Interactive Gamified Virtual Reality Training of Affine Transformations

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Abstract: Affine transformations which are used in many engineering areas often escape an intuitive approach due to their high level of complexity and abstractness. Learners not only need to understand the basic rules of matrix algebra but are also challenged to understand how the theoretically grounded aspects result in object transformations. Therefore, we developed the Gamified Training Environment for Affine Transformation that directly encodes this abstract learning content in its game mechanics. By intuitively presenting and demanding the application of affine transformations in a virtual gamified training environment, learners train the application of the knowledge due to repetition while receiving immediate and highly immersive visual feedback about the outcomes of their inputs. Also, by providing a flow-inducing gameplay, users are highly motivated to practice their knowledge thus experiencing a higher learning quality. As the immersion, presence and spatial knowledge presentation can have a positive effect on the training outcome, GEtiT explores the effectivity of different visual immersion levels by providing a desktop and a VR version. This article presents our approach of directly encoding the abstract learning content in game mechanics, describes the conceptual design as well as technical implementation and discusses the design differences between the two GEtiT versions.

Keywords: Gamification; Virtual Reality; Education; Knowledge Training

1 Introduction

In-depth understanding of affine transformation (AT) is critical for many engineering areas including robotics, 3D computer graphics, or Virtual and Augmented Reality (AR, VR). However, due to the complexity of the learning content, e.g., ATs for operations in $\mathbb{R}^3$ are commonly expressed as 4×4 matrices, developing an in-depth understanding often escapes an intuitive approach as students are challenged to learn how the theoretically grounded mathematical aspects achieve a transformation of an object thus resulting in a high degree of frustration. Furthermore, ATs are order dependent and hence different sequences of the same transformation operations can result in different outcomes. Finally, students have to understand the basic rules of matrix algebra as mappings between affine spaces are executed via matrix multiplications.

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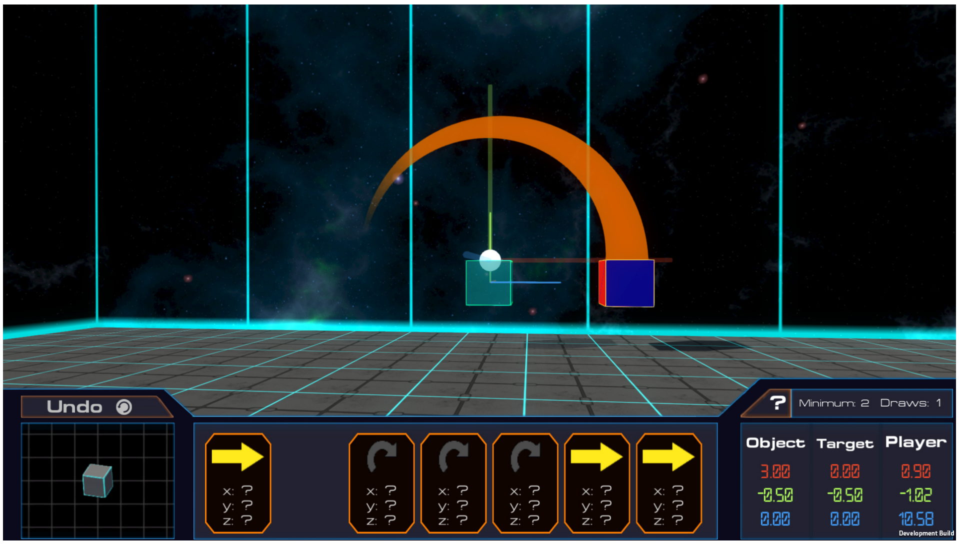

Fig. 1: *GEtiT* intuitively demonstrates the effects of the AT and challenges learners to apply their knowledge to solve puzzle exercises.

Therefore, we developed a virtual gamified training environment–the *Gamified Training Environment for Affine Transformation (GEtiT)*[2]–to intuitively train and master the application of ATs, i.e., application of transformations allowing for object translation, rotation, scaling, reflection, and shearing [OL16]. In order to do so, we developed a model to directly encode the AT knowledge in game mechanics that periodically demand the knowledge's application, provide visual feedback about the correctness and hence lead to a knowledge training due to repetition (see Figure 1). Also, as a higher visual immersion can lead to a higher presence and performance [Sl96] in the case of a virtual training simulation [SK15], we developed a specific VR version to potentially increase GEtiT's training effects by achieving a higher presence as well as a higher and more intuitive spatial knowledge presentation. For this purpose, *GEtiT-VR* implements the same core game mechanics but utilizes a higher immersive visual presentation to allow for a direct experience of an AT operation's effects. Ultimately, GEtiT is intended to demonstrate the effectivity of our knowledge encoding model which we currently prepare for publication.

This paper describes the conceptual design and technical implementation of both GEtiT versions which are based on our direct gamified knowledge encoding model, discusses their differences and presents our expectations towards their individual training effects. The paper begins with a brief description of our model we developed in order to directly encode the AT knowledge in GEtiT using game mechanics. Subsequently, we present the concept as well as technical implementation of the two GEtiT versions. Finally, this paper discusses

[2] http://www.hci.uni-wuerzburg.de/projects/getit.html

the similarities and differences between GEtiT's desktop as well as the VR version and concludes with our expectations towards the individual training effects.

2 Direct Knowledge Encoding

Game mechanics are the rules of a computer game that define what is possible, create the virtual game world [AD12] and allow players to interact [Si08] with the game. Furthermore, utilizing game mechanics demands and hence trains a specific set of human skills [OL13]. By periodically executing game mechanics, players train the encoded knowledge due to repetition [Ge07]. Learning due to repetition, or practicing, is a very important aspect of learning new knowledge as it helps learners to achieve an automatization or deepening of the learning content which facilitates a knowledge transfer to a different domain or unknown problem [Br00, Me04]. Hence, game mechanics have the potential to directly encode even abstract knowledge as their rules thus creating intuitive training environments for complex learning contents. That way, the game mechanics create a gamification metaphor for the learning content that acts as a learning affordance [DL10, KN12]. Learning affordances achieve a periodic knowledge training by demanding the application of the encoded knowledge and informing about the underlying principles.

Moreover, GEtiT moderates the knowledge's level of abstractness to facilitate the training process by intuitively presenting and demanding the learning content. For this purpose, the game mechanics were designed to scale in the complexity and level of abstractness thus resulting in a gradual increase in the learning content's as well as game's difficulty. Also, the gradual difficulty increase in combination with an immediate feedback as well as a constant stream of new challenges creates the potential for game flow [Cs10, Mc11] that keeps learners motivated and engaged.

3 Conceptual Design

Aside from encoding the AT knowledge rules in its game mechanics, GEtiT, in order to ensure an effective AT training, needs to fulfill three additional requirements: (1) The moderation of the level of abstractness requires a tailored gamification metaphor that scales the learning content's complexity. (2) A clear, intuitive and immediate feedback has to be provided to allow learners to analyze and visualize the effects of an AT operation and to learn from their potential mistakes. (3) Finally, a well-defined game goal is needed to challenge and motivate the learners to apply their AT knowledge.

As, in case of 3D computer graphics and VR/AR applications, the AT is used to transform and display objects, we adopted a frequently used manipulable object game mechanic in order to achieve similarities between the gamified training environment and a potential real world application of the learning content to facilitate a knowledge transfer process

Fig. 2: The symbols displayed on the AT cards indicate the transformation type.

[DL10, OP13]. However, instead of allowing for a direct manipulation which is commonly used in many computer games, GEtiT requires the application of an AT operation to manipulate, or transform, the object. That way, as the object immediately gets transformed based on the learners' inputs (see Figure 1), the game mechanic provides them with a visual feedback about the effects and correctness of their chosen approaches. For the purpose of enhancing the feedback, the object also casts a trail each time it gets transformed thus visualizing the effects of an individual AT and helping the learners to intuitively develop a spatial understanding for the AT knowledge. Furthermore, as the object internally stores its status, the object game mechanic also is used to provide the players with a clear goal. Each training exercise challenges them to transform the object in such a way that it matches specific victory conditions which are displayed in form of a half-transparent object ultimately representing the players' goal.

Fig. 3: On hard difficulty, learners see the matrix representation for the first time, but are only required to enter the matrix elements relevant for the chosen transformation type using the direct value configuration screen.

For the purpose of using AT operations as game inputs and achieving a moderation of the level of abstractness, we developed a special UI that provides users with access to AT operations and simultaneously informs them about the object's, target's and player's position. The AT operations are represented by AT cards of which each represents an individual mathematical operation. The AT cards display a symbol indicating the AT type (see Figure 2) and a symbolized vector or matrix representation showing predefined and undefined elements. Hence, the AT cards scale the complexity of the learning content thus achieving a moderation of the level of abstractness. GEtiT features four difficulty levels that gradually increase the learning content's abstractness. On easy difficulty, the gamified training environment only provides predefined vector AT cards that, upon activation, automatically perform the displayed transformation, and, as a result of this, learners merely need to select the correct cards to solve a level. The remaining three difficulty levels feature undefined AT cards that open a direct value configuration screen (see Figure 3) on activation allowing for the use of self-obtained computational results as inputs to the game. On medium difficulty, GEtiT still utilizes the vector representation but challenges the users to enter the vector elements. Once students move on to hard difficulty, GEtiT starts to use the 4×4 matrix representation but only requires the learners to configure those of the matrix elements that are relevant for the AT type displayed on the selected card. Finally, on expert difficulty, the moderation of the level of abstractness is scaled back completely as learners are challenged with a full transformation matrix demanding them to enter every element. At this point, the expert difficulty simulates the AT knowledge as it implements the complete set of AT knowledge rules that are directly encoded in the gamification metaphor.

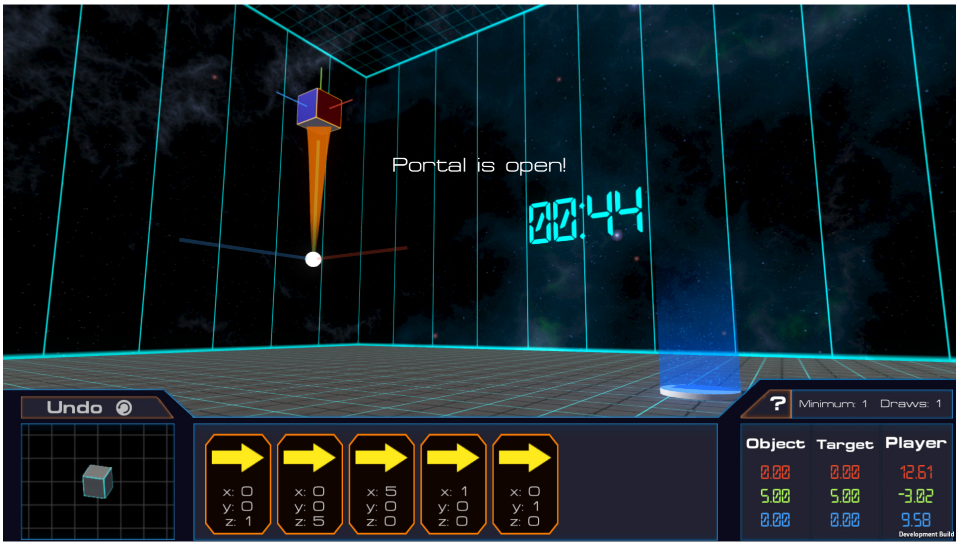

Fig. 4: After having matched the victory conditions with the object, a portal gets activated and allows players to exit the level.

The gamified training exercises are created by the level design, a selection of available AT cards, and the level-specific victory conditions. The level design determines the object's initial position, the origin's position and the position of potential obstacles that can block the object thus adding another challenge to the gameplay as players are required to translate the object around them. Also, in order to give the puzzle exercises an important meaning [Mc11], they were embedded in an escape scenario being inspired by the gameplay of Portal[3] which puts players in sealed rooms and challenges them to open the levels' exits by solving spatial puzzles. Similar to Portal, each of GEtiT's levels represents a sealed room players have to escape from by opening the level's exit–a portal (see Figure 4)–and walking through it. This, however, can only be done by solving spatial puzzles, i.e. transforming the object in such a way that it matches a level's victory conditions which subsequently opens the exit thus allowing the player to proceed to the next level (see Table 1). In addition, some levels challenge the learners to use the object as a stepping stone in order to reach the top of an obstacle or to cross a bottomless gap. As a result of this, not only the gameplay but also the AT knowledge itself becomes meaningful to the players as GEtiT turns it into a tool that allows them to exhaust the challenges.

Tab. 1: Overview of GEtiT's gameplay

Step	Task	Game mechanics
1	Enter a level	-
2	Analyze the level's spatial puzzle	Level design Object start position Victory conditions
3	Transform the object to match victory conditions using the available AT cards	AT cards Manipulable object Victory conditions
4	Leave the level	Portal

Finally, GEtiT implements additional game mechanics to keep the learners engaged and to avoid breaking the immersion. On the one hand, the gamified training environment challenges players with the indication of the minimum of cards that are needed to solve a particular level. Solving a level with the minimum or a small deviation from the minimum rewards players with points that represent their progression towards the completion of the game. That way, learners simultaneously receive feedback about their efficiency applying their AT knowledge and are challenged to retry a level when they exceeded the minimum. Moreover, users can unlock achievements for efficiently solving a level, completing the game or finding a special easter-egg hidden in one of the levels. On the other hand, GEtiT also provides a small built-in wiki that summarizes the AT knowledge for the purpose of keeping players immersed as they can look up the theoretically grounded aspects directly inside of the game.

[3] http://www.thinkwithportals.com

4 Technical Implementation

GEtiT was developed in Unity 3D[4] for PC and Mac to make the game available for most systems used by students as well as in classrooms without requiring additional powerful hardware. In addition, using Unity 3D facilitates the implementation of further game mechanics and other improvements of the game. This decision also made it easy to develop a VR-version as Unity 3D provides a good support for current VR devices of which we chose the HTC Vive[5] as it offers room-scale VR and hence a potentially higher presence. However, in order to play GEtiT-VR, a more powerful computer setup as well as the VR device are needed.

Fig. 5: Playing *GEtiT-VR* in the lab.

5 Similarities and Differences

GEtiT-VR provides a similar gameplay to GEtiT's desktop version as it utilizes the same gamification metaphor, additional game mechanics as well as training exercises, but, instead of being played on a desktop computer setup, it is played using the HTC Vive to achieve a higher level of visual immersion, presence and spatial knowledge presentation. However, despite implementing the same game mechanics, the VR port required some UI as well as interaction adjustments to ensure a good usability as well as a believable and immersive environment.

[4] https://unity3d.com
[5] https://www.vive.com

5.1 Game Controls

The interaction adjustments [un17a] were required to implement the HTC Vive controllers as the input devices used to interact with the GEtiT-VR and to successfully utilize the HTC Vive's room-scale function. For this purpose, all movement controls were mapped to the system's tracking function that tracks the position of the HTC Vive Head-Mounted Display (HMD) thus allowing users to look and walk around (see Figure 5) as long as they stay within the boundaries of the tracking area. However, as the levels are larger than the tracking area, the gamified training environment also provides the option to teleport within a level by pressing the trackpad on one of the controllers and subsequently selecting a new location by pointing at it with a target selection marker (see Figure 6). On release of the trackpad, the player is teleported to the selected location inside of the level thus providing the option to move over larger distances, to get on top of the object and to enter the portal to escape a room.

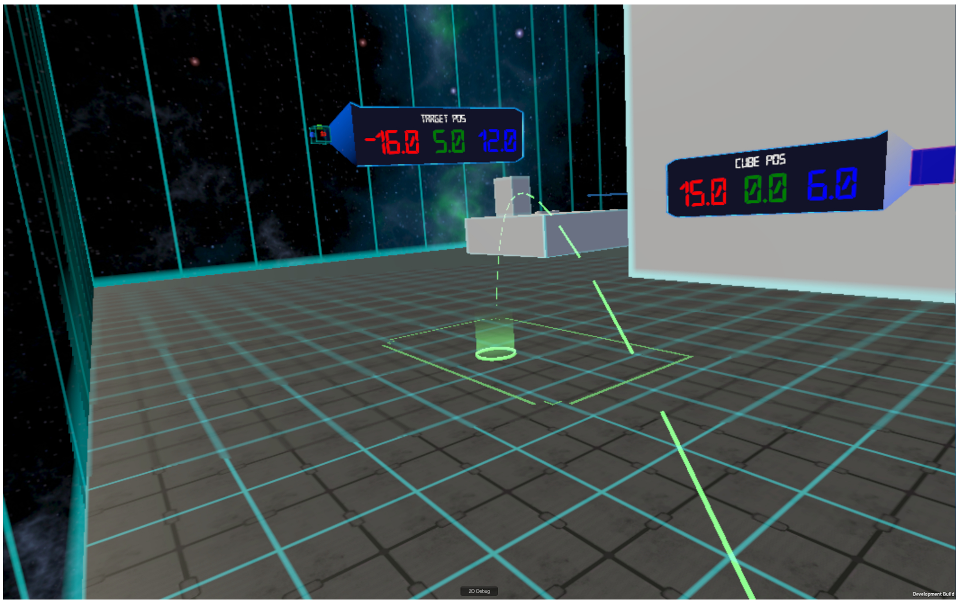

Fig. 6: Players can teleport in *GEtiT-VR* to cross larger distances, to get on top of the object and to enter the portal.

In addition to the teleport feature, the controllers are used to allow a user to select one of the AT cards, to configure a card's elements and, finally, to activate a card to apply a transformation to the object inside of GEtiT-VR. In order to select and grab a card, a player merely has to touch the desired card–they are placed on a floating console (see Figure 7) to avoid static UI elements–with one of the controllers. Afterwards, the selected card is attached to the player's controller and can be played by pulling the controller's trigger button, configured by using the controller's trackpad or placed again on the console by touching it

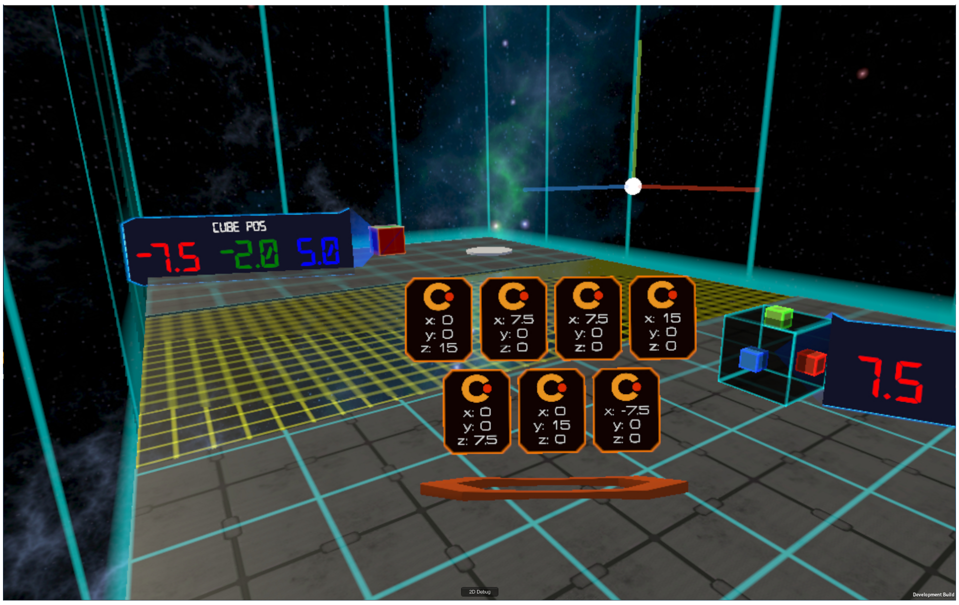

Fig. 7: All available AT cards are placed on a floating console in *GEtiT-VR*.

with the controller that holds the card. In contrast to the desktop version, GEtiT-VR provides no direct value configuration screen in order to allow for a change of a card's transformation values. Instead, by using the trackpad, a user can select the element to be changed and subsequently use an input matrix that is shown on the opposite controller (see Figure 8) to enter the desired value. For this purpose, the opposite controller itself is used for the selection and the confirmation of the values. That way, GEtiT-VR can intuitively be played independent of the player's handedness.

5.2 User Interface

As a static UI often breaks the immersion of a VR application, GEtiT's UI got adapted to fulfill the technical requirements for a good VR interface [un17b]. Instead of using a fixed bar in the UI displaying the available AT cards, GEtiT-VR follows the idea of a spatial UI and implements a floating console to provide access to them. The console can be grabbed and moved around using one of the controllers to allow players to place the console at a spot from where they can simultaneously see the available cards as well as the object thus facilitating the process of selecting the correct card. The cards itself also received a physical property and hence can be carried around. This decision was mainly made to make the virtual environment more believable and immersive.

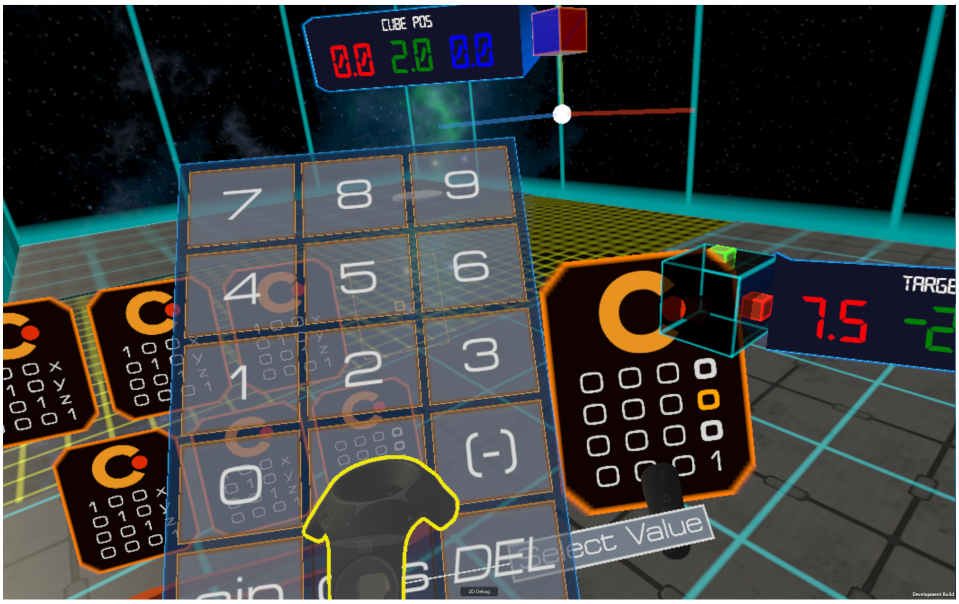

Fig. 8: *GEtiT-VR* allows for a direct value input via a special input matrix UI.

Additionally, instead of tying the indication of the object's and target's position to the player's view, both game mechanics, following again the idea of a spatial UI, received a label that displays the position information. The labels, despite being attached to their relevant object, have no fixed position or orientation. Instead they always face to the player, and, in case of one of the labels is relative to the player behind one of the level's obstacles, the label starts to shine through the obstacle thus ensuring a good visibility from any position inside of a particular level.

5.3 Walk-In Game Menu

The final challenge of the VR port was to avoid breaking the immersion when a player accesses one of the game menus, such as the level selection screen, the game options, and the wiki. This challenge was solved by turning the individual menus of the desktop version into control consoles that are placed inside of the player's futuristic playing room that provides a connection between GEtiT-VR's training exercises and the real world. Aside from the control consoles and relevant displays for the various menus, the playing room also features a fictive game console that loads and previews the available training levels–they are provided in form of cubes in a shelf–by placing one of the level cubes on top of it. In order to play a loaded level, a player has to wear a virtual in-game HMD that is connected to the game console (see Figure 9) by grabbing it with one of the controllers and putting it on with

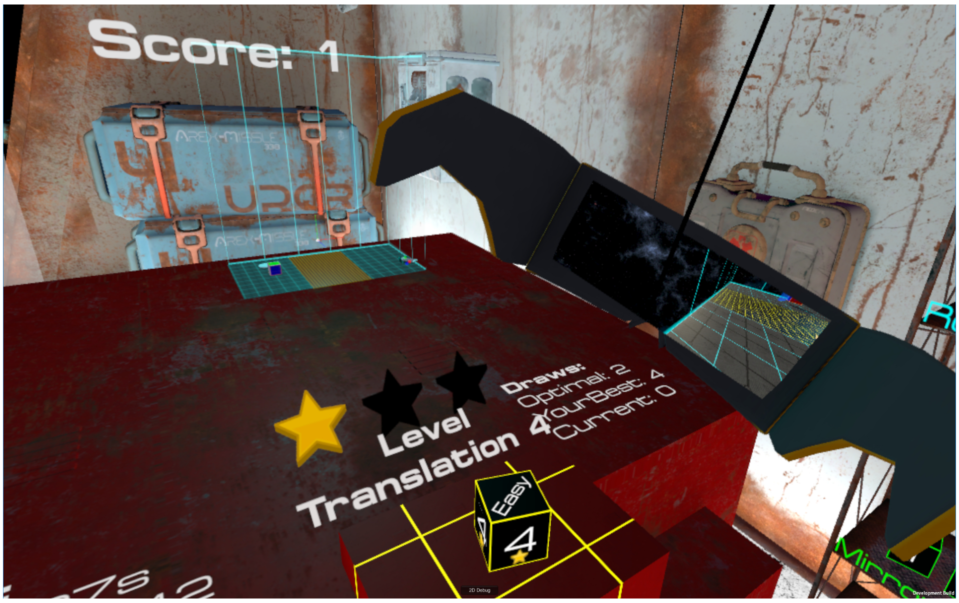

Fig. 9: *GEtiT-VR* implements the functionality of VR Head-Mounted Display devices to allow for a transition between menus and the normal gameplay.

a similar gesture one would perform to wear normal glasses. Similarly, a user can return to the playing room from one of the training exercise levels by simply taking off the virtual HMD. That way, GEtiT-VR implements the VR technology itself as a method to transition between the game and the menus in a believable and immersive way.

6 Conclusion

We described the conceptual design and technical implementation of GEtiT which is used as a demonstrator for our model describing a direct knowledge encoding using game mechanics. The virtual gamified training environment achieves an intuitive presentation and demand of the abstract AT knowledge by moderating the learning content's level of abstractness. GEtiT comes in two versions which are distinguished by their level of visual immersion and is, to our knowledge, the first gamified training environment that is based on a general knowledge encoding model.

GEtiT's desktop version was already used in three AT training modules associated with an interactive computer graphics lecture and achieved a training outcome equal to a traditional paper-based training method. In addition, GEtiT achieved a significantly higher intuitive training and a higher enjoyment of use in general. The results of the completed studies are currently in preparation for publication. Therefore, we expect GEtiT-VR, due to a higher visual immersion, presence and spatial knowledge presentation, to yield a similar or even better training outcome in a forthcoming evaluation that compares the efficiency of the two different versions.

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