Intelligent Adaptation of Digital Game-Based Learning

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ABSTRACT

Games for learning cannot take the same design approach as games when targeting audiences. While players of entertainment games have the luxury of choosing games that suit them, students using digital games for learning typically have a single game for them to learn from, regardless of whether or not it fits their playing style or learning needs. We contend that this problem can be addressed by creating games that identify the kind of player-learner using the game and adapts itself to best fit that individual. These *adaptive games* can specialize themselves according to a student's learning needs, gameplay preferences, and learning style. We present a prototype mini-game, called S.C.R.U.B., which employs this method for teaching microbiology concepts.

Categories and Subject Descriptors

H.5.2 User Interfaces---User-centered design, I.2.1 Applications and Expert Systems---Games, K.3.1 Computer Uses in Education

General Terms

Design, Human Factors, Experimentation

Keywords

User modeling, adaptive games, player types

1. INTRODUCTION

Games for entertainment are voluntary experiences; players choose when, where and what kind of games they are going to play. If a game does not appeal to a player, the player simply avoids playing it. Games for learning, on the other hand, tend to be required as part of a school curriculum or corporate training program. Players of these games have little choice as to what kind of game they will be learning from. Therefore, a single game for learning typically has a much more diverse player audience.

Even within a game for entertainment, designers must balance conflicting interests of different kinds of players. By practical necessity, design decisions often end up focusing more so on the goals of some player types and serving other player types less. For example, Squire and Steinkuehler describe tensions between players with opposing goals when they posted feature requests about how to improve Star Wars Galaxy [1]. Players highly motivated by achievement wanted more pre-set story and clearly stated, fairly enforced standards for advancement. Players who played for the role-play aspects of the game wanted more emergent play and freedom to invent their characters and actions. Typically games have been designed with a one-size fits all approach: everyone plays the same game. Game designers either focus on the interests of particular kinds of players or add features to try to balance sometimes competing player interests.

Games for learning lack the luxury of vast budgets yet must serve everyone in the class, not just interested players. A different approach in game design needs to be taken to match a digital game-based learning experience to player motivations.

Many educational theories classify different types of learners, such as Dunn and Dunn's learning style inventory [2] and Kolb's experiential learning styles [3]. A recent literature review identified 71 distinct learning style models [4]. Some models assume learning style is a fixed personality trait while others view learning style as context-specific state. Motivation is a central correlate to learning. Students who are more motivated are more likely to learn. Successful commercial games attract players because they are fun and engaging. Consequently, a key reason teachers consider using learning games in their classes is in hopes of motivating their students.

Within the very strict bounds of limited time and extensive curricular requirements, K-12 classroom teachers try to present material in different ways to get a particular point across in order to communicate that knowledge to different kinds of learners in the class (e.g. lecture, hands-on problem solving, experimentation, homework, group projects, etc.). Accommodating different learning styles in the classroom is accomplished by having the entire class engage in some activities for each learning type.

A digital game might serve some types of learners very well. Other students will be left behind simply because their learning needs are not met by the particular design of the game being played. However, there is possibly a better approach to digital game-based learning: a single game that can adapt certain features to create a tailored experience for each individual player.

We contend that it is much easier to offer a digital learning game that adapts to individual learner-player motivations than to tailor a classroom experience to meet the specific needs of each of the 20 to 30 individual learners in the class. Digital games have the potential to adapt to individual player-learner needs and interests by connecting game reward mechanics to player motivations and to learning, thereby helping each student have a more optimal learning experience. This paper presents an approach for methodically identifying the possible adaptations a game can take, and mapping those adaptations to learner needs. The paper describes a prototype mini-game, called S.C.R.U.B., which intelligently adapts its gameplay based on an individual player's learning style.

2. RELATED WORK

2.1 Learning Styles

Achievement or goal orientation refers to how individuals perceive and respond to achievement situations [5]. People who have a high achievement motivation enjoy challenges much more than those with a low achievement motivation [6]. Students' motivation to achieve at school can be based on extrinsic goals external to the learning content such as earning good grades or teacher approval. Intrinsic goals internal to the act of learning can also motivate learning, such as the pleasure of mastering a new topic or content being learned, curiosity about the subject matter, or the sense of expertise as knowledge grows. Intrinsic rewards arise from the process of learning or play and extrinsic rewards from results (grades, points, winning, or approval).

Under some circumstances, extrinsic and intrinsic motivations can coexist. In a review of 25 years of research on intrinsic versus extrinsic motivation, Lepper and Henderlong conclude that offering extrinsic rewards reduces intrinsic motivation, particularly if the extrinsic rewards are unrelated to the learning task [7]. However, extrinsic rewards can complement intrinsic motivation when the rewards provide information about competence (such as offering encouraging feedback about positive aspects of player performance) but rewards undermine intrinsic motivation when they serve only to assign status (such as grades or points).

Pursuit of certain kinds of extrinsic rewards can facilitate learning, while other performance goals inhibit learning. Elliot and Church [8] considered two quite different motivations individuals may have for pursuing extrinsic rewards, which they refer to as performance goals. Performance-approach goals involve displaying competence and earning a favorable judgment. Performance-avoiding goals focus on trying to avoid failure. Elliot and Church found positive learning outcomes for both the performance-approach and intrinsic motivation including positive emotions and absorption in the given task. Performance-avoidance prompted efforts to escape potential consequences of failure and was associated with anxiety. Performance-avoidance interfered with mental focus, blocking the individual's ability to concentrate and become absorbed in an activity. Performance-approach goals and intrinsic motivation enhanced mental focus.

Like academic achievement, a player's motivations to do well in a game also may involve intrinsic motivation and performance goals. While teachers seek to motivate learning, commercial game designers seek to motivate play. Learning game designers must motivate both play and learning.

Differing player motivations have implications for game design. Beswick [9, 10] found that intrinsically motivated individuals need time to explore. He explains that intrinsically motivated individuals "tend [to] be more aware of a wide range of phenomena, while giving careful attention to complexities, inconsistencies, novel events and unexpected possibilities. They need time and freedom to make choices, to gather and process information, and have an appreciation of well finished and integrated products, all of which may lead to a greater depth of learning and more creative output" [11]. Players who are intrinsically motivated will notice more detail and need more time to explore. Extrinsically motivated players seek external rewards such as winning and achievement. Games which force all players to hurry or which require them to follow only a single prescribed path are at odds with intrinsically motivated player goals. This has obvious consequences for the design and development of digital games for learning.

2.2 Play Styles and Types

Player type and play style are often used interchangeably. Player type is more often used to describe a persistent trait, whereas play styles treat motivations as a more temporary state, with an implication that players may adopt different play styles in different games or at different times. Player type theories strive to construct categories of game players that represent shared high-level gameplay preferences in order to better understand those groups of players. Richard Bartle was one of first researchers to observe players inside Multi-User Dungeon (MUD) games [12] in order to create a set of player types. He categorizes players into four categories: Achievers, who strive for prestige in the game by leveling up and winning; Explorers, who seeks to understand the game's environment; Socializers, who interacts with other players; Killers, who interferes with other players' experiences (e.g. killing new users, etc.).

Bartle created his player types based on personal observations of game players. Nick Yee's Daedalus Project surveyed thousands of massively multiplayer online (MMO) game players and asked what motivated them to play MMO games [13]. Although the surveys are based on self-reported responses, the resulting information found many confirmations and some contrasts with Bartle's original player types. The three main dimensions of player motivation are: achievement, social and immersion. Achievement-oriented players wish to gain power, understand the rules and compete with one another. Socially motivated players play to form personal relationships, socialize and work together. Finally, players who are motivated by immersion want to role-play, make discoveries within the game, customize their experience and escape from reality. Yee also discovered that these dimensions were not necessarily mutually exclusive. Statistically, the factors were not orthogonal. These findings demonstrate that many different motivations drive MMO players and that game designers might fruitfully incorporate features to appeal to different player motivations.

Player types were initially defined in the context of MUD roleplay games and then in graphical MMO role play games. Learning games are often single player, removing the social dimension found in MMO role play games. Education scholars have observed systematic variations in play styles, within the more narrow range of available interactions in many learning games. Klawe and colleagues [14] observed two approaches that children adopted when they tried museum kiosk learning games – rushing to beat the game, and taking time to explore. Ko [15] classified learning game players as problem solvers or random guessers. Problem solvers improved through play. They were more successful as they gained more play experience. Random guessers did not improve with experience. Heeter and Winn [16] proposed learning game play styles based on speed of play and problem-solving success. These two dimensions bring together the observations from both Klawe's and Ko's research. Heeter and Winn divided problem-solvers into Achievers and Explorers based on how quickly they finished the game (Explorers played more slowly). They also used speed of play to divide random guessers into two player types. Those who played quickly and made many mistakes were considered Careless players. Those who played slowly yet made many mistakes were labeled Lost. They randomly assigned players to one of three conditions: no bonus points, bonus points for speedy play, and bonus points for spending time looking at "fun facts." When speed was rewarded, girls played faster and made more mistakes. Boys, who already played quickly, were not affected. When time with fun facts was rewarded, boys slowed down and made fewer mistakes. Girls, who on average spent more time with fun facts even without the bonus points, did not play differently. The results suggest that in-game rewards can impede or facilitate learning, and that the impact of in-game rewards varies depending on the player's natural play style.

Player motivations closely parallel intrinsic and extrinsic learning motivations. Bartle and Yee's achievement oriented players and Heeter and Winn's Achievers all probably describe extrinsically motivated game play. Likewise, Explorers and Immersion probably describe intrinsically motivated game play. Performance-avoidance extrinsically motivated players try to avoid failure (rather than seek success) in a game.

2.3 Intelligent Tutoring and Games

The main approach to adapting digital games to individual learning needs has come from research done in intelligent tutoring systems (ITSs). Intelligent tutoring work has explored how computers can model student knowledge to provide appropriate guidance and lesson plans in non-game-focused digital learning. Intelligent tutoring systems make use of a cognitive model of the individual student interacting with the learning system and tailor problem sets and teaching tips to that particular student's perceived pedagogical needs [17]. As a student interacts with the learning environment, the system executes *model tracing*, which means to continually form a hypothesis about what strategies the student is using to solve a problem. If a student commits an error, then the system can offer helpful advice that is tailored to that student's specific needs. As a student progresses through the material, the system executes *knowledge tracing*, which builds a hypothesis about the student's proficiency in the skills being taught and presents material that addresses the student's weaknesses. In this manner, either a tutoring hint or guidance is given as well as the appropriate selection of exercises to address the student's individual needs.

Intelligent tutoring has been applied to digital game-based learning with some success [18-21]. However, these games have typically followed the student models laid out by intelligent tutoring work without refocusing on what kind of models are specifically useful for students *playing a game*. It is typical for systems to monitor player skills or knowledge (i.e. a knowledge trace) and base adaptations purely on that model. Understanding what a student does or does not know, or why they made a particular error, is without a doubt important to help tailor a learning experience. However, players who are interacting with a digital game for learning can be modeled around many more dimensions than just student knowledge. Games offer an inherently interactive experience that can make use of player intent or goals, social interests, involvement in a story [19, 20], and preferences for gameplay to create an experience that is tailored to the student as an individual in ways that is wholly difficult in other mediums. This paper explores some of these possible adaptations, specifically in how to adapt gameplay based on player motivation and learning styles.

3. S.C.R.U.B.

We have developed a digital learning game prototype called Super Covert Removal of Unwanted Bacteria, or S.C.R.U.B. for short, to use as an experimental test bed for our research in adaptive gameplay and player types. A screenshot of gameplay in S.C.R.U.B. is shown in Figure 1. S.C.R.U.B. is a mini-game that is designed to teach principles about ways of preventing the spread of microbial pathogens. The evolution and transmission of methicillin-resistant staphylococcus aureus (MRSA) touches on important topics in biology, microbiology, public, and personal health for middle and high school students, athletes, medical professionals, and the general public to learn about. S.C.R.U.B. teaches concepts about how to most effectively remove microbes from your hands; how soap, anti-biotic soap and alcohol-based hand sanitizers work on microbes; facts about MRSA; and prevention strategies for avoiding MRSA infection. S.C.R.U.B. is designed to be part of a future suite of mini-games that are focused on related topics in microbiology

The current version of S.C.R.U.B. is a simple mini-game where the player sees an extreme close up of a hand. They are given one of three different kinds of cleaning agent to "shoot" at microbes on the surface of the hand. The field of view includes generic microbes, clumps of MRSA microbes, and microscopic chunks of dirt. As soap or alcohol is shot at the microbes and dirt, the player can see on a microscopic level how that particular cleaning agent interacts with microbes and how rubbing and rinsing changes the dynamic. For example, molecules from a normal bar of soap have one end that "sticks" to grease, dirt, and microbes while the tail end is attracted to water, effectively loosening microbes from the surface of the hand and pulling them into the water. Within each round, players can take 25 actions (shoot, rub, rinse) in any order. For each cleaning agent there are two practice rounds to encourage players to experiment, followed by a single "competitive" round where the score counts.

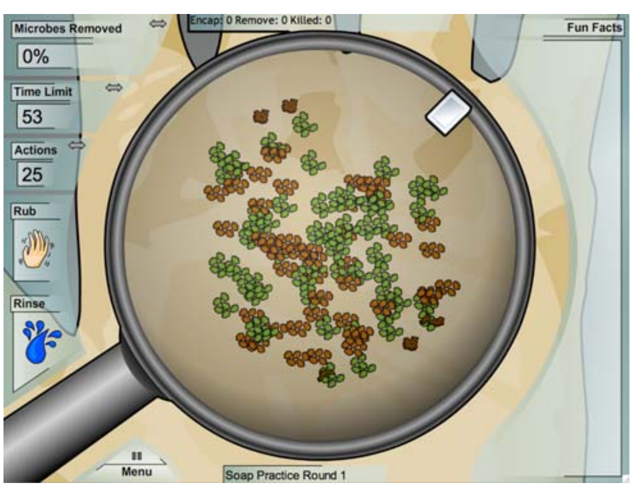

Figure 1. Screenshot of the S.C.R.U.B. mini-game.

Based on the literature review and preliminary surveys, we have determined that three player-learner motivations are of particular relevance to our prototype learning game design: intrinsically motivated *Explorers*, extrinsically motivated performance-approach *Achievers*, and extrinsically motivated performance-avoidance "*Winners*" (players who are motivated to win to avoid losing).

3.1 Design Process for Adaptation

One of the products of our work on S.C.R.U.B. is the unique process that has arisen from building a game that represents a space of possible games as opposed to what is conventionally considered a typical game design. This process involved several additional steps to the typical iterative process we normally take: *analysis*, *identification*, and *mapping*.

We first *analyzed* the game experience to identify the different features that make up the gameplay, the interface, and the knowledge presented to the player (e.g. having a high score, the visualization of text-based facts about MRSA, and having a time limit). Once these different features have been identified (which of course may change during iterative design), we then *identified* what alternate approaches could be taken within each of these features (e.g. having a high score vs. not having one) and finally how each of those differences *map* on to possible player preferences (e.g. having a high score fits an achiever profile).

As shown in Figure 2, we ended up with six initial adaptive features of particular importance to Explorers, Achievers, or Winners. It is important that Explorers have time to explore. Therefore, a countdown clock and bonus speed points are omitted for them. The countdown is also left out for Winners, on the expectation that added pressure only further interferes with their mental focus. Explorers also have a means of entering an "explore mode", in which gameplay ceases and they can more closely examine aspects of interest in the interface (while learning more about MRSA). Achievers get bonus speed points and a prominent Leader Board. We avoid distracting Winners with superfluous options or pressures, guide them into the game with a built in tutorial, and offer a "show me" alternative to answering trivia quiz questions.

This process has been well suited to working with an arcade-style game. It has been a fairly straightforward process to compartmentalize features of this simple mini-

	Intrinsic	Extrinsic	
	EXPLORER	ACHIEVER	WINNER
		Performance-Approach	Performance-Avoidance
Explore Mode	Yes	No	No
Bonus (extra) Trivia	Yes	No	No
Timer (speed bonus points)	No	Yes	No
Leader Board	No	Yes	Yes
Trivia Qs (show	No	No	Yes

Figure 2. Mapping of S.C.R.U.B. game features to player types.

game. How this design process applies to other kinds of games appears straightforward for some (e.g. first-person shooter-style games) but less so for others (e.g. turn-based strategy games). Further work in other genres will help this process mature and better understand its limitations.

3.2 Adapting Gameplay

Players can be assigned an adaptation in one of three ways. The most straightforward is to offer an initial customization screen, and allow players to pick and choose their preferred customization of the interface. A second approach is to invite players to complete a short questionnaire that is used to assign them to a player-learner type. The questionnaire asks multiple-choice questions such as "When you play a game, how important is it to you to earn a high score?" and "How often do you try to finish quickly, to make a routine task interesting?" The questions are designed to help provide evidence of preferred learning and play experiences for the individual player. Future work, as discussed later, will address how to infer these preferences by observing gameplay.

Once the questionnaire is completed, the player begins playing the mini-game. The game that is presented to them is an instantiation of the abstract game we have designed, with assignments to each of the adaptable features (see Figure 2). As mentioned earlier, future work will focus on mapping adaptations across less discrete boundaries. For example, a player may be highly motivated by achievement but also enjoys exploration. Our current approach measures player motivation along all three dimensions, but deciding how to handle conflicting motivations will require more research. For example, if a player exhibits high Explorer AND Achiever motivations, should they be constrained by the Achiever countdown clock? Doing so is at odds with their interest in taking time to explore…Future iterations of S.C.R.U.B. will look at how to select adaptations in a finer-grained manner, such as weighting features with "how much" they relate to a particular style or assigning features proportionately based on the model of the player (e.g. assigning 60% of the features for Achiever and 40% for Explorer, or better yet, deciding which features can coexist and which must remain true to the player's primary type).

4. FUTURE WORK

The preliminary results from S.C.R.U.B. show promise, but hardly hearken to a rigorous educational evaluation. Research in games for learning need be treated as rigorously as approaches in more traditional educational research [22]. Therefore, we plan to conduct a serious review of the pedagogical benefits of adaptive gameplay using S.C.R.U.B. as a platform. In order to reach this point, we anticipate conducting several more iterations of playtesting and design to create a game that is both enjoyable and gets the main learning points across to the various learning styles.

S.C.R.U.B. is intended to be a game presented as a suite of games focused on microbiology concepts. The end design will include not only adaptation within-games, but meta-adaptations that select games from the suite that are targeted for a specific individual. Games may be offered or selected based on the user displaying a lack of knowledge or comprehension of content (hearkening back to the principles of knowledge tracing in intelligent tutoring) or on the suitability of games to particular kinds of learners / players. Further design and development of the accompanying games will provide a rich, contextual experience that addresses related topics.

We plan to further the categorization of player / learner types by employing a less intrusive and obvious approach to identifying preferences. There may be some negative effects of requiring a player to take a questionnaire (e.g. student motivation dropping from having to do something bothersome just to play a learning game). Therefore, we intend to explore methods for identifying player types through actual gameplay. In other words, as opposed to providing a multiple-choice test that will be used as a method of player categorization, we would identify analogs to such a test that could be incorporated into a game or series of games. For example, players could be presented with short mini-games that vary along a specific dimension (e.g. playing a game where you S.C.R.U.B. out invading microbes to beat a time limit versus hunting microbes until you feel like moving on). Consequently, the game a player chooses would help identify their preferences. This not only removes the possibly cumbersome questionnaire approach from the experience, but also potentially allows the system to update its model of the player over time by observing which choices are made when they are presented periodically in the game experience.

We anticipate this to be a more robust approach to identifying player types in digital learning games once we have a firmer grasp on precisely what those types are and how they are identified succinctly. This approach could then be used in conjunction with the adaptive approaches presented in this paper to create digital learning experiences that are both effective and enjoyable to the individual playing it in a very unique and personalized way.

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