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Towards the Development of PIA 2.0: A Pedagogical Agent that Exhibits Synthetic Facial Expressions

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Abstract: This study reported the design and development of the initial prototype of a web-based virtual learning environment with a pedagogical agent. The pedagogical agent, named PIA 2.0 (subsequently referred to as PIA), exhibited synthetic facial expressions and body gestures. It could also provide textual feedback, hints, and encouragement messages. Grade 8, 9, and 10 students (n = 30) utilized the initial prototype of PIA. The interactions within the software were collected and analyzed through descriptive statistics and lag sequential analysis. It was revealed that students were engaged in the intervention and had a high probability of solving mathematics problems they were comfortable with, with a very small probability of changing the level of difficulty. These results were utilized to add a feature to PIA by recommending mathematics problems to be solved. The commercialization aspect of the software was also discussed. Conclusions and future research directions were provided.

Keywords: emotions, learning analytics, mathematics learning, mathematics performance, pedagogical agent

1. Introduction

Pedagogical agents (PA) are human-like characters that provide students assistance in a virtual learning environment (Veletsianos & Russel, 2013). It has already been established that PAs have a positive influence on academic performance (Davis, 2018; Martha & Santoso, 2019). A PA can exhibit synthetic facial expressions (SFEs), bodily gestures, hints, and textual feedback. SFEs are cartoon facial expressions of a pedagogical agent (Bringula et al., 2018, 2020). These cartoon facial expressions may exhibit emotions such as happiness, surprise, contempt, sadness, fear, disgust, and anger. It has been found that SFEs of a pedagogical agent (PA) are beneficial to learning (Bringula et al., 2018). For example, it was found that students who utilized a PA that exhibited different SFEs had better mathematics performance than their counterparts who utilized a PA that only exhibited a neutral SFE (Bringula et al., 2018).

However, it is still unclear if a PA with SFEs can induce persistence in solving mathematics problems. Persistence is defined as an individual's dedicated effort to achieve a goal despite encountering disruptions and interferences (Howard & Crayne, 2019). Not only does it reinforce them with emotional discernment and management, but it also makes it easier to set and achieve goals, cultivate empathy, form close relationships, make wise decisions, and improve academic performance (Baczko-Bombi, 2017; Rittle-Johnson, 2017).

Given the importance of persistence, it is imperative to understand this construct in the context of a virtual learning environment (VLE) with a PA exhibiting SFEs. To address this gap in the literature, a VLE with a PA named PIA was developed. The features of PIA included the ability to exhibit SFEs, provide textual feedback, display body gestures, and offer words of encouragement. This study reported the design and development of an initial prototype of PIA. It also reported the results of the initial data collection that served as a basis for the improvement of PIA. In addition to its technical aspects, this paper discussed the commercialization potential of the developed software.

2. Methodology

The study used an agile model and Kanban framework to develop the PIA with SFEs. The front-end design utilized React.js and TailwindCSS, while the backend was built with JavaScript, PHP, and MySQL. This preliminary study took place in one school in Manila. The findings of this initial investigation served as the basis for when the Personal Instructional Agent (PIA) would intervene. The intervention included providing body gestures, hints, words of encouragement, and suggestions to move up to the next difficulty level. Thirty students participated: 12 in Grade 8, 8 in Grade 9, and 10 in Grade 10, with an average age of 14.6 years; 60% were male.

Data was collected over three days, with 30-minute sessions as students used the software during classes. Student interactions in the VLE were collected, including solved and unsolved problems, displayed hints, difficulty levels, and time spent. Mean (M) and standard deviation (SD) were utilized to describe the data. Lag Sequential Analysis (LSA) determined transition probabilities between difficulty levels. These results guided the intervention timing of the Personal Agent (PA).

3. Results and Discussion

The VLE was designed to enhance students' persistence and mathematics performance in learning algebraic linear equations. The VLE is a web-based system that can be accessed at this link: https://pia-sfe.online/. The software has three main components: student, teacher, and administrator modules. This paper will only focus on discussing the student module. Within the student module, there is the PIA that displays SFE, body gestures, hints, textual feedback, and encouragement messages (Figure 1). PIA displays SFEs like neutral, happy, surprised, sad, and angry based on user inputs. It can also provide hints on solving mathematics problems. Additionally, it may offer options such as abandoning questions or leveling up/down recommendations.

The neutral SFE is the default facial expression of PIA. A happy SFE is displayed when a student gets a correct solution, whereas a sad expression is displayed when a student inputs a wrong solution. PIA displays a surprised expression, and the response color turns red when the student gets two correct answers followed suddenly by one incorrect answer. If the student inputs two consecutive answers that do not match the variables given, PIA displays an angry expression. The student's behavior is construed as gaming the system (i.e., inputting random characters); hence, a reprimand is given by the PIA. This feature was not present in the previous study by Bringula et al. (2018, 2020).

Students solved almost 28 problems (SD = 8.5) within the whole intervention period and rarely abandoned problems. This implies that students were engaged in the intervention since the class only ran for 30 minutes. It was also disclosed that they used the hints judiciously. As expected, the number of problems solved decreases as the levels become more challenging. This finding is consistent with the previous works of Bringula and colleagues (2020, 2023).

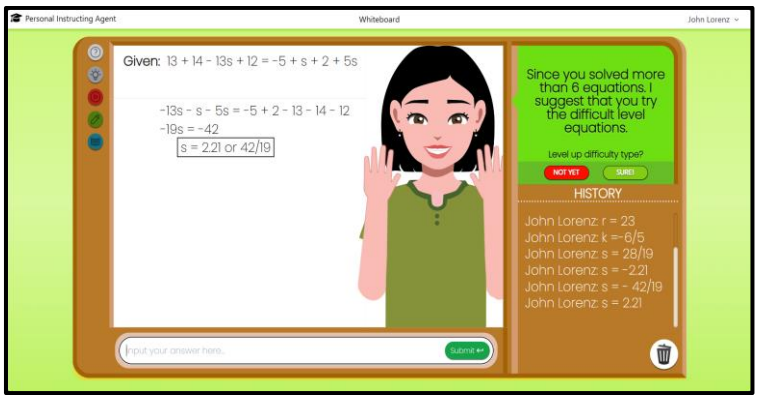

Figure 1. PIA's Interface

LSA results showed that students tend to stick to the problems they are comfortable with, resulting in both over-practice and under-practice (Easy→Easy = 94%; Average→Average = 95%; Difficult→Difficult = 93%). This is consistent with the previous findings of the study of Bringula and colleagues (2020, 2023). The results of the LSA warrant the need for the PIA to recommend leveling up the difficulty level for the students. The average number of problems solved at each difficulty level (Easy, M = 14.7, SD = 5.6; Average, M = 6.4, SD = 2.7; Difficult, M = 5.9, SD = 6.0) served as the thresholds. For example, if a student correctly solves more than six problems at the average level, PIA will recommend that the student move to the next difficulty level (Figure 1).

The commercialization aspect of this software operates through a subscription-based model. The free version of PIA includes neutral SFEs and unlimited access to easy mathematics problems. The full version incurs a monthly PHP20 (~ US$ 0.40) subscription fee, which can be canceled at any time. In this version, students gain access to unlimited average and difficult mathematics problems, and PIA will exhibit the full range of SFEs and motivational elements.

4. Conclusions and Future Works

This study reported the design, development, and initial use of a VLE with the PIA. Initial data showed student engagement and a tendency to stick with familiar problems. These interactions guided PIA's intervention, encouraging students to tackle more challenging problems. Thus, the software was successfully developed based on these initial findings. A future study will be conducted to determine if the software can reinforce persistence within this environment. It is also intended to be deployed with another set of participants to determine if PIA can influence students' abilities to solve mathematics problems. Moreover, it is planned to assess the usability of the VLE in terms of functionality, ease of use, usefulness, and satisfaction of use. This assessment will help in continuously improving the software.

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