Situated Cognitive Engineering: The Requirements and Design of Automatically Directed Scenario-based Training

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***Abstract*—Serious games enable trainees to practice independently of school, staff, and fellow students. This is important as amount of practice directly relates to training efficacy. It is also known that personalized guidance elevates the benefits of training. How to achieve automated guidance, for example to be used in serious games, is a yet unsolved issue. This paper uses the situated Cognitive Engineering method to analyze the operational demands, theoretical foundations and technological opportunities for the design of an automatically directed scenario-based training system (AD-SBT). AD-SBT guides training by selecting scenarios that match the trainee's competency level, by monitoring the training process, and by offering appropriate support. Three instructional principles are used: adapt training to the trainee's cognitive characteristics, strengthen the trainee's will to learn, and foster transfer of learned skills. This paper reports evidence taken from the literature and by means of a use case simulation to validate and verify the presented requirements for AD-SBT and the underlying claims. Results show that the introduced requirements baseline and the resulting design for AD-SBT form a good starting point for future refinement and prototyping.**

***Keywords*-director; scenario; training; cognitive engineering**

I. INTRODUCTION

Some professions (e.g., firemen, policemen, nurses) involve complex skills: integrated physical abilities, as well as cognitive abilities such as situation assessment and decision making. The most straightforward way to train complex skills is to have trainees engage in representative, real-life situations. However, research has shown that in order for training to be effective, trainees need guidance during skill acquisition [1]. Such guidance is usually offered by an instructor and in some cases even by an entire team of staff members, resulting in high costs of training in terms of money, time and resources. By simulating not only the learning environment, but also the process of guidance, these costs can be reduced.

To gain some understanding in the ways in which instructors normally guide their trainees, let us consider a clinical psychologist whose main tasks are to diagnose and treat patients suffering from mental health problems. These tasks are to be performed under varying circumstances: new patients, patients halfway their treatment, all suffering from various disorders, all in need of different treatments, etc. Not every case is equally suitable for a trainee to learn from. How suitable a training case is for a particular trainee depends on the trainee's experience and the complexity of the case.

Say, a trainee needs to practice his first intake interview in an on-the-job training setting. However, the first patient happens to be suicidal. In such a case, the instructor may decide to let this patient pass as a training case, because the trainee lacks the experience to treat this patient and to deal with the additional emotional responsibility. The next patient, a boy having trouble mourning over the death of his father, is probably a better case to start with. During training an instructor repeatedly selects an appropriate case based on the trainee's latest performance. The ultimate goal is to guide the trainee to a performance level that enables him to diagnose and treat all possible cases.

If training does not take place on-the-job, but in a role-played scenario, the instructor is able to refine the case even more, by playing the patient himself or by hiring an actor to play the patient while the instructor functions as a director. Either way, the instructor is now able to manipulate the scenario as it develops, by controlling the patient's behavior.

Selecting the appropriate learning task (scenario) and the appropriate amount of support (manipulative directions) are powerful ways to guide the trainee and create effective training situations. To be able to add automated guidance to virtual learning environments, such as serious games, it is necessary to uncover the principles underlying training task selection and manipulation. How do instructors decide what task is appropriate for a trainee to learn from? What events cause instructors to intervene in a training scenario?

This paper uses the situated Cognitive Engineering (sCE) method to achieve design principles and an architecture for automatically directed scenario-based training (AD-SBT) [2]. The sCE method has been previously applied to the defense and space domain for the design of systems involving computer-supported task performance. Its roots lie in the field of cognitive engineering, a science of user-centered design which aims to uncover the principles behind human

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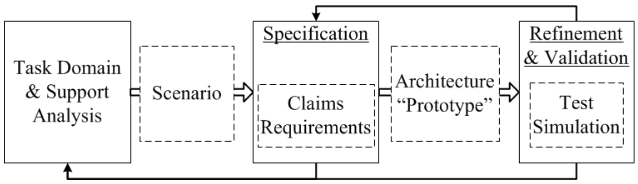

Figure 1: The situated Cognitive Engineering method [2]

action and performance that are relevant for the design of systems comprising of both people and machines, in order to maximize the performance of this joint system [3], [4].

The sCE method (Figure 1) consists of a process of iterative development cycles. Each cycle is directed at refining the system's specifications in more and more detail. The system's initial specifications follow from careful analysis of the task domain, human factors knowledge (e.g., relevant theories, guidelines and support concepts) and technological opportunities. This set of specifications, consisting of claims, requirements and use cases, forms the foundation for a prototype. This set is to be refined by evaluating the prototype. The entire development process is situated, meaning that it takes place within the context of the domain.

The current paper describes the first development cycle of the sCE method, resulting in a requirements baseline, and thereby it is structured as follows. Section II specifies the analysis of the task domain, the human factors knowledge and the technological opportunities for the intended AD-SBT system. Section II-D presents a scenario illustrating the intended use of the system. The drivers identified in Section II form the foundation for the system's specification in terms of claims and requirements presented in Section III. Section IV presents the proposed design architecture for a prototype of the system, which is based upon the aforementioned requirements. Section V describes possible ways (a test and a simulation) for (future) refinement of the requirements and verification of the architecture (prototype). Conclusions can be found in Section VI.

II. Task Domain and Support Analysis

This section covers the results of our domain and support analysis, leading to the operational, theoretical and technological drivers for AD-SBT. The operational driver, a training method called scenario-based training, is presented. Subsequently, it is shown how SBT can be structured or *directed*, by using three principles of instructional design identified in the human factors literature. These principles form the theoretical driver. Lastly, the technological opportunities for automatically directed scenario-based training are discussed. These form the technological driver for AD-SBT. Finally, the envisioned system is illustrated by means of a scenario describing the intended use of the system.

A. Operational demands: Scenario-based training (SBT)

Scenario-based training (SBT) has proven to be a powerful training method [5], [6]. It is consistent with the principles recognized in dominant instructional theories [7]. During SBT, trainees prepare, execute and evaluate training scenarios, i.e., real-life, relevant and meaningful storylines within a simulated environment (SE) [5], [8]. The fidelity of the SE may vary, ranging from the actual task environment to highly symbolic representations thereof. Training within an SE has several benefits in comparison to on-the-job training: an SE can be prepared, controlled, reused, and improved upon, leading to the reduction of risks, costs, and resources.

Training scenarios generally address specific learning objectives. To ensure their realism and didactical value, scenarios are authored and prepared in advance of the training session by an instructor. Most often the scenario contains so-called non-player characters (NPCs) with whom the trainee needs to interact, such as teammates, officers, patients, or opponents. These roles may be played by the actual persons (in case of teammates for instance), by staff members and actors (especially in case of opponents or enemies), or by virtual actors such as intelligent agents.

B. Theoretical foundation: Human factors knowledge

There are many instructional principles in the human factors literature. Three recurring and prominent principles relevant for AD-SBT are identified and described in the subsections below: 'Transfer - keeping an eye on the subject matter'; 'Adapt to the trainee's cognitive characteristics'; and 'Increase the trainee's will to learn'. These principles are used for a further specification of AD-SBT.

1) Transfer - keeping an eye on the subject matter: Effective training is supposed to lead to the display of the trained skills during future job performance (transfer) [9]. To promote transfer, training tasks should be *authentic*; i.e. represent the tasks that the trainee will perform in his future profession [10], [11]. Additionally, training tasks should come in a wide diversity; by generalizing solutions over various tasks, trainees learn to abstract away from them. This abstraction leads to the recognition of the underlying principles to be applied in the actual task environment [9].

2) Adapt to the trainee's cognitive characteristics: To facilitate learning, one needs to adapt the training to the trainee's competencies. Effective instruction takes limited working memory capacity into account. As the trainee's competencies grow during training, the amount of information that can be processed by the trainee's working memory slowly increases, allowing for the task load to increase [12]–[14]. This can be done by fading support (scaffolding); i.e. adjusting the amount of feedback, cues, simultaneous events or time restrictions [15]. Another way to increase the task load is by increasing task complexity; i.e. selecting tasks that require a little more than the trainee's current competencies.

A second aspect to keep in mind is that trainees make use of different learning strategies. This means that the instructor should be able to choose from different teaching styles, e.g., by means of examples, through learning by doing, by

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applying knowledge to cases, by evaluating and reflecting on outcomes, by connecting experiences, etc. [16]

3) Increase the trainee's will to learn: The higher a trainee's motivation, the more efforts he will put into training and into transferring the trained competencies to the actual task environment [17]. Motivation is related to the level of *self-efficacy*: the trainee's truthful beliefs about his task performance capabilities [18]. Motivation can be intrinsic (engaging in an activity for its own sake) or extrinsic (engaging in an activity as a means to an end), the former being the more favorable one, as it is positively related to trainee achievements in contrast to extrinsic motivation which is negatively related to trainee achievements [19], [20]. Intrinsic motivation is promoted by offering the trainee meaningful and relevant learning experiences [21].

As argued earlier (Section II-B2), training tasks need to be compatible with the trainee's competencies. In addition, the trainee also needs to believe in his ability to master the task (self-efficacy) in order for him to be motivated to perform the task. A balance must be found between the offered challenge and the trainee's competencies to prevent him from getting bored or frustrated.

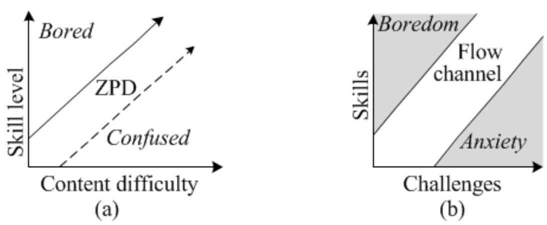

Figure 2: (a) Zone of Proximal Development (ZPD) [22] and (b) Flow [23]

Figure 2 displays two graphs representing the Zone of Proximal Development (ZPD) [22] and Flow [23]. Both figures refer to the zone between anxiety/confusion and boredom. Vygotsky's ZPD [24] is a common concept in instructional theory, representing a class of training tasks slightly more complex than the tasks the trainee is currently able to perform. Such tasks challenge the trainee to develop new skills or insights. The ZPD shows a remarkable resemblance to flow, a common concept in game research [23]. Flow is defined by Csikszentmihalyi (1991) as a mental state that results from appropriate challenge and truthful self-efficacy and is characterized by high levels of motivation, concentration and enjoyable learning. Recently, flow as a concept has been adopted by game-researchers [25], [26]. An interesting range of experiments has been published about the derivation of trainee's mental state - i.e. excitement, frustration, boredom, pleasure, challenge, interest, and even flow - by using psycho physiological measurements [27]–[29]. The results of these experiments can be used to automatically adjust the amount of challenge to keep the trainee in flow.

C. Technological opportunities

By implementing SBT into a virtual environment instead of a real one and using intelligent agent technology, it is possible to automate the NPCs [30] in such a way that they behave in a consistent and explainable fashion. This is preferable in a training system, since it results in believable and understandable NPCs. Several authors in the field of instructional design emphasize the potential of serious games in education [31]–[33], because they lead to an increase in motivation [20], [31], and because necessary adjustments to the environment and the behavior of the NPCs can be executed behind the scenes while the scenario unfolds [15]. In addition to the NPCs, we propose to introduce a director agent (DA). A DA creates suitable learning situations for the trainee by manipulating the NPC-behaviors behind the scenes in real-time.

There have been other proposals for DA architectures before, particularly within the domain of interactive narrative. One example is the Interactive Storytelling Architecture for Training (ISAT) of Magerko et al. (2005) [34], which uses partial order planning to generate variable storylines. Another example is the framework by Si, Marcella and Pynadath (2009). They describe a DA using their framework 'Thespian', which includes a runnable user model that can predict the trainee's future behavior [35]. Moreover, the agents in Thespian are able to reason about other agents' intentions. This DA intervenes by changing NPCs' beliefs and plans, possibly resulting in inconsistent NPC behaviors, which can be harmful for training since trainees may not accept these characters as realistic or believable. IN-TALE is a third example of such a framework. It was proposed by Riedl et al. (2008) [36] and should lead to believable failure of the agents' plans in case of conflicts between the NPC's plans and the DA's directions. The mentioned architectures generally focus on drama management. Although they acknowledge that their architectures also offer opportunities for training, the actual implementation of instructional theory is mostly neglected.

D. Illustration of the envisioned AD-SBT system

To illustrate the functionalities of the envisioned system, a description of a scenario in the domain of clinical psychology is given below.

Karen and Luke, two psychology students, start the training session. Karen plays the patient (NPC) while Luke plays the psychologist. The DA selects a scenario that fits Luke's learning goals, i.e. 'thorough questioning' and 'conversational management'. Karen plays a woman with bulimic disorder in denial of her problem, who was sent by her doctor. Karen follows the DA's instructions: 'change your position constantly', 'talk about your indignation for being sent to a therapist', and 'do not talk about food nor your figure'.

The DA receives updates about the conversation. Karen and Luke have been talking about Karen's household chores for a while. Luke has not asked any questions regarding the reasons that made Karen's doctor decide to redirect her to a psychologist. Moreover, Luke is not showing the right body language. Based on this information, the DA adjusts its instructions to Karen and its feedback to Luke. Karen is instructed to calm down and tell Luke why she visited her doctor. Luke receives feedback on his posture and is reminded of his learning goals to offer him a better focus. After a while, the DA stops the scenario. It encourages Karen and Luke to discuss the case, and provides them with feedback and a concise overview of the training session.

III. Requirements of an AD-SBT System

In Section II the design space for AD-SBT was presented. The current section presents the requirements for the AD-SBT system, based on this design space. During AD-SBT, training scenarios need to be automatically adapted to the trainee's cognitive and emotional state in real-time by a director agent (DA). The DA must create a wide variety of authentic training scenarios that match the trainee's needs.

A simplified list of requirements (R1 – R5) for AD-SBT is given along with the claims (C1.1 – C5.2) that should justify each of them, as they have become available by applying the sCE method. The requirements are justified when the underlying claims are validated by means of existing empirical evidence, simulations and future research.

- R1 Match scenarios to the trainee's current competencies.
  - C1.1 Presenting scenarios in order of increasing complexity and matching them to the trainee's level of experience prevents cognitive overload (see Section II-B2).
- R2 Adjust the level of scaffolding based upon the trainee's emotional responses.
  - C2.1 Adjusting the level of challenge fosters flow and high levels of motivation (see Section II-B3).
- R3 Create realistic (authentic) scenarios.
  - C3.1 Authentic training tasks foster transfer (see Section II-B1).
  - C3.2 Authentic training tasks foster motivation (see Section II-B3).
  - C3.3 Engaging in authentic training tasks fosters immersion, and thereby flow and motivation.
- R4 Create variable scenarios.
  - C4.1 This will foster transfer (see Section II-B1).
- R5 Provide feedback about interventions in the scenario.
  - C5.1 This will foster self-efficacy (see Section II-B3).
  - C5.2 This will foster a better understanding of the task domain.

IV. The Design of an AD-SBT System

In the current section the design architecture for AD-SBT (Figure 3) is presented. This architecture is based on the requirements listed in Section III. The architecture consists of two processes. Both of these adapt the scenario to fit it to the trainee's needs by instructing the agents to change their behaviors.

The first adaptation process is a *reactive process* - depicted by the solid line - that reacts upon psycho physiological measurements (bottom right) by adjusting the level of scaffolding to prevent the trainee from getting bored or frustrated. A reasoning engine (top right star) decides whether an adjustment in of the scaffolding (support/challenge) level is necessary. If so, it determines the nature of the adjustment to be made and sends this to the user model and to the agents controlling the characters and environmental elements, so they are able to change their behaviors accordingly.

The second process is a *reasoning process* (grey interrupted lines), brought about by the DA (top left circle). To decide on how to continue the scenario, the DA (1) uses a didactic reasoning engine (top left star), (2) an expert model and a scenario model (the two hexagons), and (3) consults a user model (grey striped square) and a world model (white checkered square). The user model contains the trainee's achievements, performed tasks, and reached checkpoints. The DA uses its didactic reasoning engine to reason about the user model and the expert model and decides what learning goals are suitable for the trainee. When an adjustment of the learning goals is appropriate, the DA sends a notification to the feedback engine, which should generate proper explanations for the adjustments to communicate to the trainee through the environment agent (Agent3 in Figure 3).

Once the DA has selected the learning goals, it uses the scenario database to select scenes that address these learning goals, after which it consults the world model to see what scene can be implemented without interrupting the believability of the storyline. The world model is updated with information coming from the agents and the user model (the grey dotted lines) and keeps track of all relevant facts in the world. The DA consults the world model to see what scenes fit the current world state. The DA randomly selects a scene from the resulting set - consisting of scenes appropriate for the trainee and matching the world state - and sends it to the other agents, so they are able to change their behaviors accordingly.

Note that this division into two adjustment cycles is not entirely new. VanLehn (2006) also describes two loops in the behavior of intelligent tutoring systems (ITSs); an inner and an outer loop [14]. He suggests that the outer loop is used to determine what learning task the ITS is supposed to offer next, whereas the inner loop is used to select the steps within the task, taking feedback, support and assessment into account.

V. (Future) Refinement and Validation

There are several ways to validate the claims presented in Section III. Two examples of claim validations will be presented as a further clarification of the sCE method: a test (described in [15]) and an outline for a possible use case simulation.

A. Test

An explorative study into the applicability of this architecture was conducted. For this study an AD-SBT system applied to the domain of 'in-company emergency services' was created. 'In-company emergency services' refer to a team of employees within a company who are trained to provide first-aid, extinguish small fires or clear the office

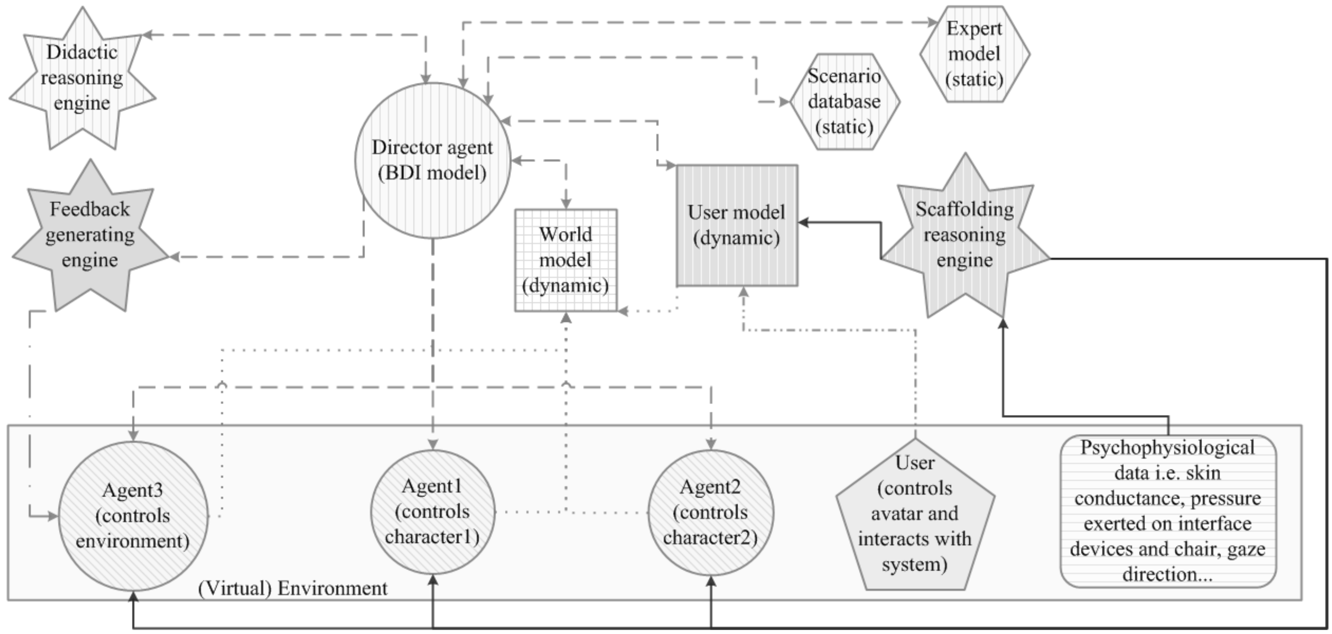

Figure 3: The Director Agent Architecture

building in case of emergencies, until the official emergency services have arrived.

Because of the cumbersome task of implementing a prototype of the envisioned training system, a Wizard of Oz prototype was developed. The simulated environment was not virtual, the NPCs were human actors and the director was also human. This created the possibility to investigate approaches for directing training without the need to actually create a virtual environment with added intelligent agent technology. Two actors received training to play the role of the NPCs in four scenarios. The human director was able to adjust the level of scaffolding by intervening in the behavior of the NPCs using a very detailed script and in-ear portophones. The aim of the interventions was to adjust the level of scaffolding to match the performance of the trainee. All of the resulting scenarios were recorded on video.

Subsequently, an experiment was conducted to test for the effects of the director's interventions upon the learning value of the scenario. Professional instructors from the domain judged twenty video fragments coming from the recordings of the study described above. In ten of these fragments, the scenarios were directed, meaning that the level of scaffolding could be adjusted in real-time according to a script. The other ten fragments came from undirected scenarios, meaning that the scenarios were not adjustable in real-time. The instructors were under the impression that all fragments were undirected and individually judged the learning value at set points in time.

The results of this experiment indicated that the DA's interventions resulted in more suitable learning situations compared to the undirected scenarios. These results support the validation of claim C2.1 and the justification of requirement R2 (Section III). Moreover, the trainees reported AD-SBT to be realistic, motivating and stimulating during interviews, thereby supporting not only the validation of claim C2.1 and justifying requirement R2, but also claim C3.2 and requirement R3. For a more extensive description of this experiment, the reader is directed to [15].

B. Use case simulation

It is emphasized that the following use case simulation is fictional. It serves as an example of how a design architecture could be verified by means of simulation through use cases. Formal use cases, however, need a far more detailed specification and should be constructed in consultation with domain experts.

Use case simulation 1

1) A trainee is currently enrolled in scene S14. He is receiving full support. His learning goal is G9.
2) The psycho physiological data imply stress indications, meaning that the trainee is in need of more support.
3) The scaffolding engine sends an update to the user model: Unable to adjust the level of scaffolding in the desired direction.
4) The director agent selects a set of less complicated, suitable learning goals {G2, G3 and G6} by reasoning about the expert and user model.
5) The world model contains conditions {C1, C3 and C14}.
6) Scene S9 and scene S11 in the scenario database both involve suitable learning goals, as selected in step 4.
7) The director agent sends a notification about the adjustment of the current learning goals to the feedback generating engine.
8) Both of the scenes proposed in step 6 are applicable, since their preconditions match the conditions in the world model.
9) The director agent randomly selects scene S11 from the set of applicable scenes as computed in step 6 and step 8.
10) The director agent notifies the agents about the scene selection.
11) The feedback generating engine sends an explanation for the adjustment of the learning goals to the environment agent.

12) The agents adjust their behavior to match scene S11.
13) The environment agent explains the new learning goals to the trainee.

This use case simulation exemplifies how the DA adjusts the learning task to address the appropriate learning goals, thereby verifying requirement R1 in Section III. The DA uses the world model to check whether the scenes are compatible with the current world state, thereby ensuring a realistic course of events, which verifies R3. Moreover, the DA creates variable scenarios by randomly selecting a scene from a set of options, thereby verifying R4. Finally, the DA provides feedback about the chosen learning path, which verifies R5.

VI. Conclusion and Future Work

Forms of training that allow students to practice independently (such as in serious games) are extremely valuable as they allow for higher frequencies and volumes of training. In this paper we argue that the benefits can be increased if such environments are equipped with a system that is able to provide the trainee with guidance: 'automatically directed scenario-based training' (AD-SBT). AD-SBT can be described as scenario-based training extended with a director agent. A director agent is able to manipulate the scenario in real-time to realize personalized interventions, guidance and support during scenario-based training.

The situated Cognitive Engineering method is used to present a design rationale for AD-SBT. This design rationale consists of (1) the operational demands, (2) relevant principles coming from instructional theory and game research and (3) the envisioned technology. The use of the method of situated Cognitive Engineering led to the identification of requirements and associated claims for an AD-SBT system. These requirements and claims (Section III) are based on knowledge about transfer, motivation, cognitive overload, and metacognitive skills. The requirements form the foundation for the 'automatically directed scenario-based training' (AD-SBT) architecture presented in Section IV. The architecture specifies two main processes: a reactive process controlling the level of scaffolding and a reasoning process controlling the complexity of the scenario.

A first test, described to a greater detail in [15], showed that AD-SBT significantly improves the learning value of the scenario, by being able to adjust the scenario in real-time to match the trainee's current needs. Moreover, trainees reported high levels of motivation during the AD-SBT scenarios. These results suggest that the requirements outlined in Section III forms a good baseline for further refinement in future research and prototyping.

Earlier research on intelligent tutoring systems has mainly focused on structuring and ordering the learning material to support the construction of well embedded and coherent knowledge structures. This guidance and support helps the trainee to comprehend the lessons to be learned. However, research on intelligent tutoring systems has neglected the importance of storylines and contextualization of learning materials to add meaning to the learning materials, to relate to the trainee's expectations and motivation, and to increase the trainee's will to learn. In contrast, research on serious games has mainly focused on engagement, motivating the trainee to learn, fostering transfer, and creating realistic learning environments. But serious games lack the structured approach to learning that is so important to guide the trainee during training. The research described here is a promising step in the development of a training system that does not only engage the trainee in active learning through participation in a storyline, but also provides the necessary guidance and support to the trainee. This research therefore helps to link various fields within the training research domain, such as serious games, scenario-based training, interactive storytelling, intelligent tutoring systems and instructional theory.

The next development cycle in the situated Cognitive Engineering process is directed at a partial implementation of the AD-SBT system. As the main focus of the research described here is automatic guidance during scenario-based training, this means that the reasoning determining the interventions will be modeled and implemented first. In order to model the reasoning process, we have to deal with a number of issues, such as: 'Is it possible to translate didactic strategies to generic rules in a didactic reasoning engine?', 'About what sorts of trainee behaviors should the director agent be able to reason?', 'What types of interventions does a human instructor perform and how can they be automated?', 'What knowledge about the trainee should be taken into account during the reasoning process?', and 'How much knowledge is needed about the possible behaviors of the non-player characters to be able to reason about and to execute effective interventions?'. The modeling, implementation, and (experimental) evaluation of the reasoning process will bring us another step closer to a fully functioning AD-SBT system.

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