Interactive Gamified 3D-Training of Affine Transformations

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Figure 1: *Symbols displayed on the cards indicate the different transformation types and their effects in GEtiT.*

Abstract

This article presents the Gamified Training Environment for Affine Transformations (GEtiT). GEtiT uses a 3D environment to visualize the effects of object rotation, translation, scaling, reflection, and shearing in 3D space. It encodes the abstract knowledge about homogeneous transformations and their order of application using specific game mechanics encoding 3D movements on different levels of abstraction. Progress in the game requires mastering of the game mechanics of a certain level of abstraction to modify objects in 3D space to a desired goal position and/or shape. Each level increases the abstraction of the representation towards a final 4×4 homogeneous matrix representation. Executing the game mechanics during the gameplay results in an effective training of knowledge due to a constant repetition. Evaluation showed a learning effect that is equal to a traditional training method while it achieved a higher enjoyment of use indicating that the learning quality was superior to the traditional training method.

Keywords: gamification, education, serious games, virtual reality

Concepts: •**Software and its engineering** → **Interactive games; Virtual worlds training simulations;** •**Computing methodologies** → Virtual reality;

1 Introduction

In-depth understanding of homogeneous transformations (HTs) is essential for many engineering areas including Virtual and Augmented Reality (AR, VR), 3D computer graphics, or robotics. However, in contrast to simple geometric tasks with an intuitive understanding, the homogeneous representation of transformations, their matrix form with potentially interdependent values, and the dependence of the order of application (i.e., multiplication of matrices) often escape an intuitive approach. Students have to understand how the theoretical grounded abstract aspects of transformations result, e.g., in changes of the object's position, rotation or dimensions and more but often encounter problems that ultimately lead to a high degree of frustration.

We developed a training system to master the application of Affine Transformations (AT), an important subset of transformations encoding rotation, translation, scaling, reflection, and shearing which are expressible as HTs. The Gamified Training Environment for Affine Transformations (GEtiT) visualizes the effects of an AT in an immersive 3D environment and encodes the learning content in its game mechanics. Each computer game consists of several game mechanics [Sicart 2008; Adams and Dormans 2012]. Here, they are used to encode the game's knowledge which is subsequently trained due to repetition [Gee 2007]. Furthermore, game mechanics demand and hence train a certain set of human skills [Oberdörfer and Latoschik 2013]. Finally, game mechanics have the potential to directly encode even abstract knowledge thus creating intuitive training environments for complex learning contents.

The GEtiT game mechanics were designed to increase in their level of abstraction as well as in the complexity of the mutual application of multiple transformations thus resulting in a gradual increase of the learning content's as well as game's difficulty. This increase in difficulty combined with constant feedback in 3D and new challenges ultimately creates a desired game flow [Csikszentmihalyi 2010; McGonigal 2011]. Hence, GEtiT is also intended to demonstrate our method describing how abstract knowledge can be directly encoded in game mechanics and to subsequently evaluate the game mechanics' potential to directly encode abstract knowledge.

2 System Design

GEtiT needs to fulfill three main requirements as an effective training system: (1) The different levels of abstraction in specification of transformations require tailored input methods. (2) Clear and intuitive feedback has to be provided to allow the players to evaluate the outcome of their actions. (3) A well-defined task is needed in order to provide the learners with a clear goal and to challenge them to apply their AT knowledge.

We adopted the idea to use a manipulable object as a common game mechanic of many computer games. In the case of GEtiT, the use case of this game mechanic is twofold: On the one hand, the object

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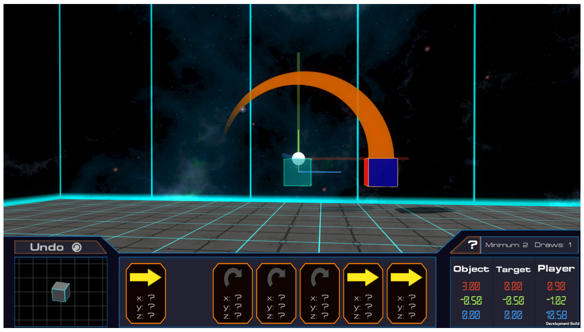

Figure 2: *Executing a rotation transformation in GEtiT.*

gets transformed based on the players' inputs thus giving them a clear feedback on the correctness of their approach. On the other hand, the object game mechanic internally stores the object's current status which can be used as a goal. The learners are then required to transform the object in such a way that it matches the victory conditions, which are displayed in form of a half-transparent object, for a particular training task (see Fig. 2).

Figure 3: *GEtiT's UI demands the application of AT.*

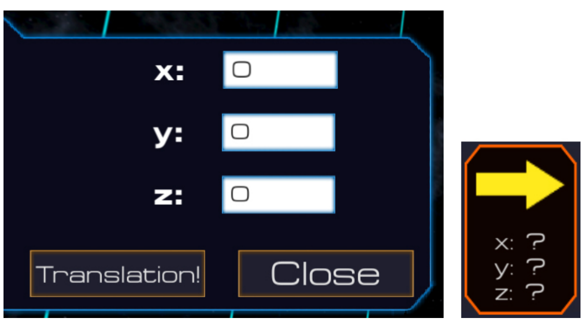

Figure 4: *Users are required to use their computational results.*

We developed a special user interface (UI) that gives the players access to AT types (properties and effects) and informs them about the object's, target's and player's position. The AT types are symbolized by cards that display a symbol indicating the type of the transformation as well as the predefined values (see Fig. 1). Depending on the game's setting, activation immediately transforms the object according to the predefined values or opens a direct value configuration screen (see Fig. 3) in order to accept self-determined computational results. In addition, the first two difficulty settings use a vector representation (see Fig. 4) of the transformations whereas the last two difficulty settings utilize a matrix representation. Both methods are used as one way to increase the level of abstraction as well as the difficulty of the learning content.

The learning tasks are created with the general game mechanic of the level design, the selection of available AT types, as well as the victory conditions. The level design determines the initial position of the object, the level's origin, and the target's position. Also, the level design is used to place obstacles between the object's initial position and the target thus requiring the learners to translate the object around the obstacles.

In addition, for the purpose of providing the players with a clear goal, a fourth game mechanic—an exit portal to escape a particular level—was added to GEtiT. The portal is, however, deactivated at the start of a level. Hence, the players are challenged to activate the portal by transforming the object in such a way that it matches the victory conditions. This way, GEtiT's gameplay becomes meaningful [McGonigal 2011] to the players and increases their motivation to tackle the learning tasks.

GEtiT players start trapped in a sealed room from which they can only escape when they open the portal. In order to do so, they need to transform the object using their transformation types in such a way that it matches the victory conditions. However, they have to pay attention to the environment as the object can not translate through obstacles that are placed inside a particular level. Once the object matches the victory conditions, the portal gets activated and the players can proceed to the next level.

3 Results and Conclusion

We have evaluated the learning effects of playing GEtiT during the summer term of 2016 by inviting students who visited a lecture on Interactive Computer Graphics to participate in our study. After being randomly assigned to a game group or a control group, the participants trained their AT knowledge with GEtiT or alternatively with traditional assignments as a control group. Finally, all completed an exam in order to assess their learning outcome.

During our study, GEtiT achieved a learning effect that is equal to the learning effect of a traditional training method. Furthermore, GEtiT achieved a higher enjoyment of use than the traditional training method indicating that the learning quality was superior to the traditional training method.

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