Extending an educational math game with a pedagogical conversational agent:

Challenges and design decisions

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1 Introduction

Over the past year we have been working with an educational game in elementary school mathematics, targeting the age group 7-12 years. Empirical testing and evaluation of the game in regular school classes over an extended period of time has evidenced positive learning effects in game-playing classes compared to controls, in terms of both increased performance on standardized math tests and students' confidence in explaining math to a peer [8].

A crucial aspect of the game concerns the inclusion of a Teachable Agent (TA) [2] – a form of AI-based educational technology which builds upon the pedagogy of "learning by teaching" [1]. In this setup, the user is in a position to "teach" a virtual agent over time, by either demonstrating how to play the game (i.e. making moves according to game rules, while the agent is put in a "Watch and learn"-mode) or by responding to multiple-choice questions from the agent that relate to particular tasks as they appear in the game. Proper (or improper) moves and answers will promote corresponding skills in the agent, which can then be set to make moves or play a session of the game on its own.

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Currently, we are working on expanding the math game for a somewhat older target group, 12-14 years. One of the main extensions consists of a module for allowing free (not multiple-choice-steered) written conversation between the student and the TA. We make a primary distinction between *on-task* dialogue, which is constrained by the present math tasks and takes a multiple-choice format, and the *off-task* dialogue, which takes the form of a chat window open to freer conversation with the agent. The off-task dialogue content, in turn, can be distinguished into *on-domain* conversation related to school, math, the math game, etc., and *off-domain* conversation, related to any other topics. These distinctions are important for our design considerations, when it comes to evaluating the pedagogical function of the social chat and optimizing its learning-promoting qualities.

From a theoretical perspective, we state two rationales for adding this novel and freer conversational module, grounded on the Enhancing Agent-Learner Interaction (EnALI) framework [10], which formulates scientific guidelines for user interaction, message, and agent characteristics design. First, by providing means for the student to bring up basically any topic for discussion, we open up a social dimension in the virtual environment which makes a natural part of traditional educational settings and affects the motivational qualities of the game. Second, this allows a broader exploration of whether such a conversational module enables additional pedagogical interventions, such as means for supporting students' math self-efficacy and attitudes towards math as a school subject. Whilst offering great potentials for education, these extensions pose specific challenges to the pedagogical and game-play design. In the next session, we highlight three such challenges and address them in terms of our design decisions.

2 Challenges and design decisions

Challenge 1: The inherent difficulty and complexity to design an agent that appears to be an expert on its domain of interest (e.g., mathematics), and the students' negative reactions and feelings when expectations of agent expertise are not met. To establish credibility and trustworthiness, it is crucial that the agent meets user expectations, answering questions promptly and adequately. Setting expectations that the agent does not meet (e.g. with regard to its intelligence) risks generating frustration and disappointment in students [5, 10]. In line with the EnALI framework, messages should be complete and specific, and appropriate to the receiver's abilities, experiences and frame of reference. In our implementations, we utilize the "*teachable"* role of the agent. This means that its message should not portray the agent as an expert in math or playing the game. Besides, in our project, the fact that the agent is a fictitious character allows us to handle a number of issues that may be problematic in traditional student-agent conversations, such as topics relating to family, gender, and life history. To base decisions on dialogue management of topics unrelated to mathematics (i.e. off-task content) that the agent displays knowledge about, we include end-users in extensive pilot-testing during the design and development process.

Challenge 2: The appeal of off-domain agent-learner conversation. That learners focus almost exclusively on *off-domain conversation* with the agent may happen as a result of (a) the on-domain conversation being disappointing and/or (b) the students finding off-domain conversation much more interesting, even to the point where they are strongly immersed in this conversation and forego the learning task [9]. We address this challenge through the off-task dialogue strategy used by the agent. By introducing a more sophisticated mixed-initiative dialogue strategy than in traditional chat-based architectures, the agent can steer away from long off-domain conversations and reintroduce the learning task. Importantly, a *fluid transition between on-task and off-task conversations* is reached for by enabling the agent to suggest on-task topics that relate to the ensuing off-task conversation.

Challenge 3: Abusive student comments. A third challenge relates to avoiding conversations where students abuse the agents [3, 4]. This challenge has been addressed by enabling the agent to give very neutral responses following the user's verbal abuses. In contrast to previous studies [11], where the agent unsuccessfully responded to abuse by lecturing the user on foul language or acting submissively, in our approach the agent notes that it is not interested in certain topics and will not comment it, while attempting not to be provocative. In addition, it was hypothesized that visual appearance plays a role in managing user-agent interactions, where important design decisions concern iconization in terms of agent appearance [6, 7].

In sum, we have aimed to describe and exemplify specific design and research considerations in developing efficient and engaging pedagogical agents that not only capitalize on technological advancements but are also sensitive to cognitive, emotional, and social aspects while valuing and maintaining ecological validity in the educational context.

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