Towards Progress Assessment for Adaptive Hints in Educational Virtual Reality Games

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Abstract
One strength of educational games is their adaptivity to the individual learning progress. Methods to assess progress during gameplay are limited, especially in virtual reality (VR) settings, which show great potential for educational games because of their high immersion. We propose the concept of adaptive hints using progress assessment based on player behavior tracked through a VR-system's tracking capabilities. We implemented *Social Engineer*, a VR-based educational game teaching basic knowledge about social engineering (SE). In two user studies, we will evaluate the performance of the progress assessment and the effects of the intervention through adaptive hints on the players' experience and learning effects. This research can potentially benefit researchers and practitioners, who want to assess progress in educational games and leverage the real-time assessment for adaptive hint systems with the potential of improved player experience and learning outcomes.

Author Keywords
serious games; educational games; virtual reality; adaptive hints; player state assessment; stealth assessment;

CCS Concepts
•**Human-centered computing** → **Virtual reality;** •**Applied computing** → *Computer-assisted instruction; Interactive learning environments;*

Introduction

Educational virtual reality (VR) games have great potential for teaching, especially due to their high immersion. For example, Makransky et al. [17] have shown the effectivity and efficiency of VR educational games for the education of laboratory safety training. Similarly, educational games, in general, can benefit from adaptivity to the players' individual needs [23], leading to personalized learning experiences [20]. Help could be automatically provided by the application when a player is stuck, while detailed step by step explanations could be skipped for learners with prior knowledge. This ensures a comfortable mental effort and stress, which results in an improved learning outcome [8, 24, 25], and an overall improved game experience [5, 28]. Automatic adaptivity helps further to make educational VR games classroom-ready, as a single teacher cannot be expected to guide multiple students at once.

However, assessing in-game progress in VR settings is challenging. It is difficult to know if players intentionally do not work towards goals or cannot make progress because they are stuck. Therefore, methods that detect progress based on behavior could be beneficial for educational games. Contemporary VR head-mounted displays (HMDs) provide a variety of tracking capabilities that lend themselves to assessing the players' state. For instance, previous work has used indicators for player state based on *head movements* [12, 21, 22], *hand movements* [12, 21], and *gaze behavior* [16, 26, 27]. We will use the additional sensor data a VR HMD can provide to recognize the current player state and create new adaption metrics for educational games based on (1) eye-tracking, (2) hand/controller movement, (3) head movement, and (4) body movement data.

We created an educational game that is used to teach company employees the risks of social engineering (SE) and show common attacks (see Beckers et al. [4]). The educational goal is to create a sustainable awareness for SE and to improve the security of a company. In the game, players take up the role of a penetration tester (PT) and gain basic SE knowledge by conducting three SE attacks (e.g., see Figure 1). We propose adaptive automated hints based on the players' in-game progress as detected by their behavior sensed through the VR HMD tracking system.

Figure 1: In the role of a PT, a player applies *dumpster diving* on an office paper bin to retrieve confidential documents.

In this paper, we propose the concept of progress detection and adaptive hints as well as two user studies that will evaluate the validity of this approach and its effects on player experience and learning outcome. First, we will investigate appropriate indicators used for progress detection. In a first study, participants will play *Social Engineer* without progress detection or adaptive hints, but participants can request hints by themselves by pressing a dedicated help button. By recording and afterward analyzing their behavior, we aim to find indicators that suggest if a player is stuck and needs help. As a second step, we will create and implement the adaptive help system that will provide hints to the players before they get stuck. In a second user study, we will compare the effects of the adaptive help system on player experience and learning outcomes.

Our contributions are (1) the concept of in-game progress assessment based on player behavior in educational VR games, (2) the concept of adaptive hint system using this progress detection, (3) and the VR-based educational game *Social Engineer*. We are currently working to expand this research with two user studies that evaluate the value of different indicators for progress assessment and the effects of the adaptive hint systems on player experience and learning outcomes.

Related Work

Our work is strongly influenced by previous work on *adaptivity in educational games* and *adaptive hints*.

Adaptivity in Educational Games

Adaptivity in educational games can benefit players by taking into account their individual needs [23]. Shute [25] describes the trend in educational games in the last years to use stealth assessment techniques to automatically score the player success and its learning progress to improve game instructions and create adaptivity in educational games. Stealth assessment has the benefit that it does not interrupt the game flow [25]. This supports learning, as it maintains the flow and creates an excellent experience so that a player is completely engaged in the game [8, 25].

An adaptive educational game should guide the player to the next step to find the solution [7]. This means that the learning flow of the player has to be understood so that it is possible to make ad hoc changes to the current learning unit [7]. We will investigate behavioral indicators based on *head* [12, 21, 22], *hand* [12, 21], and *foot movements* [9, 19], as well as *gaze behavior* [16, 26, 27] and apply this to VR HMDs. This way, we aim for stealth assessment that will be unobtrusive and allows to provide adaptive hints during the learning task.

Adaptive Hints

Applying adaptivity to help or hint systems is challenging, however. A study by Anderson et al. [3] found mixed results of the effects of on-demand help, where it even affected player experience negatively for one game. Asking for help is unpopular for players and they ignore unspecific hints as well [2]. This highlights that games could benefit from automated hint systems that intervene only when progress is hindered, which can lead to frustration [11].

O'Rourke et al. [18] conducted a study with 50,000 students playing a 2D browser game and found similar negative effects on learning performance when providing hints. This could be linked to the previously explained maintenance of flow during gameplay [8, 25]. One limitation of O'Rourke et al. [18] was that their hints did not adapt to the players' partial solution of the level. As such, automated adaptive hint systems could be beneficial for educational games.

Another suggestion from O'Rourke et al. [18] is that the effective representation of a hint cannot be directly transferred from one medium (e.g., existing educational tools) to an educational game. In our approach, we use basic text messages, as they are an established way to show hints in commercial games [18]. They are sufficient, as we do not evaluate the effectivity of hint representations as O'Rourke et al. [18] but focus on the evaluation of VR player progress assessment. We refrained from modifying players' VR field of view or automatic camera movements for guidance, as this can induce motion sickness [14].

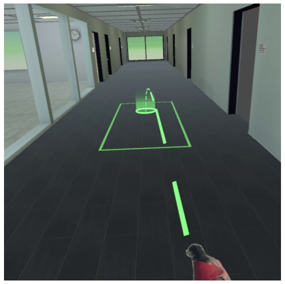

Figure 2: Use of teleportation system for game world exploration.

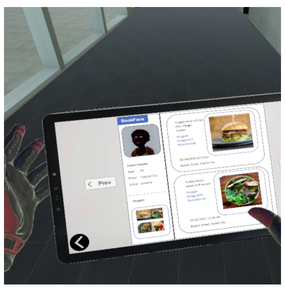

Figure 3: Interaction with a virtual tablet computer.

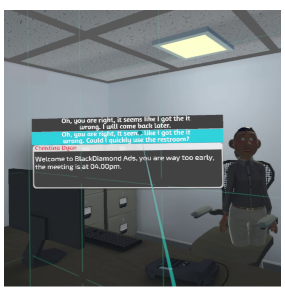

Figure 4: Selection of an answer option in a dialogue with an NPC.

Educational Game Context: Social Engineer

We designed and implemented *Social Engineer*, an immersive single-player first-person VR educational game for the HTC VIVE platform [15].

Game Content

The game conveys the risks posed by SE to company employees inside typical office buildings. *Social Engineer* is inspired by the card game designed by Beckers et al. [4]. No prior SE, specific computer, or hacking knowledge is necessary to learn with the game. The current prototype consists of an open world office building, structured by three tasks with increasing difficulty. The player impersonates a PT.

To ensure the technical and theoretical accuracy of the implemented SE attacks and tasks, the in-game stories were developed in cooperation with a cybersecurity company. Based on informal interviews with two SE experts, we designed realistic tasks that resemble SE attack procedures used in practice. This design approach also includes the implementation of realistic non-player character (NPC) behavior during a SE attack. Within our game, the following three core interaction tasks represent the actual interactions of an attacker with the real world during a SE attack.

Game World Exploration: To explore the office building, the player can move without restrictions inside the VIVE tracking space. Larger distances can be reached with a teleportation system (see Figure 2).

Object Interaction: Documents can be accessed via a graphical user interface (GUI) in the form of a virtual tablet computer (see Figure 3). The available documents are websites, social media pages, and common company documents (e.g., printed e-mails, telephone lists, etc.). In addition, the player can interact with other objects such as doors, chairs, computers, trash cans, and USB sticks.

Dialogue with NPCs: Through a text-based dialogue system, the player can talk to NPCs and vice-versa. Text panels and answer options are positioned next to the NPC in world space (see Figure 4).

SE tasks

On behalf of a security company, the PT's assignment is to carry out a security inspection in a medium-sized advertisement agency. The focus of such an inspection is uncovering cybersecurity vulnerabilities using common SE attack techniques. There are seven basic SE attack techniques in the current prototype: *impersonation*, *social networking*, *dumpster diving*, *email phishing*, *voice phishing*, *USB dropping*, and *hostile situation*. The available SE attack techniques are explained in a tutorial before the game start and can be looked up anytime during the game. The overarching game goal, synonymous with the PT's assignment, is fulfilled when at least one vulnerability regarding security and data confidentiality has been identified and exploited in each of the three tasks. Learning success is achieved because the player is immediately made aware of the effects such a vulnerability can have.

The open game world and the flexible story encourage independent thinking and problem-solving. In order to achieve a goal, the player can choose different paths and combinations of basic SE attack techniques. Each of these paths consists of several intermediate goals.

Exemplary SE Attack

One goal is to obtain confidential drawings for a planned advertising campaign. A solution consists of several steps. While exploring the game world, the first step is to find out where the drawings could be located. Subsequently, by deciding to impersonate a cleaning person, the PT persuades employees to gain access to the target office. The PT then continues playing the role within the office in order to be-

Figure 5: Presentation of a hint in form of an on-screen message.

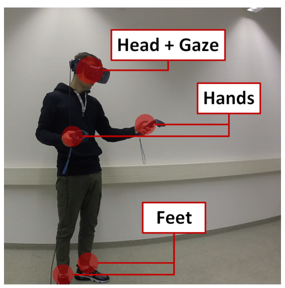

Figure 6: Progress assessment indicators on the body of a player.

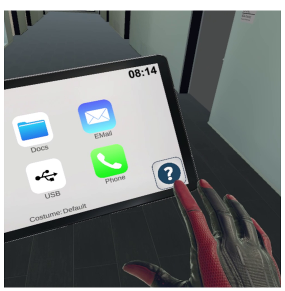

Figure 7: Help button in the preliminary study.

have inconspicuously and to be left unsupervised. At the right moment, the PT can take pictures of the drawings directly from the drawing table or search a paper bin for other design drafts. The *impersonation*, which is the key element in this example solution path, has the most chances of success if a suitable costume is worn in addition to choosing appropriate dialog options.

Progress Assessment for Adaptive Hints

Due to increasing task difficulty and multiple possible combinations of SE attacks, it may happen that a player gets stuck. In this case, a hint system can help the player to make progress [16]. The hint system provides a short textual instruction as an on-screen message on the virtual tablet computer, that explains the necessary steps to reach the next intermediate goal (see Figure 5). The current prototype provides exactly one hint for each intermediate goal.

We propose adaptive hints through progress detection in a way that continuously monitors the player state and adapts game features when undesirable states occur [10, 23]. We monitor the players' behavior to infer their in-game progress towards their next goal. If their behavior indicates that they do not make progress, a hint will be displayed automatically.

To assess player progress, we evaluate behavioral indicators that are available through the HMD itself and by commercially available tracking devices that belong to it. This has the benefit that no specialized hardware is required, which increases applicability to other educational games. We use indicators of four different categories. Our implementation uses a (1) HTC VIVE Pro Eye HMD that provides (2) real-time eye tracking, (3) two VIVE controllers, and (4) additional VIVE trackers (see Figure 6).

Head movements [12, 21, 22] are measured with the HMD tracking. It provides information about the look direction, head orientation, and the intensity of head movement as well as head shaking.

Gaze behavior [16, 26, 27] can be measured with built-in HMD eye tracking devices. We want to measure the number, duration and frequency of saccades, fixations and blinks as well as gaze positions and scanpaths.

Hand movements [12, 21] can be collected with the information of controllers that the player is holding while playing. We want to measure the controller positions, the intensity of controller movements, shakes, and grip strength. Additionally, we can use the controllers to measure all button presses.

Foot movements [9, 19] can be accessed by additional trackers that are mounted on each foot. We want to measure the intensity of feet movements, feet rotations, and the distance between both feet.

Study Design

We propose two studies to (1) determine indicators for progress assessment and (2) measure the effects of adaptive hints on players.

Preliminary Study

This preliminary study will be conducted with our first prototype of the SE VR educational game *Social Engineer*. Participants will play it with no guidance provided but with the possibility to request help in form of a hint whenever they do not know what to do by pressing a help button on the virtual tablet computer (see Figure 7). The goal is to collect user behavior data in different game tasks to determine behavioral indicators of hindered progress by analyzing how players behave when they need help. We will code this data, analyze the player state and the game progress, and define a combination of behavioral features as patterns for each game task indicating that help is needed. This will be implemented in the second prototype for the main study that will provide automatic adaptive hints.

Main Study
In the second study, adaptive hints will be presented to the participants when their behavior indicates that they get stuck to keep the flow of the game and reduce frustration. Besides the adaptive hints, there is no difference to the first prototype and the previously used SE tasks. The effect of the adaptive hints will be compared to on-demand help (similar to the implementation of the preliminary study) and no help. Our goal is to explore the effects of these conditions on player experience and learning outcomes based on self-assessment as well as knowledge tests.

We will measure experience-based and learning-based values. For experience-based, we will measure (1) player experience (PXI [1]), (2) mental effort (NASA-TLX [13]), and (3) usability (SUS [6]). For learning outcomes, we will conduct (4) a self-assessment questionnaire of awareness and sensibility about SE, and (5) an evaluation of the learning effect by conducting a pre- and post-test of knowledge.

Discussion

We have created an educational VR game called *Social Engineer* for teaching employees the risks of SE attacks. We have proposed how we plan to conduct two studies and will first collect user behavior data to determine behavioral indicators. They will be used to provide adaptive hints to the players timely before they would get stuck. Their effect on experience-based and learning-based values will be evaluated during the second study.

This approach seems promising, as related work has shown how important it is to reduce the number of displayed hints [2, 3, 18] and to keep the flow high [8, 25]. Related work uses metrics based on *head* [12, 21, 22], *hand* [12, 21], and *foot movements* [9, 19], as well as *gaze behavior* [16, 26, 27]. To the best of our knowledge, it is not explored how this could be achieved in VR by using the additional data ((1) eye tracking, (2) hand/controller movement, (3) head movement, (4) body movement) commercially available HMDs can provide.

We plan to show findings how players react when they get stuck. Do they have more frequent or shorter movement patterns? Do they change their gaze patterns more often and randomly look everywhere to find a clue that could possibly help? These findings can be applied to systems that provide no textual hints as well. The progress state can be used to adapt the game scene and create NPCs for support if a player struggles to proceed or create additional obstacles for skilled players. Therefore, adaptive hints could be used to adapt the difficulty and the scope of a learning unit as well. This ongoing work will be beneficial for the design and implementation of educational games used in practice, teaching, and research.

Conclusion

Social Engineer is a SE educational VR game that allows determining behavioral indicators for adaptive player progress assessment. With our proposed studies, we will collect data needed to find behavioral patterns for progress assessment and evaluate the effects of adaptive hints on player experience and learning outcomes. This novel approach of VR specific player state assessment can be beneficial for educational games that adapt to the learners' individual needs and skills.

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