Towards using pedagogical agents to orchestrate collaborative learning activities combining music and mathematics in K-12

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Abstract

Research on pedagogical agents (PAs) focuses on personalizing and adapting content and instruction to students' diverse needs to support learning. Teachers can use this technology to support individual students' work. However, it is not clear what could be the impact of a PA that helps teachers to orchestrate collaborative learning activities on the classroom level. Our work explores two dimensions. Firstly, the effects of employing a PA in a technology-enhanced learning setting to promote students' motivation and learning outcomes. To that end, we will conduct a series of studies employing various methods and data (tests, questionnaires, observations, and students' performance data). Secondly, this work aims to develop a design framework based on teachers' expectations and needs when using a PA to orchestrate collaborative learning tasks. To build the PA design framework, we will conduct a study to categorize teachers' PA expectations and needs, accompanied with findings from the literature. Our hypothesis is that classrooms, where the PA is used to support teachers in the learning activity, will demonstrate high learning gains and students' perceived motivation.

Keywords

Pedagogical agent, collaboration, class orchestration, music and mathematics.

1. Introduction

1.1. Pedagogical agents

Pedagogical agents (PAs) are lifelike virtual characters playing an educational role, aiming to facilitate learning in digital learning environments (DLE) [1]. For instance, PAs facilitate learning by providing students with scaffolding [2] and guidance [3]. PAs can be combined with the support of various forms, such as text, voice, 2D or 3D character, and human-like appearance [4]. The roles PAs can play in the DLE, may include tutor [5], expert, mentor, motivator [6] student [7] Depending on the PA system, the behaviour of the agent can support cognitive, metacognitive [2] motivational, or social [8] aspects of learning.

Integrating PAs in learning digital systems goes in line with social learning theory [9]. The main premise of this theory is that learning is a social contextualized process, thus, in digital learning systems, PAs serve as a social entity that can simulate real-life interactions, such as role modelling. However, reviews discuss mixed evidence on the benefits PAs can have on learning [1, 10]. For instance, Schroeder et al. [10] meta-analysis reported a small but statistically significant ($g = .19$, $p < .001$) learning effect in favor for agent-based systems. They found this effect to be prominent in K-12 education and discussed that motivational benefits may be related to this

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positive result. Kim & Baylor [6] suggests that a single agent design or behaviour can't fit all students' needs. Therefore, they stress the importance of designing the PA with the appropriate persona and media features to adequately support every student's learning process.

Literature shows that PAs can contribute to the motivation of students at an individual level [8]. Our research interest is whether a PA that targets the classroom as a whole, would have a similar impact on students' motivation, thus, better learning outcomes.

1.2. Collaboration and technology

Dillenbourg [11] defines collaborative learning as the situation in which two or more people learn or attempt to learn something together. The research field that explores how technology impacts and can promote collaboration is computer supported collaborative learning. Stahl et al. [12] have defined this as the field to study how learning can be scaffolding in computer-supported collaboration scenarios. We first need to contextualize the collaborative learning scenario to design appropriate scaffolding towards the reinforcement of domain knowledge acquisition and collaboration. To that end, we will build on a technology-enhanced method that combines music and mathematics in collaborative learning tasks [13]. In this case technology is used both on the individual and classroom level.

1.3. Music and mathematics

According to Tobias [14], teaching and learning experiences that are not based on a traditional mathematics curriculum can bridge the achievement gap and reduce mathematical anxiety. To that end, we argue that combining mathematics with music may potentially help to bridge the achievement gap and reduce anxiety. However, it is not evident what pedagogical strategies need to be considered to ensure this successful combination. For instance, Vaughn [15] found that there was a positive association between the voluntary study of music and mathematical achievement. It is important to note that in Vaughn's study, the academic and learning activities did not occur in the same learning space. Conversely, when arts are used as a vehicle for teaching mathematics in the same session instead of a different parallel activity, it contributes positively to learning outcomes as it helps to: (i) promote communication among students; (ii) transform learning environments; (iii) reach students that otherwise may not be reachable; (iv) offer new challenges to successful students; (v) decrease curricula fragmentation; (vi) connect in-school learning with real-world, among others [16] [17]. This was also confirmed by a study from An et al. [18] which demonstrated that integrated music and math lessons have a positive impact on multiple mathematical abilities.

1.4. Classroom orchestration and technology

PAs are typically used to support students on the individual level, while it is not clear how a PA can be used in the classroom as a teacher's support in classroom orchestration. Dillenbourg [19] defined classroom orchestration as a teacher's ability to manage, in real-time, the activities and contextual constraints inherent to the learning session. This managerial instance encompasses the nature of the activity (for example, individual, teamwork, class-wide), the pedagogical tools (such as simulations, wikis, quizzes), and the distribution channels (for example laptops, tablets, smartPhones). Conversely – and complementary – to instructional design and adaptive learning, classroom orchestration deals with extrinsic activities (moving chairs, collecting papers, checking on students' activity status, student log-in problems) and extrinsic constraints (discipline, limited lesson time, energy management, classroom physical space) [19]. Regarding the technological aspects, related work has explored teachers' needs for educational technologies. For example, Holstein et al. [20] showed that teachers expressed their wish to be able to see students thinking process and being able to adopt system-like features like monitoring all students at the same time. Furthermore, another case study by Chounta et al. [21] showed that teachers would like to receive support to be more efficient and effective in their practice. The authors convey the message that systems including artificial intelligent techniques, could address such teachers' needs. Amarasinghe et al. [22], presented the notion of orchestration agents, which can help teachers by suggesting orchestration actions, thus offloading decision-making responsibilities whilst respecting their agency. They referred to the latter scenario as a hybrid human-machine approach. Our work expands on what teachers expect from a PA (in the form of a 2D character) helping them at a classroom level and exploring the impact of a hybrid system solution for K-12 education.

For our PA system, we envision the agent helping teachers with the activities as well as orchestration decisions. One example of an activity employed at a classroom level can be found in Chin et al. [23]. In this case, the feature allowed the teacher to show on a projected screen students' teachable agents with the aim to discuss on agents' different answers, hence, students understanding. Additionally, we are taking inspiration from existing PA systems targeting mathematics [2] [8]. However, our approach is different from the aforementioned studies in that the learning activities combine music and mathematics as means to motivate and support students' conceptual and procedural knowledge understanding.

1.5. Research questions

To understand how PA technology could support social dimensions on the classroom level rather than the individual level, we further investigate when and how a PA can help teachers in collaborative learning activity while motivating students to learn and be engaged in the task. To that end, the PA will be used in the classroom by integrating a virtual character to assist the teacher. We are interested to see whether employing a PA in the classroom makes a difference in terms of learning outcomes and contribute to students' motivation in the collaborative activity. In this study, we examine the following research questions (RQs):

[RQ1] Which kind of interventions and affordances do the current PA systems in K-12 education have for teachers at a classroom level?
[RQ2] What do teachers expect and need from a PA helping them to instruct and orchestrate collaborative learning activities?
[RQ3] What is the impact, in terms of learning gains and motivation, when employing a PA hybrid system at a classroom level?
[RQ4] What benefits, challenges, and constraints can be seen when employing a PA at a classroom level?

2. Methodology outline

In this study, we have selected a mixed-method approach. In terms of qualitative research, we will conduct a literature review and a case study to develop the design framework for our PA. In terms of quantitative research, we will conduct a series of studies to report on the learning outcomes and perceived students' motivation via tests and questionnaires. We elaborate more on the planned studies in the next sections.

2.1. Participants

For the case study, we plan to carry out focus groups with teachers (n = 5 to 7) to understand their expectations and needs when using a PA as orchestration support at a classroom level. The target population are mathematics teachers from primary education. For the pilot study, we will test the PA in one elementary classroom (n = 15-30 students). This will allow us to modify and adjust the PA system as well as our planned measuring instruments. Finally for the main study, we will employ the PA system in elementary classrooms (n = (4 to 8) including experimental and control groups) to evaluate the PA design framework based on teachers' insights, and to evaluate students' (100-200) learning gains and perceived motivation.

2.2. Materials

Pedagogical Agent and learning activities. For the PA system, we are using a face tracking solution, the agent can emulate gestures, eye blinking, lip-synching to a sound source, and head swing. Additionally, by key commands, the agent can walk, run, wave, point out, and trigger special moves (i.e., thinking pose, wearing glasses, eating a banana). On the other hand, for the learning activities, we want to build on prior research done with an educational game that combines music and mathematics in the format of a board game and a digital version. In the case of the board-game format, two elementary schools in Belgrade, Serbia, played the game for two sessions. Students were randomly assigned to play in small groups and to answer questionnaires targeting their learning experience. The results showed that the educational game supported their cognitive development while boosting their motivation and desire to have success on the learning tasks [24]. Building on the latter study, we used the digital version of the game and focused on group formation strategies and learning outcomes [13]. Using students' prior knowledge (as assessed by pre-knowledge tests), authors formed homogeneous (high or low performers only) and heterogeneous (high and low performers mixed together) groups and explored whether their game performance would be reflected on students' learning gains. Conversely to related research [25], the aforementioned study reported students belonging to heterogeneous condition to benefit less than homogeneous groups in terms of learning gains. However, this was not the case for the game score, where HE groups outperformed HO groups playing the game [13]. This article is particularly relevant because we are considering the authors' suggestions to better align the educational game with the learning goals and to enhance the collaboration activities.

Instruments. Furtermore, we will create an interview protocol and we will carry out teachers' focus groups. The aim is to develop a design framework based on their expectations and needs when collaborating and employing a pedagogical agent in the classroom. Regarding the students, they will be asked to answer a questionnaire (still to be defined) targeting motivation, from which we will analyze and report on PA effects and design challenges. Finally, we will use students' data to find a possible correlation between their perceived motivation and their learning outcomes (pre-post tests evaluation).

2.3. Study design and procedure

In the following figure (Figure 1) we present and describe the aim of the planned studies and timeline. We link each study to our research questions.

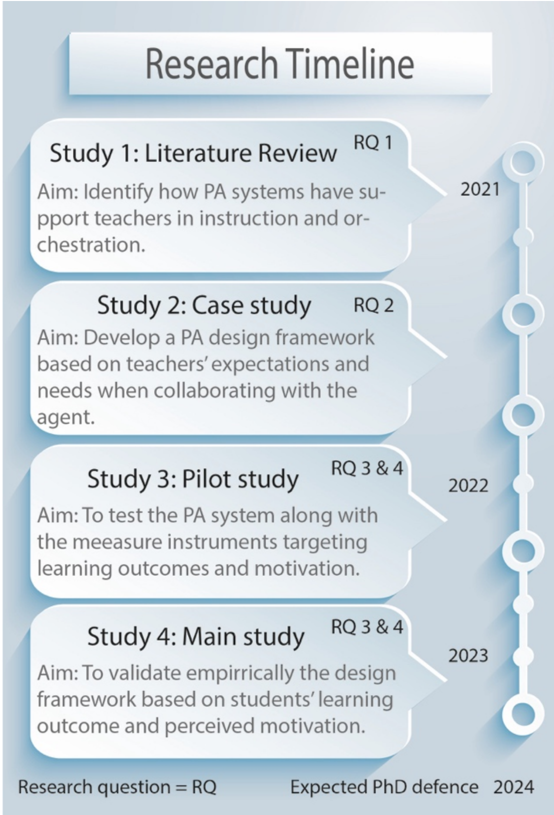

Figure 1: Research timeline and plan.

We will adapt collaborative learning activities with and without the PA (independent variable), as they will serve as the educational context of the experiments. We will divide half of the participating school groups of students into experimental condition (with PA) and control group (without PA). Our dependent variables are, on one hand, students' performance (as assessed by pre and post knowledge tests) along with their perceived motivation when working with or without the agent (questionnaires); and on the other hand, teachers' evaluation of the PA when facilitating the orchestration of the collaborative tasks.

We hypothesize that the experimental group will benefit more from having a PA helping the teacher to orchestrate the collaborative learning activity. The benefits will be reflected in terms of students' learning outcomes and motivation. On the other hand, we expect teachers to evaluate the PA system in the expected dimensions we will be able to find after concluding the case study with them.

3. Progress so far

We are currently in the process of conducting a systematic literature review (SLR) considering all types of PAs addressing mathematics education in K-12 education. The aim is to identify all pedagogical affordances these systems offer teachers when PAs are used on a classroom level. We envision the findings of the latter will support us in designing and proposing a theoretical framework for teachers' interventions in PA systems, and to classify PA systems affordances when using them on the classroom level for supporting instruction and orchestration activities. In parallel, we are in the process of conducting focus groups to understand teachers' expectations and needs when having a PA helping them to orchestrate collaborative activities in the classroom. From both, the SLR and the case study, we aim to have the pedagogical and orchestral design requirements to be met by the PA.

Technology wise, currently, we are performing tests with the PA system in real-time in remote teaching settings (video conferencing platforms) and classrooms settings by using projection. The aim is to test and adjust PA social cues, signals, reactions [26], and social fidelity contributors (i.e., personalization, slang, politeness, enthusiasm, interactivity) [27].

4. Theoretical and practical contributions

We envision that this research will contribute to the field of PA by bringing teachers' perspectives and needs when having the agent in a classroom collaborative setting. Moreover, by using PA systems technology at a classroom level, it could create a bond between the agent and student that could impact learning outcomes. Finally, this study will report on an innovative technology-enhanced learning scenario, and future research could potentially expand on the psychological, collaborative, and social effects this technology may bring for both teachers and students.

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