Situated cognitive engineering: the requirements and design of directed scenario-based training

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Abstract. The development of adaptive virtual learning environments as an educative tool is promising. In this paper we use the situated cognitive engineering method to analyze the operational demands, theoretical foundations and technological opportunities for the design of a Director Agent (DA). A DA uses its knowledge about the virtual world, the trainee, the task domain, and the scenario to intervene in the course of events during the training scenario. The goal of these interventions is to achieve and maintain effectiveness and efficiency of training. A task domain and support analysis is conducted to specify the requirements of a director agent, subsequently, a design architecture that meets these requirements is proposed together with possibilities for future validation.

Keywords: director agent, requirements, scenario-based training

1 Introduction

Training programs are designed to prepare trainees to proficiently perform their future profession. A profession normally consists of several tasks. Let us, for example, consider a clinical psychologist whose main task it is to diagnose and treat patients suffering from mental health problems. This task has several instantiations; e.g. the task might involve a new patient, or a patient who is at the end of his treatment. However, what task instantiations are suitable to learn from depends on the trainee's current knowledge and skill level. Training programs are designed to support the trainee during his acquisition of the knowledge and skills required to perform all the task instantiations the job entails. This is done by careful selection and ordering of the offered training scenarios.

Say, a trainee needs to practice her first intake interview in an on-the-job training setting. However, the first patient happens to be a suicidal person. The instructor decides that the risk of the patient committing suicide is a reason to let this patient pass as a training case. In other words: It is important to consider whether a particular task instantiation is appropriate for the *trainee*. To gain more control over the training situation, the patient can be replaced with an *actor*. And to support the trainee, the instructor might function as a *director*, i.e. instructing the actor how to behave. Selecting the appropriate task instantiation (training scenario) and the appropriate amount of support is a powerful way to create effective learning situations.

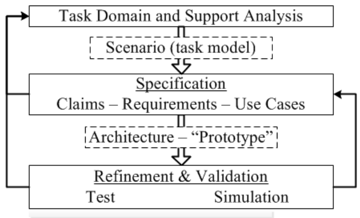

Fig. 1: The situated Cognitive Engineering method [13]

We will use the situated Cognitive Engineering method [13] (see Fig. 1) to achieve a design rationale and architecture for an automated training system. The task domain and support analysis, described in Section 2, leads to the identification of the operational, theoretical and technological drivers for a system consisting of three actors: a trainee, an actor and a director. The intended use of the system will be exemplified by a scenario presented in Section 2. The drivers identified in Section 2 form the foundation for the claims and requirements presented in Section 3. Based on these requirements, we propose the design architecture for a Director Agent presented in Section 4. In Section 5 we will describe possible ways for (future) refinement of the requirements and validation of the architecture. Conclusions can be found in Section 6.

2 Task Domain and Support Analysis

Transfer, authentic tasks and scenario-based training. In order for training to be effective, the trained skills need to carry over to the actual task environment (transfer) [1]. Therefore, training tasks should be *authentic*; i.e. represent the tasks the trainee will perform in his future profession [5]. Additionally, training tasks should come in a wide diversity. By generalizing solutions over various tasks, trainees learn to abstract away from them, leading to the recognition of the underlying principles to be applied in the actual task environment [1].

During scenario-based training, trainees prepare, execute and evaluate training tasks within a simulated environment [3, 14]. The fidelity of the simulated environment may vary, ranging from the actual task environment to symbolic representations thereof, as long as the simulated environment shows the resemblance to the actual task environment to promote transfer. Important benefits of training within a simulated environment are the reduction of risks, costs and resources, and the possibilities to deliver feedback and to exert control over the scenario. We argue that, by controlling the scenario, the learning situation can be attuned to the trainee's needs, leading to better training outcomes.

Controlling the scenario at two levels. Effective instruction takes *limited working memory capacity* into account. Experts working on complex tasks develop automated cognitive processes and mental models as a result of experience, which function as a work-around to this limitation [9]. Training should therefore facilitate the construction of mental models and ample and directed practice of the required cognitive processes. As a result, the amount of information that can be processed by the trainee's working memory slowly increases, allowing for the task load to increase [20, 21]. 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 more than the trainee's current competencies.

The importance of motivation. Another important aspect to learning is motivation [17]; the higher the trainee's motivation, the more effort he will put into training and in transferring the trained competencies to the actual task environment. Motivation is related to high levels of *self-efficacy*: the trainee's truthful beliefs about his performance capabilities on a specific task [7]. Motivation can be intrinsic (engaging in an activity for its own sake) or extrinsic (engaging in an activity as a means to an end). Intrinsic motivation is more favorable, since it has been related to successful student achievements. Intrinsic motivation is promoted by offering the trainee meaningful and relevant learning experiences.

The area between frustration and boredom. As argued, 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. A balance must be found between the offered challenge and the trainee's competencies, to prohibit the trainee from reaching the mental states of frustration and boredom.

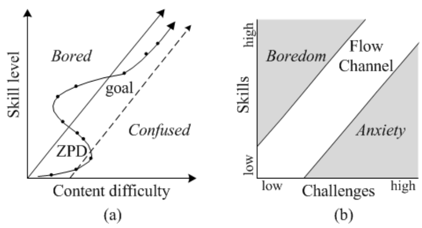

Fig. 2: (a) The Zone of Proximal Development (ZPD) [11] and (b) Flow [4]

In Fig. 2 we present two graphs representing the Zone of Proximal Development [11] and Flow [4]. Both figures refer to the zone between frustration and boredom. Vygotsky's Zone of Proximal Development (ZPD) [22] is a common concept in instruction theory. Tasks within the ZPD challenge the trainee to develop new skills or insights and are slightly more complex than the tasks the trainee is currently able to perform. The ZPD shows a remarkable resemblance to flow [4], a common concept in game research. 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. Sweetser and Wyeth (2005) developed a construct called 'Game-Flow' [19] to evaluate player ejoyment in games, by looking at game characteristics, e.g. appropriate challenge, skill enhancement possibilities, clear goals, feedback, and immersion. Some of the mental states associated with flow - i.e. excitement, frustration, boredom, pleasure, challenge, and interest - have been successfully derived from psychophysiological measurements [6, 10, 12].

Control over a virtual training environment. Our goal is the automatic attunement of training scenarios to the trainee's needs. By implementing SBT into a virtual environment instead of a real one and using intelligent agent technology, it becomes possible to automate all non-player characters (NPCs) involved in the training scenario, e.g. patients and patients' family members [2]. In addition to the role-playing characters, we propose a director agent (DA), an automated system that creates suitable learning situations for the trainee by controlling the course of events and NPC-behaviors behind the scenes in realtime.

There have been other proposals for DA architectures before, mainly within the domain of interactive narrative, such as IN-TALE (Interactive Narrative Tacit Adaptive Leader Experience) [16], ISAT (Interactive Storytelling Architecture for Training) [8] and Thespian [18]. However, these architectures generally focus on the generation of a consistent storyline and believable characters, and merely stress the possibilities for their application to training purposes. The actual implementation of instructional theory is mostly neglected.

Illustration of the envisioned system. To illustrate the functionalities of the envisioned system, we describe a scenario in the domain of clinical psychology.

Karen and Luke start the training session; they access their personal user models. Karen plays the patient (NPC) while Luke participates in training. Based upon Luke's user model, the Director Agent (DA) selects a scenario that fits Luke's learning goals, i.e. 'thorough, analytical questioning' and 'conversational management'. Karen plays a woman with bulimic disorder in denial of her problem, who was sent by her doctor. Karen starts her roleplay by following the DA's instructions: 'fiddle with your hair', 'change poitions constantly', 'tell him you are aghast that your doctor sent you here', and 'do not talk about food nor about your figure'.

The DA receives updates about the conversation; i.e. Karen and Luke have been talking about Karen's household chores for ten minutes. Luke has not asked any questions to find out why Karen was sent by her doctor, nor why she went to visit her doctor in the first place. 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 start talking about the reason her doctor sent her to Luke. Luke receives feedback on his posture and is reminded of his learning goals to offer him a better focus. After a while, the DA decides to stop the scenario and encourages Karen and Luke to discuss the case. The DA provides them with feedback and a concise overview of the training session.

3 Requirements of a Director Agent training program

The main requirement of the Director Agent (DA) is to facilitate learning. The DA must create a wide variety of authentic learning tasks that match the trainee's needs. We will give a simplified list of requirements (R1 – R6) for the DA along with the claims (C1.1 – C6.3) that should justify each of them, as an example of the sCE method (see Fig. 1). These requirements need to be justified by validating the underlying claims. This validation can be done by means of existing empirical evidence, simulations and future research.

- R1 Offer the trainee training tasks appropriate to the trainee's current skill level.
  - C1.1 The trainee will be prevented from experiencing cognitive overload, by matching tasks of increasing complexity to the trainee's current skill level.
- R2 Adjust the level of scaffolding during task performance to keep the trainee within the zone of proximal development.
  - C2.1 The trainee will experience high levels of motivation and flow, when offered learning situations that lie within the ZPD.
- R3 Create situations that resemble real-world situations that the trainee may encounter during his future job performance.
  - C3.1 Transfer from the (virtual) learning environment to the future task environment will be promoted, by creating authentic training scenarios.
  - C3.2 The trainee will experience higher levels of motivation, when the scenarios are meaningful, contextualized and the trainee perceives them to be relevant.
- R4 Create a realistic course of events.
  - C4.1 Transfer from the (virtual) learning environment to the future task environment will be promoted, by creating authentic training scenarios.
  - C4.2 The trainee will experience higher levels of immersion, when the scenarios contain realistic cause and effect relationships and NPC behaviors.
- R5 Create variable scenarios.
  - C5.1 Transfer will be promoted by offering the trainee a variety of scenarios, helping the trainee to generalize over various learning tasks.
  - C5.2 By offering the trainee a variety of scenarios the trainee will assign a higher replayability to the game, resulting in more frequent training occasions.
- R6 Deliver feedback to the trainee about choices regarding adjustments in the level of scaffolding and the learning goals.
  - C6.1 The trainee will gain a better understanding of his own learning progression, as a result of delivered feedback.
  - C6.2 The trainee will gain a better understanding of the task model and the relations between tasks, skills and knowledge, as a result of delivered feedback.
  - C6.3 The trainee will be able to create an accurate self-image of his abilities (self-efficacy) as a result of delivered feedback.

4 The Director Agent Architecture

In the current section we present a design architecture of the Director Agent (DA), depicted in Fig. 3, based on the requirements listed in Section 3. Below, we will explain the principal components and processes in Fig. 3. The architecture consists of two processes, both of which attune the scenario to the trainee's needs by instructing the agents to change their behaviors.

The first process is a *reactive process* - depicted by the solid line - that reacts upon psychophysiological measurements (bottom right) in order to adjust the level of scaffolding in such a way that the trainee does not get bored or frustrated. A reasoning engine (top right star) uses the measurements to decide whether an adjustment in support is necessary. If so, it sends a notification to the User Model and to the agents controlling the characters and environmental elements, which will change their behaviors accordingly.

The second process is a *reasoning process* (grey interrupted lines), revolving around 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) uses a task 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 user's achieved learning goals and performed tasks. The DA uses its didactic reasoning engine to reason about the user model and the task model and decides which learning goals are suitable for the trainee. The DA sends

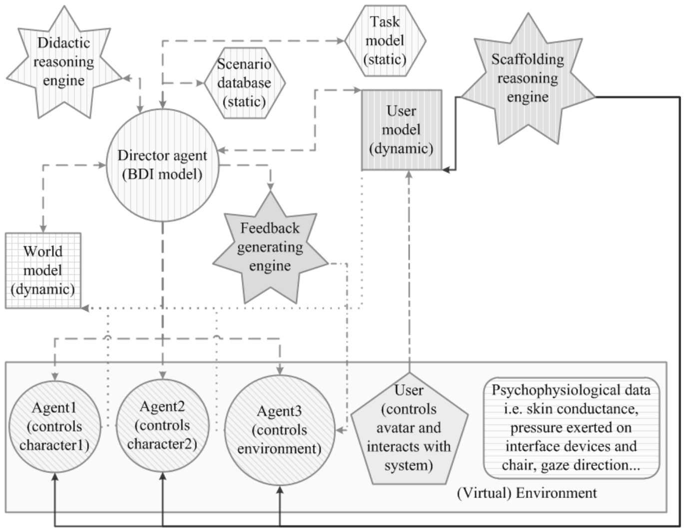

Fig. 3: The Director Agent Architecture

notifications about possible learning goal adjustments to the feedback engine, which generates proper explanations for the adjustments to communicate to the trainee through the environment agent (Agent3 in Fig 3).

Once the DA has selected the appropriate learning goals, it uses the scenario database to select scenes that address these learning goals, after which it consults the world model to see which one of these is easiest to implement without interrupting the believability of the storyline. The world model is updated with information about the world coming from the agents and the user model (the grey dotted lines) and functions as a filter; it keeps track of all relevant facts in the world. The DA consults the world model to see which 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, which will change their behaviors accordingly.

5 (Future) refinement and validation

There are several ways to validate the claims presented in Section 3. We will now offer two examples of claim validations, a test (described in [15]) and an outline for a possible use case, as a further clarification of the sCE method (Fig. 1).

Test. We have conducted an experiment (published and described in [15]) where humans played the role of agents in the system outlined above. A director was able to adjust the level of scaffolding by intervening in the behavior of the NPCs. This was done according to a very detailed script. The aim of the adjustments was to attune the scenario to the performance of the trainees. We recorded the scenarios on video. Naive professional instructors in the domain judged the DA's interventions to result in more suitable learning situations compared to the non-directed scenarios. These results support the validation of claims C1.1 and C2.2 and the justification of requirements R1 and R2 (Section 3).

Use case. We emphasize that the following use case is fictional and merely serves as an example of how a design architecture can be validated by means of simulation through use cases. Formal use cases, however, need a far more detailed specification and should be constructed together with domain experts.

Use case 1

1. Trainee is playing scene S14 at scaffolding level 0, in order to achieve learning goal G9.
2. Psychophysiological measurements indicate that the level of scaffolding needs to be decreased.
3. The scaffolding reasoning engine updates the user model about an inability to adjust the level in the desired direction.
4. The DA decides to select less complicated learning goals G2, G3 and G6.
5. The DA sends a notification about the learning goals to the feedback generating engine.
6. The world model contains conditions C1, C3 and C14.
7. The DA selects scene S9 and S11, since both of them involve learning goals G2 and G6 and their preconditions contain {C1}, and {C3,C14} respectively.
8. The DA randomly selects S11 from these two options and communicates this to the agents.
9. The feedback generating engine sends an explanation to the environment agent.
10. The agents adjust their behavior to match scene S11.
11. The environment agent explains the new pursued learning goals to the trainee.

As can be seen in the use case described here, the DA attunes the offered learning task to match the trainee's learning goals, thereby verifying requirement R1 in Section 3. Moreover, the DA uses the world model to check whether the scenes are suitable for the current world state, thereby ensuring a realistic course of events, which verifies R4. Moreover, the DA creates variable scenarios, since it randomly selects a scene from a set of options, thereby verifying R5. Finally, the DA gives feedback about the chosen learning path, which verifies R6.

6 Conclusions

We have used the situated Cognitive Engineering method for a design rationale consisting of operational demands, instructional theory, game research and envisioned technology. This forms the foundation for a requirements baseline, along with claims regarding transfer, motivation, cognitive overload, replayability, and metacognitive skills, as described in Section 3. This led to the Director Agent architecture presented in Section 4 - consisting of a reactive process and a reasoning process. A first test, described in [15], showed that this requirements baseline forms a good starting point for further refinement.

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