Physical Games in Computer Education

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ABSTRACT

With the continual growth in popularity of computer science and software engineering based education courses there is much merit in exploring effective teaching methods in the area. This article will review the current state of alternative teaching methods for such courses, with an emphasis on physical serious games (in particular card and board games). Through a critical analysis of other studies in the area I hope to gain insight on effective theories and methodologies with the ultimate intent to develop a board or card game to teach some form of computer science concepts.

General Terms
Experimentation, Human Factors, Theory, Verification.

Keywords
computer science; physical games; serious games; computer education.

1. INTRODUCTION

Physical games such as card games and board games have been popular amongst children and adults alike for generations and continue to captivate the world to this day. While often seen as simply a form of entertainment, physical games hold the potential for powerful forms of learning as active learning tools [3]. Using physical games as a form of introduction to computer science is an exciting concept that many educators have taken note of. Their main interest in this type of research has spawned from a need to find effective alternative means of teaching computer science in situations where the course content may be seen as uninteresting or difficult. It is thought that game based learning approaches excel in these such scenarios where traditional teaching methods may falter [4][5]. While many of these ideas have yet to be extensively researched [2], what the area may lack in research, it more than makes up for in potential. Unlike typical forms of education, (physical) games have an intrinsic motivation factor ideal for deep engagement and learning [1][7]. As well as motivational benefits, physical games often encourage reflection on the activity. This is essential for the process of learning as it connects classroom experiences with previous learning experiences [6], strengthening mental bonds and adding another facet to a student's knowledge.

This article will be reviewing some of the recent research of physical games in computer science. It will begin with a comparison of physical games and video games both generally and specific to teaching. It will then evaluate how educational theories have been integrated into physical games for education. This will be followed by some study findings of requirements and obstacles for success, taking particular note of general limitations of physical games. Finally I will review how research in this area has been analysed through collection of data and testing methods.

2. PHYSICAL GAMES

While perhaps conceived to be better suited for entertaining younger children, physical games inherently hold benefits for social interaction, problem solving, and self-reflection [2][6][7]. One of the most useful traits of physical games for education is the lack of negative repercussions for failure [6]. In a gaming environment mistakes are able to be made freely. If a minor mistake is made in a game it will often not have a lasting effect, and if a serious mistake is made in a game everything will be reset upon the starting of a new game. Allowing students to learn from their mistakes is ideal for technically complex subjects such as computer science but may not always be possible within a traditional classroom environment [6]. Upon completion of a game students have the opportunity to reflect, asking themselves questions such as “what went well in that game?” and “what could I have done better?” After this self-reflection student can immediately put it to good use when playing again. As well as internal contemplation physical games are great for social interaction and discussion among peers [7]. This is to be discussed later in relation to the educational theory of social constructivism.

Another reason why physical games pair nicely with traditional forms of both theoretical and practical education (as compared to video games) is that in general there is little-to-no degree of mental or physical agility required [2]. Board and card games are most often turn-based, meaning the game can only change as the players act, allowing them to dictate the pace. In doing so the players have time to think about their next turn and strategize for future turns [2]. I believe that this mirrors real world problem solving and software development far more closely than that of faster-paced, time-based video games.

3. EDUCATIONAL VIDEO GAMES

While not the primary focus of this review, modern technologies have opened new and interesting opportunities for the utilisation of physical games. Sivak et al [14] conducted a research study following their development of an educational board game which, after critical analysis of the implicit functionalities and limitations of a physical game, was converted into a digital version. Although the final output was not a physical game, the studies methodological steps to reaching that point were very insightful. By comparing a physical and digital version of the same game many strengths and weaknesses of both sides were highlighted. The primary issues that arose for the board game was the length and number of rounds, the lack of instruction, and the need for manual calculation [14] (although this issue is specific to their game as it requires a lot of mathematical calculations within the game). The problem of game-time is a recurring theme throughout all studies I have reviewed, but other than Sivak et al [14] no researchers have suggested a sound solution to the problem. Most have simply ignored it, claiming the students just need more time with the game to understand the mechanics better, and therefore speed up decision making and streamline the game-play. While this may be true, I disagree with simply ignoring this problem and hoping it will cure itself with time as I feel that, even if the game-time will reduce as players get more experience, first impressions of the game is important and if a student feels the game is dragging on too long it may have a negative impact and ultimately hinder their acceptance of the game. Unfortunately the one study that has proposed an actual solution (Sivak et al [14]) have done so by using a digital version of the game. This bypasses set up time, and offers a built-in instruction booklet and in-game calculator. This will not be a viable solution for my development of an educational physical game so I will definitely have to keep game-length in mind as I would hate for it to be the limiting factor of success for my game.

Another very interesting use of both physical and computer based games for educational purposes is Jonas' [15] use of the popular mathematical strategy game Quoridor with the software development environment Greenfoot. In this case the game itself was not teaching computer science concepts but it was instead used as more of a teaching tool. Jonas used a relatively different approach to using board games to teach computer science topics. His group of first year students were assigned to learn how to play the game Quoridor. After thoroughly learning the game the students then used their strategic knowledge to create an algorithm to decide on moves. This algorithm was then implemented in a virtual version of the game as a means of developing java programming skills. While this example did not directly cover the development of a physical game for educational purposes, I thought it was a noteworthy example of indirect utilisation of a board game which none of the other papers I found had touched on.

4. EDUCATIONAL THEORIES

While general traits of physical games are great for enticing people to play, the success of educational games are heavily reliant on the underlying educational theories within development. Although the studies that did mention educational theories did not go into that much detail, it was encouraging to see they had them in mind, and at least tried to incorporate them into the game. It was also good to see that they were attempting to use more modern learning theories, rather than primitive ones such as the behaviourist theory.

The three main ideas that I think are most important to this area are active learning, social cognitive learning, and constructivism. In the following blocks I will be overviewing these theories, analysing how the researchers have included them in the development of their game, and noting any parts that I believe are missing.

4.1 ACTIVE LEARNING

The most common educational theory mentioned as a main contributor to the effectiveness of educational physical games is active learning. Prince states "active learning is generally defined as any instructional method that engages students in the learning process" [13]. Many of the other researchers (as well as myself) feel as though card and board games fit perfectly within this definition as increasing engagement of students is one of the fundamental inspirations for using physical games for education.

While all those who mentioned active learning for educational physical games hold it in high regards, only Gibson et al [1] deem it as a necessity. I believe their idea of having gameplay teach the content rather than separating it from the teaching is as crucial to the success of student learning as it is difficult to properly implement. Unfortunately the papers that do reference active learning simply mention that it is useful for student learning but do not go into detail of how they incorporated it into their game. I feel as though they were more than ready to just assume that seeing as they were creating a physical game, it would automatically be engaging to students and thus help them learn. While I completely agree that utilising active learning within an educational game is beneficial, I think that the researchers should be putting time toward actually implementing measures to do so, rather than just assuming that it will happen on its own.

4.2 SOCIAL COGNITIVE LEARNING

The social cognitive theory is based around the idea that individuals can acquire knowledge by observing others within a social construct. As physical games tend to be multiplayer (usually 2-8 players), I believe social cognitive learning has a deep inherent relationship with physical games. With most games a player will have to observe what their opponents/teammates are doing to be able to make the best strategic decisions. In doing so they may pick up better strategies, or at least different ways of solving problems that their own.

Surprisingly none of the papers have made mention of this theory, the closest being Denning et al [7] who while discussing the benefits of using a physical game for education state that "physical games can create a social environment, which can foster interaction and discussion of ideas encountered" [7]. I think that it's a shame the other researchers haven't taken the time to consider how their game may make the best use of social learning. Similar to active learning theories I get the feeling that the studies are either just assuming that creating a multiplayer game will automatically have a social aspect, or they have simply not considered it at all.

4.3 CONSTRUCTIVISM

The third and final educational theory mentioned within the papers is constructivism. The constructivism theory places different roles on the student and the teacher. The student is no longer an empty vessel waiting to be filled by the knowledge of the teacher, they are now encouraged to be actively involved in their own learning process, and the teacher now takes more of a facilitator role. Again I believe this theory fits perfectly with physical games. The students, as players, now dictate how the game unfolds.

Both Carrington et al [8] and Sivak et al [14] make mention of constructivism without going into that much detail, however they do go on to suggest that teachers should use serious physical games as a supplement to relevant material. This should be utilised if the content is especially complex [14], which is often the case with computer science and software engineering subjects. They both suggest that when teaching computer science concepts, games should not be used alone to educate , the teacher should introduce concepts to their students, and then treat the physical game as a practical form of reinforcement of ideas much like a lab or tutorial would [8][14]. I agree that for more complex topics this may be the best use of the games, however I think that physical games may still be utilised to great success in introducing simpler concepts.

5. GAME BALANCE AND DESIGN

Correctly balancing the gameplay of a serious physical game is crucial to the effectiveness and overall success. Even with excellent core concepts designed for the subject matter of the game, it simply will not succeed to its fullest potential without a well thought out balanced gameplay. I found that all studies that actually created an educational game thoroughly documented difficulties that arose when developing their game. I found that Denning et al [7] had the most extensive list of the most important game mechanics. These were; number of players, time to learn the rules, gameplay time, selecting relevant and interesting topics, replay value, the cooperative vs competitive paradigm, ability to recover from a losing streak, and the variety of winning strategies [7]. I believe this list represents the findings of almost all of the other studies. Of this list I find the final three most interesting, but was slightly upset that they were not further investigated. Most physical games are competitive but I would be very interested in seeing how a cooperative educational board game would fare against a typical competitive educational board game in terms of student engagement and overall learning. When developing my game I will also be trying to think of ways for players to recover from losing streaks, and having multiple potential win conditions. I think these two ideas are very difficult to design for but their payoffs in terms of player satisfaction could be immense.

The one idea that Denning et al [7] did not mention that was present in the studies of both Gibson et al [1] and Chen et al [10] was selecting an appropriate level of difficulty and enough complexity as to increase the longevity of the game. Chen et al [10] states that by using an appropriate level of difficult, players "are motivated by the challenge of competing for the goal." They go onto mention the idea of self-efficacy [10], which is essentially the self-belief of a player in their capacity to succeed. This should drive the students to keep playing which would hopefully lead to increased learning. Gibson et al [1] takes a more theoretical approach for selecting difficulty to increase engagement and immersion. It was great to see them considering Vygotsky's Zone of Proximal Development, which in essence is about balancing the difficulty of a game where it is not too difficult as to lead to frustration but also not too easy as to lead to boredom. A closely related idea that Chen et al [10] go on to discuss is that players should be working on the edge of their ability to maximise their increase of skill. Both of these ideas seem to be closely related to the depth of complexity within a game. Having a game that can grow with the player is an incredibly difficult task especially for physical games, but I believe if it is pulled off correctly it will get a student further than a game that could be played and mastered in a single session. While neither Gibson nor Chen go on to suggest methods how to incorporate this in general, or even how they incorporated this, my thoughts is that it can be done so through supporting strategic nuances such as sequencing your moves based on reading your opponents.

6. COLLECTING DATA/ TESTING

While many of the core concepts and general gameplay have been well designed I believe that proper user testing of physical games is essential for success. Unfortunately, unlike virtual subject matter (such as computer based lecturing, testing, and gaming), physical games require space in the real world and as such cannot be in more than one place at once. This creates real difficulties for testing physical games, especially in early stages of development as it is likely that not many physical copies of the game exist. An implication of this is that it becomes incredibly difficult to have a large number of real users test the game without a massive investment in time. This is very apparent in the physical game design papers I have reviewed (as seen in Table 1).

Table 1. Analysis of education games' testing methods.

Study	Test Participants	Qualitative	Quantitative
[6]	40	X	X
[7]	46	X	X
[8]	24	X	
[9]	43	X	X
[10]	6	X	
[11]	28	X	X
[12]	30	X	
Average	**31**	**7 / 7**	**4 / 7**

As seen in Table 1 the average number of test participants is around the size of a lab or tutorial class which seems to be the most common form of user testing as the majority of these studies have been completed by educators that have students as a readily accessible resources. It was great to see that all of these studies reported some form of success of their game, unfortunately by having such small study sizes it narrows the researcher into relying more on qualitative data than quantitative data. Although Table 1 shows that the majority of these studies do in fact perform some sort of quantitative study I am hesitant to believe that it can be considered representative of a larger filed of users (keeping in mind that all but Denning et al [7] only tested on a single group of their students while developing their game). Another slight concern was the conclusions drawn from the small amount of user testing done. The most heinous example being Chen et al [10] who had an excellent theoretical analysis of education in physical games, but after only one testing session with 6 students from a local primary school claimed that using physical games in primary education was "more fun and more interesting that traditional lectures" and their educational game "is better than digital games because it creates more social interactions, and can be easily made available" [10]. While these may be entirely true it is unacceptable to jump to such conclusions based on comments made by such a small number of 4th grade students.

Sivak et al [14] like many others made use of several small focus groups consisting of target population representatives as they were developing their board game. In doing so they were able to identify some of the most fundamental issues to their design at a very early stage. Again this idea of incremental testing while developing the game common among all studies I have seen. Generally this form of early-and-often testing follows a similar approach to Sivak et al [14] where the game is introduced and played by students in lab or lecture time. The only study that had a slight variation on this was for the development of the Denning et al [7] computer science card game Control-Alt-Hack. The differences between this study and all others is that rather than simply testing the game on a representative group of users, Denning et al tested their game on a much wider population of undergraduates, graduates, high school teachers, and lecturers [7]. By doing so they were able to observe a much wider scope and get opinions from all skill levels of the content (computer science security). I believe this form of user testing is necessary for the most holistic view of what does and does not work. Unfortunately it does come at the cost of time and is limited by person availability.

One thing that Table 1 does not display is the post-development user testing. The primary reason I did not include these statistics is that, once again, Denning et al [7] were the only group to document any form of testing after the game development was completed. By doing so Denning et al were able to gauge the success of their game on a far larger scale. By sending out 800 free copies of their Control-Alt-Hack card game to 150 educators (in the related field of computer science technology), Denning et al received feedback from over 450 students who had used their game [7]. This wide spread user testing was also the only sign of intent to actually share the game with other educators. The vast majority of papers I read were more than content with developing, testing, and administering their game entirely within their educational organisation. A potential reason for excluding any documentation on using the game outside of their own context would be that the studies were intended to focus purely on development of the game. I would hope that this is the case and that these sort of researchers are in fact very willing to share with others, as the ultimate goal is not that they were simply able to create a good educational game, but that they were able to create a good education game that actually helped students learn.

7. SUMMARY

The papers I have reviewed have shed useful insight on what it takes to create a successful educational physical game. Through their documentation of development I have seen what educational professionals have found to be the biggest benefits and difficulties of physical games for educational purposes. With this knowledge I hope to create a successful game of my own.

Throughout my research it was encouraging to see that people are still interested in this area (the vast majority of the papers I have looked at were written within the last 5 years). I believe that physical games for computer science education is an incredibly complex task to crack and further research on the topic is necessary. While it may not have the backing of video games for education [10] physical games continue to hold a lot of potential as both an introduction to newcomers as well as an aid for students to develop their computer science skills.

In my opinion the biggest gap in this research area is the void between researchers. While all of the studies who created a game have documented successes through their students' feedback, none have mentioned any form of collaboration between themselves and other researchers working on similar studies. It seems as though the isolation of research may be hindering the progression towards create a truly successful educational board/card game. Individual successes are not being fully utilised for the greater good of computer science education. I hope that in the future more collaboration will ultimately lead to more successful student learning and a progression of computer science education.

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