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Integrating cluster and sequential analysis to explore learners' flow and behavioral patterns in a simulation game with situated-learning context for science courses: A video-based process exploration

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ABSTRACT

Much emphasis has been placed on the research on applying digital games in science education. Among the studies, the advantages and limitations of role-playing simulation games deserve further exploration. However, existing analyses of the behavioral patterns of role-playing simulation games in science education remain substantially lacking, particularly the integration of diverse behavioral pattern analysis methods. This study thus seeks to analyze the videotaped learning process of 86 college students in game-based learning activities that utilize a role-playing simulation game. This study used the integrated method of sequential analysis and cluster analysis and explored the learners' flow state and learning behavioral patterns. The results show that the use of integrated behavioral pattern analysis helps to explore the traits and limitations of role-playing simulation games in science education as well as learners' reflective behavior patterns.

This study identifies a wide variety of learning behavior patterns from three potential clusters of learners and then discusses the learning process of each cluster. The different levels of flow experienced by the learners affected their learning behavior patterns; learners with higher levels of flow demonstrated a more in-depth reflective process. The study further discusses the results of these analyses and makes relevant recommendations for the systems development of the games, its educational applications, and evaluation methods.

1. Introduction

1.1. The application of simulation games with situated-learning context in science courses

Play is an important human behavior; many studies in the fields of philosophy and psychology have emphasized the importance of play in human life (Bruner, 1972; Gross, 1901; Millar, 1968; Patrick, 1916; Schiller, 1954; Sutton-Smith, 1967; Vygotsky, 1967). Prensky (2007) suggested diverse advantages and features of digital game-based learning (DGBL) that include entertainment, regularity, objectives, human–computer interaction, feedback, problem-solving abilities, interactivity, and scenarios, all of which may enhance the learning process. Presently, DGBL has gained the attention of educational technology researchers, and a considerable number of studies have identified positive effects and the value of DGBL (Amory & Seagram, 2003; Annetta, 2010; Annetta, Minogu, Holmes, & Cheng, 2009; Hou, 2012; Kiili, 2005; Kiili, 2007; Kim, Park, & Baek, 2009).

To facilitate the construction of procedural knowledge (such as experimental procedures in chemistry) for learners in science courses, laboratory teaching with experiment manipulations has been commonly employed. However, the factors of cost, time, and space in laboratory teaching may limit the number of times the learners can enter the lab and thus the frequency of manipulation (e.g., Limniou, Papadopoulos, & Whitehead, 2009; Mitchell & Savill-Smith, 2004). Thus, to help learners conduct science experiment activities and understand scientific knowledge after physical manipulation, technology-supported instruction in science procedural knowledge has gradually gained prominence (Akpinar & Bal, 2006; Liu & Su, 2011; Pol, Harskamp, & Suhre, 2005; Yang, & Heh, 2007). Studies have also observed that applications of educational technology enhance learners' ability to explore and plan and enhance their procedural knowledge in laboratory learning (Pol, Harskamp, Suhre, & Goedhart, 2008; Pol et al., 2005). With the aid of technology, multimedia-supported demonstrations or

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realistic problem-solving scenarios can lead learners to problem solving and metacognitive processes connecting prior knowledge and reflection, all of which are essential in science education (e.g., Driver, Guesne, & Tiberghien, 1985; Ormrod, 1998; Posner, Strike, Hewson, & Gerzog, 1982; Vosniadou, 2001).

Among many educational technology tools, simulation software is able to provide users with secure manipulations and more practice opportunities because of its appropriate simplification of the realistic context (Alessi & Trollip, 2001). Simulation software should promote the learning and reflection of procedural knowledge. Rutten, van Joolingen, & van der Veen (2012) also observed a positive effect of simulation software on learning performance in science teaching. Many studies have applied simulation software in science teaching such as physical experiments (Pol et al., 2005; Pol et al., 2008; Yang & Heh, 2007), molecular dynamics (Stern, Barnea, & Shauli, 2008), and electronics (Liu & Su, 2011) and observed the effects of simulation software to be positive. Studies also discovered that the manipulation of simulation software enhances the understanding of scientific knowledge (Zacharia & Olympiou, 2011; Zacharia, Olympiou, & Papaevripidou, 2008). Challenging and entertaining scenarios that are integrated into simulation software may enhance learners' motivation and avoid the boredom caused by learners' repeated manipulation in traditional simulation software in virtual laboratories. Therefore, integrating game mechanisms into educational simulation software to develop educational simulation games (e.g., Barab et al., 2009; Hou & Chou, 2011; Hou & Li, 2014) should be beneficial to laboratory teaching. In addition, previous studies have suggested that games in science education should contain learning strategies that promote metacognition (Anderson & Barnett, 2013). Li and Tsai (2013) observed that most existing studies have focused on utilizing games to promote the learning of scientific knowledge and scientific concepts and only a handful have aimed at software application to elevate students' problem-solving skills. Simulation games can combine appropriate story scenarios so that learners can be more involved in the problem-solving tasks of the game by repeatedly performing manipulation in the experiments and reflecting, thus achieving the effectiveness of metacognition. Therefore, simulation games that combine story scenarios and backed by situated learning theory (Brown, Collins, & Duguid, 1989) may promote learners' motivation and learning transfer in a subsequent realistic context.

Situated learning theory emphasizes the connection between knowledge and situation (Brown et al., 1989). In a game with situated learning context, players may explore and learn by means of the simulated stories and roles in the tasks of the game. Pantidos, Spathi, and Vitoratos (2001), who applied situated learning activities and role-playing tasks in science teaching, found that these activities helped students become familiar with the contents of a physics curriculum with better understandings. Such a teaching approach promotes learners' motivation and decision-making ability when they encounter events in the real world (Bos & Shami, 2006; Pata, Lehtinen, & Sarapuu, 2006; Wishart, Oades, & Morris, 2007), leading to learning transfer. By establishing a real-life-oriented scenario, players can face the challenges in the game, explore game stories, and collect cues and materials while conducting simulation manipulations in the experiment to complete mission objectives. Previous studies have showed that games with situated scenarios advanced students' learning in scientific knowledge (Barab et al., 2009). Although the evaluations and analyses of learning process on general educational games and simulation software have been studied (Barab et al., 2009; Liu, Cheng, & Huang, 2011), in-depth analyses of behavioral patterns in simulation games in science education that combine situated scenarios remain inadequate.

Moreover, applying a multi-approach behavior pattern analysis may enable advance triangulation of the results of learning processes and behavior pattern analysis. Compared to single-method analyses, such an analytical method can explain in-depth "why" or "how" simulation games promote learning while exploring the limitations of the game design. Therefore, this study seeks to explore in-depth learners' behavioral patterns in a simulation game with situated-learning context in science education.

1.2. Multi-approach pattern analysis on flow and learning behavior in simulation games with situated-learning context

Compared to players of popular casual games, players of educational simulation games perform complex procedural knowledge-related operations; thus, greater focus and involvement in the game and its learning content during the gaming process are required. Flow refers to a person's mental state when he is fully immersed in an activity and filtering out irrelevant emotions (Csikszentmihalyi, 1975). Flow and the intrinsic motivation of the activity participants are highly correlated (Moneta, 2012), which helps to reflect learners' intensity of motivation and focus on educational games. During educational gaming, the relation between learners' motivation, focus and learning behaviors is a significant issue worthy of exploration; furthermore, flow also serves as an important indicator of game-based learning (Bressler & Bodzin, 2013). Therefore, understanding the relation between flow and learning behaviors will facilitate the design of educational simulation games that elevate students' motivation and allow them to acquire greater procedural knowledge.

Recent research on game-based learning has been devoted to learners' flow experience, including research on learners' flow state and the association between learners' flow, acceptance and learning effectiveness (Hou & Li, 2014). Some studies indicate that the challenge and clarity of the objectives of a game have a significant effect on learners' flow experience (Hou & Li, 2014; Wang & Chen, 2010). Liu et al. (2011) observed that students participating in digital simulation games are more prone to flow state than those engaged in traditional methods of learning; studies also note that the players' flow state and their fidelity to the game are positively correlated (Faiola, Newlon, Pfaff, & Smyslova, 2013). In game-based learning, the manifestation of flow is closely related to the players' prior knowledge and the game's interactive mechanisms (Admiraal, Huizenga, Akkerman, & ten Dam, 2011; Hwang, Hong, Hao, & Jong, 2011). Liu et al. (2011) further explored the correlation between learners' flow experience in simulation software operations and problem-solving strategies. However, sufficient studies have not yet been conducted exploring the behavioral pattern analysis of the application of simulation games with situated-learning context in science education. Compared to conventional learning performance assessment and self-report questionnaires, behavioral pattern analysis can conduct a more in-depth exploration of manipulation learning processes in scientific experiments. Presently, analyses on learning performance, acceptance, and flow in simulation games with situated-learning context are available (Hou & Chou, 2012; Hou & Li, 2014) but lack a detailed examination of these behavioral patterns. Therefore, this study utilizes a multi-approach analysis for in-depth results.

Simulation games with situated-learning context require both story scenarios and virtual manipulations; therefore, a wide range of analyses of players' behavioral patterns such as observation, exploration, analysis, and experimental manipulation should be conducted simultaneously in this study. Moreover, the latent learning behavioral patterns of learners with different degrees of flow should also be examined. By applying cluster analysis (e.g., Hou, 2012; Hou & Li, 2014), the potential cluster patterns of learners' various behaviors can be explored (for example, by analyzing