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Modeling how incoming knowledge, persistence, affective states, and in-game progress influence student learning from an educational game

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ABSTRACT

This study investigated the relationships among incoming knowledge, persistence, affective states, in-game progress, and consequently learning outcomes for students using the game Physics Playground. We used structural equation modeling to examine these relations. We tested three models, obtaining a model with good fit to the data. We found evidence that both the pretest and the in-game measure of student performance significantly predicted learning outcome, while the in-game measure of performance was predicted by pretest data, frustration, and engaged concentration. Moreover, we found evidence for two indirect paths from engaged concentration and frustration to learning, via the in-game progress measure. We discuss the importance of these findings, and consider viable next steps concerning the design of effective learning supports within game environments.

1. Introduction

Good teachers are keenly aware that students differ along a number of important dimensions which can influence learning. The process of learning new knowledge and skills can trigger a range of emotional responses, wide variation in students' behaviors, and consequently varying learning outcomes. While one teacher cannot manage all of these individual differences in a typical classroom setting, some educational games are beginning to model—with the goal to support—such variation (e.g., Conati & Maclaren, 2009). The main goal of these adaptive educational games is to create an engaging and flexible environment that supports learning for a broad range of learners. Accomplishing this goal depends largely on accurately measuring relevant learner characteristics, such as the type and level of knowledge, skills, personality traits, as well as dynamic cognitive and affective states —and then determining how to leverage the information to improve student learning (Conati, 2002; Park & Lee, 2004; Shute & Zapata-Rivera, 2012; Shute, Lajoie, & Gluck, 2000; Snow, 1994). An additional challenge involves doing all this within the context of a game without disrupting flow (Csikszentmihalyi, 1990), which is often experienced while interacting with a well-designed game.

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This paper describes the results from a multi-method study, which assessed learners along multiple dimensions, including field observations of student affect, measures of persistence and gameplay, and learning (i.e., conceptual physics understanding), within an educational game called Physics Playground (see Shute & Ventura, 2013). The primary aim of our research is to establish the ways that specific affective states (e.g., frustration, confusion boredom, and engaged concentration), persistence, and in-game performance collectively influence learning. We use a structural equation modeling framework to investigate how these factors interact to influence each other and ultimately learning. While individual pairs of these measures have previously been researched, this paper represents – to the best of our knowledge – the first attempt to integrate all of these factors into a comprehensive model.

We chose to use an educational game for our assessment and learning environment for several reasons. Educational games have emerged as a genre of technology that has particularly high potential for creating rich and engaging learning experiences that capture students' enthusiasm and promote meaningful learning (see Clark, Tanner-Smith, & Killingsworth, 2014 for a recent meta-analysis). That is, core features of well-designed games (e.g., problem solving, adaptive challenges, and ongoing feedback) can engender motivation, which in turn supports engagement and learning (e.g., Shute, Rieber, & Van Eck, 2011). In addition, adaptive challenges and dynamic performance feedback in a game help to create an environment that can foster the sense of flow (Csikszentmihalyi, 1990) and potentially cultivate the growth mindset that engenders effort-driven, challenge-centered competency development (Dweck, 2006; Yeager & Dweck, 2012). These same good-game features can also potentially influence persistence (or "learned industriousness," see Eisenberger, 1992) where individuals who are required to exert high effort in one task will continue to exert high effort in a subsequent task (Shute, Ventura, & Ke, 2015). Finally, games allow us to use performance-based assessments of constructs like persistence and engagement which can be more authentic and valid than their self-report measure counterparts (Duckworth & Yeager, 2015; Ventura & Shute, 2013).

Well-designed games can also promote meaningful affective experiences for students, which is important given the inevitable role that affect plays during learning (e.g., Calvo & D'Mello, 2011; Kim & Pekrun, 2014). This is particularly important because affect can indirectly influence learning outcomes by modulating cognitive processes in significant ways (see Fiedler & Beier, 2014). Positive affective states such as delight, excitement, and eureka are experienced when tasks are completed, challenges are conquered, insights are unveiled, and major discoveries are made via creative exploration and problem solving. However, not all affective states experienced in good games are necessarily positively experienced. For example, students get confused when outcomes do not match expectations, when they encounter challenging impasses, and when they are unsure about how to proceed (e.g., Andres et al., 2014; D'Mello & Graesser, 2014a). Frustration occurs when students make mistakes, get stuck, or when important goals are blocked (Kapoor, Burleson, & Picard, 2007). Gee has noted that frustration is a characteristic aspect of many games, even highly successful games; though in a game context, even frustration can be part of a challenging and enjoyable overall experience (Gee, 2007).

Mild levels of confusion and frustration are important parts of the effortful problem solving needed to successfully surmount challenges and learn (D'Mello & Graesser, 2014b). However, intense or prolonged confusion and frustration can lead to anxiety and possibly despair (Zeidner, 2007). When this occurs, students are at risk of becoming disinterested and disillusioned which can lead to boredom and eventual disengagement (D'Mello & Graesser, 2012; Pekrun, Goetz, Daniels, Stupnisky, & Perry, 2010). Instead of engaging deeply in creative exploration, struggling and disengaged students exhibit problematic behaviors such as systematic guessing (Rodrigo et al., 2007) or looking for solutions rather than discovering them (e.g., Aleven, McLaren, Roll, & Koedinger, 2006; Nelson-Legall, 1987). These behaviors associated with boredom—and the negative affect that triggers them (Baker, D'Mello, Rodrigo, & Graesser, 2010)—lead to poorer learning, lower self-efficacy, diminished interest, and increased attrition (Csikszentmihalyi, 1975; Mann & Robinson, 2009; Patrick, Skinner, & Connell, 1993; Perkins & Hill, 1985; San Pedro, Baker, Bowers, & Heffernan, 2013). To prevent this negative spiral, research is needed for developing just-in-time, affect-sensitive interventions that help students persist through the "hard fun" of learning with games without losing the qualities that make games uniquely engaging and effective. An important first step in this research is to understand relationships between affect, in-game progress, and learning outcomes during game-play.

The current study is focused on modeling the relationships among affective states, in-game performance, persistence, and outcome measures of understanding physics principles, within the context of the game Physics Playground. The data we used in this paper were collected while students interacted with the game in their school's computer lab. A unique feature of the research presented here is the use of behavioral and observational measures rather than self-report measures, where possible. That is, surveys were only used for collecting student demographic information, but observational and performance-based measures were used for the other constructs. Recent reports on how the various constructs targeted in this study are currently measured underscore the overreliance on student self-report measures by the education research community (e.g., Atkins-Burnett, Fernández, Akers, Jacobson, & Smither-Wulsin, 2012; Duckworth & Yeager, 2015; Farrington et al., 2012).

Currently, the field finds itself in a loop where self-report data informs theory and program interventions, which use self-report measures to evaluate the program. However, self-report measures for constructs such as persistence (e.g., *I work hard no matter how difficult the task*) have several limitations. First, they are subject to "social desirability effects" that can lead to false reports about behavior, attitudes, and beliefs (Krosnick, 1999; Paulhaus, 1991). This refers to the tendency for people to answer in line with what society or the researchers view as favorable rather than their actual beliefs. This effect can lead to the inflation of scores related to good behaviors and/or the reduction of scores related to bad behaviors in the self-report. Another issue with self-report is that people sometimes have different conceptual understandings of the questions (e.g., what it means to "work hard" as part of a persistence question), leading to low reliability and validity (Lanyon & Goodstein, 1997). Finally, self-report items often require that individuals have explicit knowledge of their skills and dispositions (see, e.g., Schmitt,