compare the usability of both GEtiT versions, i.e., the *VR* and the *desktop-3D (3D)* conditions. This study, however, was not designed to test the serious game's learning effects.

Experimental Tasks

In total, participants were orally given six experimental tasks for each of the two systems. They assessed the usability of the game controls, the UI and the UI's adjustments based on the moderation of the level of abstraction. Table 1 provides an overview of the experimental tasks.

Measures

Simulator Sickness. The simulator sickness was measured for all participants before and after the GEtiT VR experimental playing session using the *simulator sickness questionnaire* (*SSQ*) [37].

Effectiveness. The effectiveness was measured by logging the successfully solved experimental tasks. Also, the amount and the content of questions regarding each individual experimental task was logged.

Efficiency. The efficiency was determined by measuring the *time* needed for the completion of each individual experimental task.

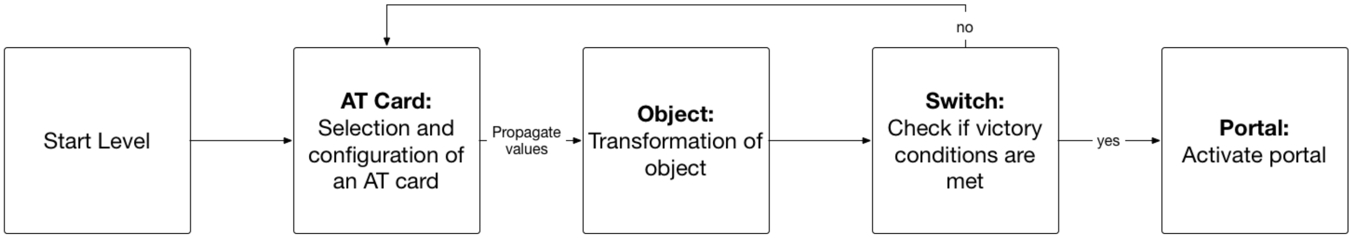

Figure 7: Schematic representation of GEtiT's gameplay.

Table 1: Overview of Experimental Tasks

Item	Task	Assessment goals
1	Create and load a profile	Text input UI design
2	Solve "Translation Easy 1"	AT card interaction Basic locomotion
3	Solve "Translation Easy 4"	AT card interaction Advanced locomotion (overleaping a gap, see Figure 5)
4	Solve a specific medium translation level (indicated by 2 stars)	Level selection interface AT card interaction Direct value configuration screen
5	Solve "Rotation Expert 1"	AT card interaction Wiki interaction Direct value configuration screen
6	Solve medium levels for 5 minutes	Gaming flow

Also, the perceived task load was measured using the *NASA-TLX* [29]. To facilitate the evaluation process, the modified *Raw NASA-TLX* [28] version was used. This version eliminates the weighting process and only implements the six sub-scales to measure the overall task load. Participants filled in the questionnaire after each experimental task. To streamline the procedure and to reduce a potential negative effect caused by the necessity to don and to remove the HMD on a frequent basis, the assessment tool was directly presented inside of the simulations. In GEtiT VR, a diegetic panel (apparent size of $1m \times 0.3m$) displayed one of the six continuous rating scales at a time (see Figure 8). Participants entered their ratings with one of the controllers by touching

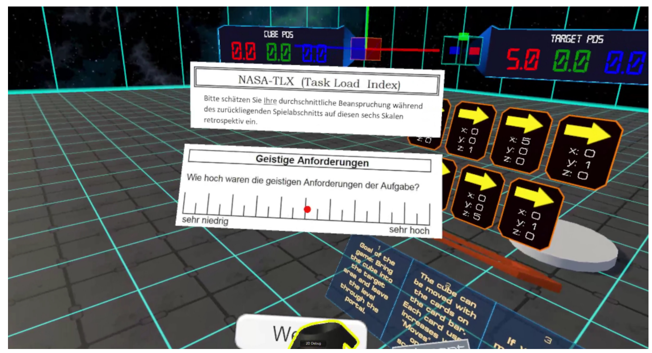

Figure 8: Using the NASA-TLX questionnaire directly in VR.

the scale and pulling the trigger button. In GEtiT, a 2D UI overlay displayed the continuous rating scales. Users entered their ratings with the mouse following the principle of an online web-based survey system.

Satisfaction. The *QUESI* [46] was used to assess the perceived intuitive use of both systems. It was filled in after each experimental playing session.

At the end of the experiment, participants were asked to express their *preference* for one of the two systems and to reason their selection.

Flow. For the purpose of measuring the flow-inducing aspects of the gameplay, the study included the *flow short scale* (*FSS*) [62]. The participants completed this assessment tool after both experimental conditions.

Aparatus

GEtiT and GEtiT VR were played on the same computer (CPU: Intel Core i7-6700K @ 4.00GHz, RAM: 16GB, Graphics card: MSI NVIDIA GeForce GTX 1080 Ti 16GB) in a climatized room. An HTC Vive HMD (resolution: 2160×1200, 1080×1200 per eye; refresh rate: 90 Hz) was connected to the computer and the HTC Vive's tracking area had a size of $2.5m \times 2.5m$ (see Figure 9). On this machine, GEtiT VR was continuously running with 90 frames per second. An over-ear headset (133,85 Ohm, 10 Hz - 30.000 Hz, sound pressure level: 96,31 dB) provided the participants with an immersive

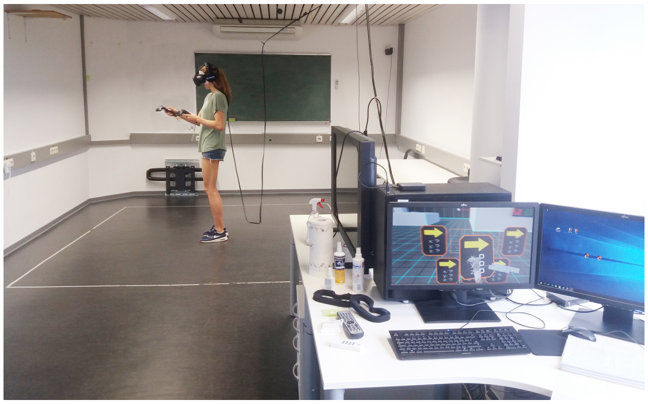

Figure 9: Playing *GEtiT VR* in the lab.

audio experience. The computer and the computer screen (24", resolution: 1920×1080) were placed on top of a rectangular ($1.5m \times 1m$) office table. A standard office chair was provided for playing GEtiT. The headphones and HMD were cleaned after a participant finished the experiment.

Procedure

The experiment consisted of seven stages and followed a within-design. The two GEtiT versions were played in counterbalanced order.
(1) *Introduction:* The participant is introduced to the overall design of the experiment and the implemented health and safety rules. Subsequently, a quick overview over the AT knowledge is given to allow for a self-assessment of the AT expertise level. The participant then signs a written consent form. Finally, a demography questionnaire is filled in.
(2) ***GEtiT VR*** *pre-questionnaire:* The participant fills in the pre-SSQ questionnaire.
(3) *GEtiT VR gameplay:* The participant dons the HTC Vive HMD, controllers, and headphones. Then the participant receives a quick introduction to the functionality of the devices and the chaperone system. After a check if the participant experiences an effect of simulation sickness, the first experimental task is orally communicated. Once the participant has solved a task, the in-VR NASA-TLX is filled in. This procedure is repeated until all six experimental tasks are completed. Once the participant has filled in the last NASA-TLX questionnaire, they receive assistance to remove the VR equipment.
(4) *GEtiT VR post-questionnaire:* The participant fills in the post-SSQ, QUESI and FSS questionnaires.
(5) ***GEtiT*** *gameplay:* The participant gets seated at the office desk. After a quick introduction, the first experimental task is orally communicated. After completion of a task, the in-simulation NASA-TLX is activated. This procedure is repeated until all six experimental tasks are completed.
(6) *GEtiT post-questionnaire:* The participant fills in the QUESI and FSS questionnaires.
(7) *Conclusion:* The participant is asked which of the systems would be the participant's choice for an AT knowledge learning. Also, the participant is asked to reason their choice.

Participants

In total, 13 participants were recruited from the undergraduate students who were enrolled at the University of Würzburg. An online participant recruitment system that rewards students with credits mandatory for obtaining their Bachelor's degrees was used. Two participants (novice computer game players based on self-report) had to be removed from the sample as they not only decided to stop trying to overleap the gap in GEtiT during experimental task 3, but also showed a high degree of frustration which potentially influenced their ratings of both systems. The remaining participants ($n = 11$, 7 females, 4 males) had a mean age of 20.45 ($SD = 1.51$) and reported no previous GEtiT or GEtiT VR experience. Also, none of them had severe visual impairments. Ten participants used an HTC Vive or Oculus Rift ($M = 1.45$ hours, $SD = 0.93$) before and six participants reported a previous computer game experience with a mean weekly playtime of 13.58 hours ($SD = 16.06$). The participants' mean AT knowledge was 2.18 (1 = no previous knowledge, 5 = expert knowledge, $SD = 0.87$) based on self-report.

6 RESULTS

As the study used two conditions and followed a within-design, all results were compared using *paired t-tests*. The effect size was determined by computing the *Cohen's D. Pearson's product-moment correlation* was computed to test for a correlation.

Simulator Sickness

The evaluation of the pre-SSQ and post-SSQ total scores revealed no effect of a simulator sickness ($M_{pre} = 27.54$, $SD_{pre} = 34.45$, $M_{post} = 15.98$, $SD_{post} = 17.47$, $t(10) = 1.65$, $p = 0.13$) during the gameplay of GEtiT VR.

Effectiveness

All participants managed to complete every experimental task while playing GEtiT VR, but two of them, who subsequently were excluded from the sample, decided to stop trying to solve experimental task 3 while playing GEtiT. The experiment conductor was asked 8 times in total for additional advise while GEtiT VR was played and 2 times during the GEtiT playing phase. GEtiT VR's problems were related to experimental task 1 that required participants to enter their name using the controllers (5 questions) and experimental task 4 (3 questions) challenging participants for the first time to configure a card's values. During the GEtiT

Table 2: Mean Times (s) for Each Experimental Task

Exp. Task	M_{VR}	SD_{VR}	M_{3D}	SD_{3D}	p
1	69.27	29.52	19.73	10.35	< 0.001
2	108.91	43.06	99.73	39.54	0.65
3	95.36	24.52	172.27	104.21	0.02
4	161.18	46.37	70.00	73.98	0.01
5	214.00	83.72	137.55	42.54	0.02
6	300	–	300	–	–

Table 3: Mean Total Task Load for Each Task

Exp. Task	M_{VR}	SD_{VR}	M_{3D}	SD_{3D}	p
1	33.03	13.63	19.62	13.37	< 0.001
2	34.85	13.06	30.76	14.01	0.38
3	38.86	13.70	44.24	13.97	0.26
4	44.55	10.87	26.89	20.01	0.002
5	44.70	16.65	33.41	15.87	0.03
6	42.58	13.22	43.33	13.46	0.79

playing phase, only experimental task 5 raised 2 questions concerning the input format of cosine values.

Efficiency

Time. On average, the participants needed 499.27s to solve all GEtiT tasks ($SD_{3D} = 223$, excluding exp. task 6) and 648.73s to complete all GEtiT VR tasks ($SD_{VR} = 142.68$, excluding exp. task 6). The two systems did not significantly differ in regard to the overall time needed ($t(10) = 1.81$, $p = 0.08$). However, as Table 2 depicts, experimental task 1, 4 and 5 were solved significantly faster while playing GEtiT and experimental task 3 was solved significantly faster while playing GEtiT VR. As overleaping a gap is a common computer game challenge, the Pearson's product-moment correlation was computed to check whether previous gameplay experience had an effect on a participant's performance. It revealed a significant correlation ($cor = 2.47$, $p = 0.04$) between the time needed for GEtiT experimental task 3 and the previous computer game experience.

NASA-TLX. The participants gave a mean total score of 33.04 ($SD_{3D} = 12.74$) for GEtiT and 39.76 ($SD_{VR} = 10.72$) for GEtiT VR on the NASA-TLX across all experimental tasks. A t-test revealed a significant difference ($t(10) = 2.53$, $p = 0.03$, $CohensD = 0.57$) between the task load of both system. The significant differences between the two systems (see Table 4) were in the physical demand ($t(10) = 4.44$, $p = 0.001$, $CohensD = 1.19$) and effort ($t(10) = 3.35$, $p = 0.007$, $CohensD = 0.48$). In particular, as Table 3 displays, a significant difference in the task load was also found for experimental task 1 ($t(10) = 4.65$, $p < 0.001$, $CohensD = 0.99$), 4 ($t(10) = 4.23$, $p = 0.002$, $CohensD = 1.10$), and 5 ($t(10) = 2.52$, $p = 0.03$, $CohensD = 0.69$). These tasks required the participants to enter a profile name and to enter values in the direct value configuration screen. Despite the significant difference between both systems, the overall and the task-specific task load were below the neutral mid-point of the scale (0 = low task load, 100 = high task load).

Table 4: Mean Subscale Load Across All Tasks

Scale	M_{VR}	SD_{VR}	M_{3D}	SD_{3D}	p
Mental Dem.	48.41	13.71	40.76	15.75	0.08
Physical Dem.	27.65	12.95	11.74	13.79	0.001
Temporal Dem.	39.39	14.40	37.27	14.64	0.62
Performance	46.14	12.57	39.77	15.86	0.20
Effort	44.47	11.90	37.73	15.87	0.007
Frustration	32.50	17.26	30.98	19.63	0.75

Satisfaction

No significant difference ($t(10) = 0.01$, $p = 0.99$) was found between the participants' intuitive use ratings ($M_{VR} = 3.41$, $SD_{VR} = 0.92$, $M_{3D} = 3.41$, $SD_{3D} = 1.18$) on the QUESI questionnaire. The total intuitive use scores for both systems were above the neutral mid-point of scale (1 = negative perception, 5 = positive perception).

All participants agreed that they would use one of the two systems for an AT knowledge learning. Nine (82%) participants expressed a preference for GEtiT VR, whereas two participants (18%) would rather use GEtiT. The participants who preferred GEtiT VR explained their decision with a higher fun factor and a more intuitive demonstration of the AT knowledge. The decision for GEtiT was based on the well know input techniques and a simpler interaction. Overall, the participants' statements indicated that both versions of the serious game elicit motivating, intuitive, and educational aspects.

Flow

The FSS measured the systems' overall flow experience (1 = low flow, 7 = high flow) and worry values (1 = low worry, 9 = high worry) testing for a potential boredom or anxiety of the users. No significant difference was found between the flow ($M_{VR} = 4.45$, $SD_{VR} = 0.68$, $M_{3D} = 4.18$, $SD_{3D} = 0.79$, $t(10) = 1.65$, $p = 0.13$) and the worry value ($M_{VR} = 4.67$, $SD_{VR} = 0.63$, $M_{3D} = 4.94$, $SD_{3D} = 0.61$, $t(10) = 1.69$, $p = 0.12$) of both system. GEtiT and GEtiT VR scored above the neutral mid-point of the flow scale and above the neutral mid-point of the worry scale.

7 DISCUSSION

The study evaluated the usability and the gameplay experience of both GEtiT versions. Aside from two participants who gave up on trying to cross the gap during experimental task 3, all tasks were successfully completed thus confirming GEtiT's intuitive design and effectiveness. As the participants rated their AT knowledge level low to medium, this result also indicates the effectiveness of the knowledge moderation. The participants managed to solve the tested levels without an in-depth preexisting knowledge. Hence, the moderation resulted in an intuitive and comprehensible presentation and application requirement of the AT knowledge.

The above neutral mid-point ratings on the FSS indicate that GEtiT exhibits flow-inducing aspects and creates a compelling gameplay. This is important as flow affects a user's performance thus also increasing the learning quality. The preference and reasoning of the participants confirmed a higher joy of use and a more intuitive knowledge demonstration when using the VR version. As a result, the user study indicates that VR technology is beneficial for the learning quality.

The time needed and the overall issues experienced by novice computer game players during the performance of experimental task 3 are explainable by the three stages of skill acquisition [3, 18]. During the *cognitive stage*, a motor skill, such as using the keyboard to achieve a locomotion inside of a computer game, is encoded in a *declarative form*. It describes all necessary steps for the skill's performance: using WASD for steering and pressing the spacebar to jump. During this stage, the skill's performance is poor and all encoded steps are followed closely. Subsequently, during the *associative* and the *autonomous* stage, errors are removed and, due to a periodical practice, the skill's performance gets automated and encoded in a *procedural form*. As a result, participants who were novice gamers needed more attempts and time to overcome the challenge of crossing the gap or even decided to abort this task. This assumption is supported by the correlation between previous computer game experience and time needed for the task. Despite only 4 of the 108 levels feature the gap, this outcome indicates the necessity to either provide an easier way to cross it or to label the 4 levels as particular difficult. Both methods potentially decrease a learner's frustration when playing GEtiT for the first time. However, the result that no participant experienced issues with the locomotion inside of GEtiT VR confirms the intuitive aspects of the *point & teleport* technique [5].

The time needed and the task load for experimental tasks that require a text input show that GEtiT's UI is well designed and allows for a high efficiency when a keyboard is used. This result is supported by the good perceived intuitive use rating. Simultaneously, the results of experimental task 2 and 3 show that the HTC Vive controllers enable users to easily perform natural gestures and interactions, such as selecting and activating a card. However, they are complicated to operate when a selection-based text input is required [75]. Instead of simply typing on a keyboard, users are challenged to individually select the inputs using the controller. The study indicates and confirms the importance of evaluating different VR typing techniques. Despite the higher task load and slower input times, the perceived intuitive use did not differ between GEtiT VR and GEtiT thus confirming the naturalness of the provided diegetic interface elements [23].

8 CONCLUSION AND FUTURE WORK

We developed, to the best of our knowledge, the first 3D and VR transfer-oriented serious game for ATs: GEtiT. It combines the learning effects of game mechanics with the potential of 3D and VR technology to provide an intuitive knowledge visualization. The gamified knowledge encoding transformed the AT knowledge into clear rules that subsequently were mapped to game mechanics as their internal rules. GEtiT fulfills the conditions for optimal learning by achieving a highly motivating and repetitive knowledge learning. The achieved learning requires preexisting knowledge and provides immediate feedback. Finally, by moderating the knowledge's level of abstraction, an intuitive and comprehensible learning and demonstration of ATs is achieved.

The study validated our conceptual approach by demonstrating GEtiT's high flow-inducing aspects, good perceived intuitive use, and low task load. The study's results show a higher enjoyment when using GEtiT VR suggesting that using immersive VR enhances the learning quality. The results also demonstrated the effectiveness of VR technology to visually present and to require abstract knowledge. However, when requiring selection-based text input, the results indicate the importance of researching further input techniques that reduce a user's task load and interaction time. Overall, this paper contributes to the on-going process of researching the educational potentials of immersive VR by presenting and evaluating a VR serious game.

Future research is needed to implement and evaluate intuitive selection-based text input techniques to increase GEtiT VR's overall usability. A different future research direction would be to add formative feedback to the gameplay. Feedback is an important influence on the learning outcome [30]. In case of computer graphics learning, providing formative feedback can improve the learning outcome [31]. GEtiT only provides feedback by providing a visual demonstration of the results, i.e., the object casts a trail, and showing a debriefing screen. Thus, providing additional formative feedback might result in an increased learning outcome.

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REFERENCES

[1] Ernest Adams and Joris Dormans. 2012. *Game Mechanics.* New Riders, Berkeley.

[2] Eike Falk Anderson, Leigh McLoughlin, Fotis Liarokapis, Christopher Peters, Panagiotis Petridis, and Sara de Freitas. 2009. Serious Games in Cultural Heritage. In *The 10th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST.* Malta, 29–48.

[3] John R Anderson. 2015. *Cognitive Psychology and Its Implications* (8th ed.). Worth Publishers.

[4] Doug A Bowman, Ernst Kruijff, Joseph J LaViola Jr, and Ivan Poupyrev. 2001. An introduction to 3-D user interface design. *Presence: Teleoperators and virtual environments* 10, 1 (2001), 96–108.

[5] Evren Bozgeyikli, Andrew Raij, Srinivas Katkoori, and Rajiv Dubey. 2016. Point & Teleport Locomotion Technique for Virtual Reality. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play.* ACM, Austin, TX, USA, 205–216.

[6] Evren Bozgeyikli, Andrew Raij, Srinivas Katkoori, and Rajiv Dubey. 2019. Locomotion in virtual reality for room scale tracked areas. *International Journal of Human-Computer Studies* 122 (2019), 38–49. https://doi.org/10.1016/j.ijhcs.2018.08.002

[7] Jere Brophy. 2000. *Teaching.* Educational Practices Series, Vol. 1. International Academy of Education & International Bureau of Education, Brussels.

[8] Dennis Charsky. 2010. From Edutainment to Serious Games: A Change in the Use of Game Characteristics. *Games and Culture* 5, 2 (March 2010), 177–198. https://doi.org/10.1177/1555412009354727

[9] Isabelle D Cherney. 2008. Mom, Let Me Play More Computer Games: They Improve My Mental Rotation Skills. *Sex Roles* 59, 11-12 (July 2008), 776–786.

[10] David Crookall. 2011. Serious Games, Debriefing, and Simulation/Gaming as a Discipline. *Simulation & Gaming* 41, 6 (Jan. 2011), 898–920. https://doi.org/10.1177/1046878110390784

[11] Mihaly Csikszentmihalyi. 1990. *Flow: The Psychology of Optimal Experience.* Harper-Perennial, New York, NY, USA.

[12] Barney Dalgarno and Mark J. W. Lee. 2010. What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology* 41, 1 (2010), 10–32. https://doi.org/10.1111/j.1467-8535.2009.01038.x

[13] Suzanne de Castell, Jennifer Jenson, and Nicholas Taylor. 2010. Educational Games: Moving from Theory to Practice. In *Educational gameplay and simulation environments : case studies and lessons learned*, David Kaufman and Louise Sauvé (Eds.). Information Science Reference, Hershey, PA, 133–145.

[14] Sara de Freitas and Fotis Liarokapis. 2011. Serious Games: A New Paradigm for Education? In *Serious Games and Edutainment Applications*, Minhua Ma, Andreas Oikonomou, and Lakhmi C Jain (Eds.). Springer-Verlag, London, 9–23. https://doi.org/10.1007/978-1-4471-2161-9_2

[15] Christopher J Dede. 2009. Immersive Interfaces for Engagement and Learning. *Science* 323 (2009).

[16] Christopher J Dede, Jeffrey Jacobson, and John Richards. 2017. Introduction: Virtual, Augmented, and Mixed Realities in Education. In *Virtual, Augmented, and Mixed Realities in Education*, Dejian Liu, Christopher J Dede, Ronghuai Huang, and John Richards (Eds.). Springer, Singapoore.

[17] K Anders Ericsson, Ralf Th Krampe, and Clemens Tesch-Römer. 1993. The Role of Deliberate Practice in the Acquisition of Expert Performance. *Psychological Review* 100, 3 (1993), 363–406.

[18] Paul Morris Fitts and Michael I Posner. 1967. *Human performance.* Brooks Cole.

[19] J Foley, A van Dam, S Feiner, and J Hughes. 1990. *Computer Graphics: Principles and Practice.* Addison-Wesley, Reading, MA, USA.

[20] Laura Freina and Michela Ott. 2015. A Literature Review on Immersive Virtual Reality in Education: State Of The Art and Perspectives. In *Proceedings of the 11th eLearning and Software for Education (eLSE).* Bucharest, Romania.

[21] K S Fu, R Gonzalez, and C S G Lee. 1987. *Robotics: Control, Sensing, Vision and Intelligence.* McGraw-Hill Education, New York.

[22] James Paul Gee. 2007. *What video games have to teach us about learning and literacy* (1 ed.). Palgrave Macmillan, New York.

[23] Sanjay Ghosh, Chivukula Sai Shruthi, Himanshu Bansal, and Arvind Sethia. 2017. What is User's Perception of Naturalness? An Exploration of Natural User Experience. In *Human-Computer Interaction - INTERACT 2017*, Regina Bernhaupt, Girish Dalvi, Anirudha Joshi, Devanuj K. Balkrishan, Jacki O'Neill, and Marco Winckler (Eds.). Springer International Publishing, Cham, 224–242.

[24] Georg Gittler and Judith Glück. 1998. Differential transfer of learning: Effects of instruction in descriptive geometry on spatial test performance. *Journal of Geometry and Graphics* 2, 1 (1998), 71–84.

[25] C Shawn Green and Daphne Bavelier. 2003. Action video game modifies visual selective attention. *Nature* 423, 6939 (2003), 534–537.

[26] C Shawn Green and Daphne Bavelier. 2007. Action-video-game experience alters the spatial resolution of vision. *Psychological Science* 18, 1 (2007), 88–94.

[27] Anthony Gurr. 2010. Video Games and the Challenge of Engaging the 'Net' Generation. In *Educational gameplay and simulation environments : case studies and lessons learned*, David Kaufman and Louise Sauvé (Eds.). Information Science Reference, Hershey, PA, USA, 119–131.

[28] Sandra G. Hart. 2006. NASA-Task Load Index (NASA-TLX); 20 Years Later. In *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting.* Santa Monica, 904–908.

[29] Sandra G. Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Human Mental Workload*, P. A. Hancock and N Meshkati (Eds.). Elsevier Science Publishers B.V., Amsterdam, 139–183.

[30] John Hattie and Helen Timperley. 2007. The Power of Feedback. *Review of Educational Research* 77, 1 (2007), 81–112. https://doi.org/10.3102/003465430298487

[31] Blake Hodgkinson, Christof Lutteroth, and Burkhard Wünsche. 2016. glGetFeedback—Towards automatic feedback and assessment for OpenGL 3D modelling assignments. In *2016 International Conference on Image and Vision Computing New Zealand (IVCNZ).* IEEE, 1–6.

[32] Philip N. Johnson-Laird. 1983. *Mental Models. Towards a Cognitive Science of Language, Inference, and Consciousness.* Harvard University Press.

[33] Mona Erfani Joorabchi and Magy Seif El-Nasr. 2011. Measuring the Impact of Knowledge Gained from Playing FPS and RPG Games on Gameplay Performance. In *Entertainment Computing – ICEC 2011.* Springer, Vancouver, BC, Canada, 300–306. https://doi.org/10.1007/978-3-642-24500-8_33

[34] Victor Kaptelinin and Bonnie A Nardi. 2012. Affordances in HCI: Toward a Mediated Action Perspective. In *CHI 2012 Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems.* ACM, Austin, TX, USA, 967–976. https://doi.org/10.1145/2207676.2208541

[35] Hannes Kaufmann. 2006. The potential of augmented reality in dynamic geometry education. *12th International Converence on Geometry and Graphics* (2006).

[36] Hannes Kaufmann, Dieter Schmalstieg, and Michael Wagner. 2000. Construct3D: A Virtual Reality Application for Mathematics and Geometry Education. *Education and Information Technologies* 5, 4 (2000), 263–276.

[37] Robert S Kennedy, Norman E Lane, Kevin S Berbaum, and Michael G Lilienthal. 1993. Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *The International Journal*

of Aviation Psychology 3, 3 (1993), 203–220. https://doi.org/10.1207/s15327108ijap0303_3

[38] Mina Khan, Fernando Trujano, Ashris Choudhury, and Pattie Maes. 2018. Mathland: Playful Mathematical Learning in Mixed Reality. In *CHI'18 Extended Abstracts*. Montréal, Canada.

[39] Joseph J LaViola Jr, Ernst Kruijff, Ryan P McMahan, Doug Bowman, and Ivan P Poupyrev. 2017. *3D user interfaces: Theory and practice*. Addison-Wesley Professional.

[40] Timothy Lynam, Raphael Mathevet, Michel Etienne, Samantha Stone-Jovicich, Anne Leitch, Nathalie Jones, Helen Ross, Derick Du Toit, Sharon Pollard, Harry Biggs, and Pascal Perez. 2012. Waypoints on a Journey of Discovery: Mental Models in Human-Environment Interactions. *Ecology and Society* 17, 3 (2012). https://doi.org/10.5751/ES-05118-170323

[41] Guido Makransky and Lau Lilleholt. 2018. A structural equation modeling investigation of the emotional value of immersive virtual reality in education. *Educational Technology Research and Development* (2018). https://doi.org/10.1007/s11423-018-9581-2

[42] Jorge Martín-Gutiérrez, Carlos Efrén Mora, Beatriz Añorbe-Díaz, and Antonio González-Marrero. 2017. Virtual Technologies Trends in Education. *EURASIA Journal of Mathematics Science and Technology Education* 13, 2 (2017), 469–486. https://doi.org/10.12973/eurasia.2017.00626a

[43] Jane McGonigal. 2011. *Reality is broken : why games make us better and how they can change the world* (1 ed.). Penguin Press, New York.

[44] Daniel Medeiros, Eduardo Cordeiro, Daniel Mendes, Maurício Sousa, Alberto Raposo, Alfredo Ferreira, and Joaquim Jorge. 2016. Effects of Speed and Transitions on Target-based Travel Techniques. In *Proceedings of the 22Nd ACM Conference on Virtual Reality Software and Technology (VRST '16)*. ACM, New York, NY, USA, 327–328. https://doi.org/10.1145/2993369.2996348

[45] Jose Mestre. 2002. *Transfer of Learning: Issues and Research Agenda*. National Science Foundation, Washington, D.C.

[46] Anja Naumann and Jörn Hurtienne. 2010. Benchmarks for Intuitive Interaction with Mobile Devices. In *Proceedings of MobileHCI'10*. Lisboa, Portugal.

[47] Sebastian Oberdörfer, Martin Fischbach, and Marc Erich Latoschik. 2018. Effects of VE Transition Techniques on Presence, IVBO, Efficiency, and Naturalness. In *Proceedings of the 6th Symposium on Spatial User Interaction*. ACM, Berlin, Germany.

[48] Sebastian Oberdörfer, David Heidrich, and Marc Erich Latoschik. 2017. Interactive Gamified Virtual Reality Training of Affine Transformations. In *Proceedings of DeLFI and GMW Workshops 2017*, Carsten Ullrich and Martin Wessner (Eds.). Chemnitz, Germany.

[49] Sebastian Oberdörfer and Marc Erich Latoschik. 2013. Develop your strengths by gaming. In *Informatik 2013 - Proceedings of 43rd annual German conference on informatics*, Matthias Horbach (Ed.), Vol. P-220. Gesellschaft für Informatik, Koblenz, Germany, 2346–2357.

[50] Sebastian Oberdörfer and Marc Erich Latoschik. 2016. Interactive gamified 3D-training of affine transformations. In *Proceedings of the 22nd ACM Conference on Virtual Reality Software and Technology (VRST '16)*. ACM Press, Garching, Germany, 343–344. https://doi.org/10.1145/2993369.2996314

[51] Sebastian Oberdörfer and Marc Erich Latoschik. 2018. Effective Orbital Mechanics Knowledge Training Using Game Mechanics. In *Proceedings of the 10th International Conference on Virtual Worlds and Games for Serious Applications (VS Games 2018)*. Würzburg, Germany.

[52] Sebastian Oberdörfer and Marc Erich Latoschik. 2018. Effectivity of Affine Transformation Knowledge Training Using Game Mechanics. In *Proceedings of the 10th International Conference on Virtual Worlds and Games for Serious Applications (VS Games 2018)*. Würzburg, Germany.

[53] Sebastian Oberdörfer and Marc Erich Latoschik. 2018. Gamified Knowledge Encoding: Knowledge Training Using Game Mechanics. In *Proceedings of the 10th International Conference on Virtual Worlds and Games for Serious Applications (VS Games 2018)*. Würzburg, Germany.

[54] Adam C Oei and Michael D Patterson. 2013. Enhancing Cognition with Video Games: A Multiple Game Training Study. *PLoS ONE* 8, 3 (Feb. 2013), e58546. https://doi.org/10.1371/journal.pone.0058546

[55] Lauri-Matti Palmunen, Elina Pelto, Anni Paalumäki, and Timo Lainema. 2013. Formation of Novice Business Students' Mental Models Through Simulation Gaming. *Simulation & Gaming* 44, 6 (2013), 846–868.

[56] David Perry and Rusel DeMaria. 2009. *David Perry on Game Design: A Brainstorming Toolbox*. Course Technology, Boston, MA, USA.

[57] Marios Pittalis and Constantinos Christou. 2010. Types of reasoning in 3D geometry thinking and their relation with spatial ability. *Educational Studies in Mathematics* 75, 2 (2010), 191–212. https://doi.org/10.1007/s10649-010-9251-8

[58] Patrick Prax. 2010. Leadership Style in World of Warcraft Raid Guilds. In *Proceedings of DiGRA Nordic 2010*. DiGRA, Stockholm, Sweden.

[59] Lin Qiu, Wendy Weini Tay, and Junwei Wu. 2009. The impact of virtual teamwork on real-world collaboration. *ACE'09 Proceedings of the International Conference on Advances in Computer Enterntainment Technology* (2009), 44–51.

[60] Jens Rasmussen. 1983. Skills, Rules, and Knowledge; Signals, Signs, and Symbols, and Other Distinctions in Human Performance Models. *IEEE Transactions on Systems, Man, and Cybernetics* 13, 3 (1983), 257–266.

[61] Byron Reeves, Thomas W Malone, and Tony O'Discoll. 2008. Leadership's Online Labs. *Harvard Business Review* 86, 5 (2008), 58–66.

[62] Falko Rheinberg, Regina Vollmeyer, and Stefan Engeser. 2003. Die Erfassung des Flow-Erlebens. In *Diagnostik von Motivation und Selbstkonzept*, J Stiensmeier-Pelster and Falko Rheinberg (Eds.). Hogrefe, Göttingen, 261–279.

[63] Sebastian Richter and Ulrike Lechner. 2011. Communication content relations to coordination and trust over time: a computer game perspective. In *C&T'11 Proceedings of the 5th International Conference on Communities and Technologies*. ACM, Brisbane, Australia, 60–68. https://doi.org/10.1145/2103354.2103363

[64] Christian B Rogers, Hazim El-Mounaryi, Tamer Wasfy, and Jesse Satterwhite. 2017. Assessment of STEM e-Learning in an Immersive Virtual Reality (VR) Environment. *Computers in Education* 8, 4 (2017).

[65] James C Rosser, Jr, Paul J Lynch, Laurie Cuddihy, Douglas A Gentile, Jonathan Klonsky, and Ronald Merrell. 2007. The impact of video games on training surgeons in the 21st century. *Archives of Surgery* 142, 2 (2007), 181.

[66] P Salomoni, C Prandi, M Roccetti, L Casanova, and L Marchetti. 2016. Assessing the efficacy of a diegetic game interface with Oculus Rift. In *2016 13th IEEE Annual Consumer Communications & Networking Conference (CCNC)*. 387–392. https://doi.org/10.1109/CCNC.2016.7444811

[67] Kevin Saunders and Jeannie Novak. 2013. *Game Development Essentials: Game Interface Design* (2nd ed.). Cengage Learning.

[68] Ralph Schroeder. 2011. *Being There Together : Social Interaction in Virtual Environments* (1 ed.). Oxford University Press, New York.

[69] Norbert M. Seel. 2003. *Psychologie des Lernens* (2 ed.). Reinhardt Verlag.

[70] Miguel Sicart. 2008. Defining game mechanics. *Game Studies* 8, 2 (2008).

[71] Anna Siewiorek and Andres Gegenfurtner. 2010. Leading to win: the influence of leadership styles on team performance during a computer game training. In *ICLS '10 Proceedings of the 9th International Conference of the Learning Sciences*, Vol. 1. ACM, Chicago, IL, USA, 524–531.

[72] Mel Slater. 2009. Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 364, 1535 (2009),

3549–3557.

[73] Mel Slater, Vasilis Linakis, Martin Usoh, and Rob Kooper. 1996. Immersion, Presence, and Performance in Virtual Environments: An Experiment with Tri-Dimensional Chess. In *ACM Virtual Reality Software and Technology (VRST)*. 163–172.

[74] Mel Slater and Sylvia Wilbur. 1997. A Framework for Immersive Virtual Environments (FIVE): Speculations on the Role of Presence in Virtual Environments. *Presence* 6, 6 (1997), 603–616. https://doi.org/10.1162/pres.1997.6.6.603

[75] Marco Speicher, Anna Maria Feit, Pascal Ziegler, and Antonio Krüger. 2018. Selection-based Text Entry in Virtual Reality. In *Proceedings of CHI 2018*. Montréal, Canada.

[76] Larry R Squire. 1992. Declarative and Nondeclarative Memory: Multiple Brain Systems Supporting Learning and Memory. *Journal of Cognitive Neuroscience* 4, 3 (1992), 232–243.

[77] Jonathan A. Stevens and J. Peter Kincaid. 2015. The Relationship between Presence and Performance in Virtual Simulation Training. *Open Journal of Modelling and Simulation* 3 (2015), 41–48.

[78] Take-Two Interactive. 2011–2018. Kerbal Space Program. available at https://kerbalspaceprogram.com.

[79] Gerhard Tulodziecki, Bardo Herzig, and Silke Grafe. 2010. *Medienbildung in Schule und Unterricht*. Julius Klinkhardt.

[80] Unity. 2017. unity 5.5.2p1. available at https://unity3d.com/unity/qa/patch-releases/5.5.2p1.

[81] Unity. 2017. unity asset store. available at https://www.assetstore.unity3d.com.

[82] Valve Coorperation. 2015–2018. SteamVR Plugin. available at https://www.assetstore.unity3d.com/en/#!/content/32647.

[83] David Weibel and Bartholomäus Wissmath. 2011. Immersion in Computer Games: The Role of Spatial Presence and Flow. *International Journal of Computer Games Technology* 2011 (2011). https://doi.org/10.1155/2011/282345

[84] Bernd Weidenmann. 2009. Multimedia, Multicodierung und Multimodalität beim Online-Lernen. In *Online Lernen. Handbuch für Wissenschaft und Praxis*, L. J. Issing and P. Klimsa (Eds.). Oldenbourg, Chapter 5, 73–86.