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A Cross-Cultural Evaluation of a Computer Science Teaching Game

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Abstract

The use of games for education has attracted a lot of attention in developed nations worldwide, and is gradually penetrating the developing world. Despite that there are educational and efficiency benefits from the cross-cultural implementation of educational games, most educational games are not designed for cross-cultural usage. This paper seeks to contribute to designing cross-culturally relevant educational games, and examine this in the particular context of computer science (CS) education through a CS teaching game for middle school students. We implemented this game in the USA and Nigeria in order to find what cross-cultural differences may need attention for future work. Results highlight that both populations find the game enjoyable yet challenging. However, a clear difference is noticeable in the learning outcomes, which may have been a result of the game's design and the evaluation instruments. Therefore, a cross-cultural perspective is needed to both educational game design and its evaluation.

Introduction

There has been an increased interest in the use of games for teaching computer science (Harteveld et al., 2014). This use is likely to grow in the future with initiatives such as Computer Science for All (The White House, 2016). Games are particularly appealing to broadening computer science (CS) education due to their affordance to engage users (Chande et al., 2015; Papastergiou, 2009). Although much emphasis has been put on broadening CS to girls and underrepresented groups specifically through games (Kafai et al., 2008), so far initiatives have not been pursued to broaden CS cross-culturally through games, that is, to make a CS teaching game that would be appealing to two or more different cultures or countries. The aim of this paper is to initiate this type of broadening in addition to the ones frequently advocated for, with a focus on broadening a game from a developed country towards a developing country. The entire world would benefit from a population that is more computer literate and building a completely new game tailored to each culture is not efficient. Additionally, in the case of developing countries it allows for accessibility to technologies that may help them in their development and prevent a larger gap between nations from occurring.

Because games are like every other artifact culturally defined, most educational games are designed and evaluated for certain groups of people with similar culture and interests, or within the same geopolitical areas. The implication of this is that players will not easily understand nor appreciate the design for a game that is contrary to their attitudes, customs, and beliefs, and this may happen within the same country because cultures are not necessarily bound by borders. This lack of cross-cultural usage is representative for the field of educational games in general and not specific to CS teaching games only. To be validated as being truly cross-cultural, a game should be designed and evaluated among groups of people across varying cultures.

This lack of cross-cultural usage is representative for the field of educational games in general and not specific to CS teaching games only. Existing efforts thus far have been sparse. Kam et al. (2007) evaluated the efficacy of eight educational games among rural children in India to identify the role of contextual factors, and then Kam et al. (2009) conducted an exploratory study to inform the design of a new videogame that rural children in India found to be more intuitive and engaging. Although this work specifically considered culture in designing an educational game, the work still focused on a specific group and, therefore, is not cross-cultural. In terms of truly cross-cultural efforts on educational games, Khaled et al. (2006) developed two versions of a persuasive game to educate citizens about smoking cessation, one for New Zealand Europeans and one for the Maori. They concluded it is best to design with the cultural background of the intended audience in mind. This conclusion is aligned with the findings of Folajimi et al. (2012). After implementing a game for educating children about sickle cell disease and implemented with UK and Nigerian children, it was concluded that educational games need to be built with a view to varying cultural backgrounds. Other efforts have involved using existing theories about cultures as input to the design and implementation of games, such as Hofstede's cultural dimensions (Hofstede & Pedersen, 1999). Additionally, for entertainment games specifically there have been various practical examples as well as documented ones (e.g., O'Hagan & Mangiron, 2013) about the need for game localization, which mostly involves cosmetic adjustments to a game (e.g., changing from red to green blood for games distributed in Germany).

In this paper, we seek to contribute to the design of cross-culturally relevant educational games, and examine this in the particular context of CS education. Acknowledging that varying designs may be necessary based on the work in this area thus far, our efforts have focused on first establishing the differences between two clearly different cultures in order to make design recommendations for future work. For this effort, we have investigated the cross-cultural use and impact of a CS teaching game called *GrACE* (named after Grace Hopper). Based on a review of existing CS teaching games (Harteveld et al., 2014), *GrACE* was originally developed to teach CS concepts to middle school students in the USA. Results from an experimental pilot study highlighted moderate improvements in the CS concept being taught through the game (Horn et al., 2016). To assess the cross-cultural use and impact, we have later implemented the same study with middle school students in Nigeria. Although the choice of Nigeria was majorly because of convenience due to opportunities provided to the researchers, we see it as a step towards expanding the reach of the game to the rest of the developing and developed nations in the world. The results of this Nigerian implementation and the comparison with the US implementation are reported in this paper. Before we discuss these results, we will first elaborate on *GrACE* itself and summarize the results from the USA pilot study.

Broadening CS with *GrACE*

GrACE has been developed to explore the potential of Procedural Content Generation (PCG) for teaching CS concepts. PCG is the practice of creating game content automatically with a computer (Smith, 2014). A related aim is to broaden CS and while the main aim has been to broaden CS to be more inclusive to girls, we have been additionally starting to explore broadening cross-culturally by implementing the game in Nigeria as well. As PCG can automatically create content, we anticipate that in the future, once it is clear what the design requirements are per gender and culture, we can generate content tailored to the user. In illustrating the potential of PCG, we have initially focused on teaching the CS concept of the Minimum Spanning Tree (MST). A MST connects all the nodes with the minimal total weighting for its edges in a given graph.

Figure 1. GrACE user interface. Players need to collect all the vegetables.

The Design of *GrACE*

The game is centered on two characters–a mouse and a rabbit–whose goal it is to collect all the vegetables in each level (see Figure 1). Vegetables (nodes) in the ground are connected by cracks (edges) that only the mouse can fit through. Edge weight corresponds to the amount of bunny energy needed to dig along a crack. Players control the mouse as it explores the map and flags cracks for the rabbit. To minimize the bunny's digging energy, players must find and flag the MST. Initially, players can only see the starting node and the nodes connected to it. Players choose an edge to traverse at which point the next node and its connections are revealed. This mechanic discourages players from solving the puzzle visually by examining the entire graph at once. Instead, we designed the game around limited information exploration to encourage stepwise thinking and mimicry of MST solving algorithms. At any point, a player may drop a flag on an edge connected to their current node indicating it is part of the minimum spanning tree. Flags can be removed from edges connected to the player's current node as well. Once all nodes have been explored and all desired edges have been flagged, players may submit their answer. If the answer is correct, players move on to the next level which increases in difficulty. All puzzles/levels are generated by the computer based on this difficulty, which is defined in the current version as the number of nodes and edges.

The USA Evaluation of *GrACE*

We developed a three-hour procedure that included about an hour of gameplay with *GrACE* and evaluated the results of this implementation with an experimental pilot study (Horn et al., 2016). We implemented this procedure as part of a summer program for middle school students (ages 10-14 years) in the USA. The program selects 48 middle school talented students each year (with an average of B or higher in their course work), and focuses on STEM content. The program historically supports underserved and underrepresented students with limited opportunities, is gender balanced by recruiting an equal amount of boys and girls, and is free of charge. The USA experimental setup involved completion of pre-questionnaire after an explanation on how to play the game. This was followed by game play, post-questionnaire evaluation and a semi-structured discussion on the topic of CS and the MST concept in particular. During the day of implementation, 43 students participated, 22 identifying as female and 21 as male. These students reported a high level of enjoyment but also found it frustrating, challenging, and hard. Their perceived experience was unrelated to their moderate improvement in the conceptual understanding of the MST problem.

Methods

We applied the same setup from the USA pilot study to the Nigerian groups, and made modifications where necessary in the procedure and material. For example, we modified terms such that it would be comprehensible and familiar to Nigerian students (e.g., changing Mayor to Governor).

Participants

The pilot study was replicated in two contexts: the Nigeria Geek Girls Collaborative Camp (Summer Camp) and the Ogunsanya Girls Science Academy (Academy). The first context is a computer training and mentoring camp for Nigerian secondary school girls (ages 10-16 years) with the aim of enhancing the talent and skills needed to fuel technological and economic growth. To reach out to the best talents, notwithstanding their social or economic background, the camp is free of charge. The 2015 camp consisted of 40 participants, with 36 opting to participate in the pilot, including four male non-campers who indicated interest in evaluating the game. Of these 36, one student was excluded for neither having survey nor game data. Parental consent and school approval were received from each participant. The second context is an all girls secondary school with a special focus on preparing girls for STEM careers. Of the 30 students that participated from the Science Academy, two students were excluded for lack of survey and game data thereby leaving us with 28 participants. By default, all participants from this group are female boarding house students of the same school and study science related subjects. Computer science is one of the major subjects taught in the school and almost all the students have personal computers.

Materials

The materials used in this study include a questionnaire, comprehension test, and the game. The pre-questionnaire captured game attitudes and the post-questionnaire demographics and game experience. For game attitudes we aimed to measure the constructs of *Liking* (3 items; αUS = .76, αNIG = .54) and *Leisure* (4 items; αUS = .85, αNIG = .75). Liking measures how much the students like playing video games; Leisure measures the degree to which games are incorporated in the leisure time of participants. Regarding their game experience, we aimed to measure how much participants liked playing with the construct *Enjoyment* (4 items; αUS = .93, αNIG = .69) and had trouble with playing with the construct *Difficulty* (3 items; αUS = .87, αNIG = .32). For both game attitude and game experience we used 7-point Likert items adapted from the New Computer Game Attitude Scale (NCGAS; Liu et al., 2013) and existing Game Experience Questionnaires (GEQ; Norman, 2013), respectively. Based on factor analyses (principal axis factoring, varimax) and a comparison of similarity indices (after procrustean rotated loadings), and specifically Tucker's coefficient of congruence (Lorenzo-Seva & ten Berge, 2006), we concluded that our instruments have been applied to a different population reasonably well but need to be viewed with caution due to the low internal consistency with the Nigerian sample. The Difficulty construct seems not to generalize and for this reason we excluded this from our analysis.

The comprehension test aimed to measure a conceptual understanding of the MST before and after playing. The test concerns a multiple-choice assessment of three puzzles with three questions each. The first puzzle is based on edited screenshots from the game ("Game"); the second is an adaptation from the "Muddy City" exercise from CS Unplugged (Bell et al., 2015), which involves paving roads between houses ("House"); and the third is an abstract graph with nodes and edges that we referred to as circles and lines ("Abstract"). For each puzzle one question involved the problem of adding a single edge ("Addition"), one about removing a single edge ("Subtraction"), and one about correcting an incorrect spanning tree ("Correction"). One point is awarded for each correctly answered question. As during the Camp implementation about half of the participants did not receive the house subtraction question, we excluded this question from our analysis. We counterbalanced the test distribution and similarly to the US Pilot did not find a significant difference between the two versions.

The game was instrumented to track all player actions (e.g., placing or removing a flag, submitting an answer) and game states (e.g., mouse and bunny energy). We used USB sticks to retrieve this data from the personal and lab computers used in the study. Unfortunately, a significant number of files got corrupted, leaving us with eight complete data sets for the Summer Camp and 21 for the Science Academy implementation.

Procedure

At the Summer Camp, the study was implemented as part of an educational games activity; for the Science Academy implementation the team was able to organize an informal, extracurricular activity on a Saturday. In both cases, the experiment followed the same pattern as the USA implementation. For the Summer Camp, the study took approximately 3.5 hours, with one hour of gameplay, while in the case of the Science Academy, the experiment took about 2.5 hours to complete.

Results

In detailing our results, we focus on the main outcomes from the survey, comprehension test, and the game data. In describing our results, we make a specific mention whenever we found a relevant difference compared to the USA pilot study.

Survey

The majority of the Nigerian students (52.5%) reported to play more than 1-2 days a week (as opposed to 61.9% of US students). Interestingly, most (39.3%) reported to play games multiple times a day, which is more than what the US students reported (16.7%). Despite seemingly playing more games on a daily basis, the Nigerian students disliked various game genres more so compared to the US students, with an almost entire dislike for strategy, role-playing, and simulation games. Except for the adventure genre, which was more favored by the Science Academy students (81.9% vs. 55.9%), there were no differences between the two Nigerian groups, suggesting that they were homogenous in terms of what games they play and like. Similar to game genres, the Nigerian students liked fewer school subjects than the US students.

Regarding game attitudes, the majority of students indicated a liking of games, similar to the US students. When it came down to the degree to what games are part of their leisure time it becomes clear that for Nigerian girls games play overall a more important role than for US girls, $t(77) = -3.24$, $p = .002$, $r = .35$, but less so than compared to US boys, $t(75) = 2.68$, $p = .009$, $r = .29$. Interestingly, the statements where the Nigerian girls ranked similarly to the US girls, it is where the US boys scored higher, indicating more of a gender difference rather than a cross-cultural one. The US boys scored higher on thinking about games while not playing, considering games to be part of their life, and spending their free time on playing games. For the latter statement, the Nigerian girls did differ compared to the US girls but this is attributed to the Academy girls. They are spending more of their free time playing games compared to the Camp girls, $U = 281$, $p = .005$, $r = .36$. Overall, the Academy girls indicated a more important role for games in their leisure compared to the Camp girls, $t(50) = -2.82$, $p = .007$, $r = .31$.

As for how the participants experienced the game, it is clear that the Nigerians enjoyed the game more so, $t(77) = -2.11$, $p = .038$, $r = .23$. They would recommend this game to their friends, want to play it at home, and have learned from it more so than what the US participants. No differences were noticeable in terms of the difficulty of the game. However, amongst the two Nigerian groups it is noticeable that Academy girls found it more challenging, $U = 330$, $p = .030$, $r = .28$, and experienced more frustration, $U = 331$, $p = .025$, $r = .28$.

With the US participants a predisposition was noticed in how the game is experienced. For the Nigerian sample, however, no differences were found regarding their preferences in game genres and school subjects. Unlike the US audience, both Liking and Leisure do not correlate to their Enjoyment as well as how frequently they play games.

Comprehension

In order to calculate the performance on the comprehension test, we calculated in addition to the total scores the scores per puzzle (Game, House, and Abstract) and per type of question (Addition, Subtraction, and Correction). Table 1 provides an overview of the average scores per implementation on all these items. Immediately apparent is that large disparity between the US participants and the Nigerian participants. Where the US participants answered on average 60% of the test correct already, and moderately improved after playing, the Nigerian students answered 30% or less on average correct, and there is no noticeable improvement. In fact, for the Camp participants a decrease is almost observable, $t(33) = -1.87$, $p = .071$, $r = .31$. Specifically, they seemed to have trouble with the addition questions, $t(33) = -2.54$, $p = .016$, $r = .40$. When looking at the maximum total scores, we see that with the US pilot a perfect score increased from four to 12 participants. With the Nigerians, on the other hand, three students received a score of five points at the start. After playing, one participant received a score of six points and none got five points.

Item (max)	US Pilot (*N* = 43)		Nigerian Camp (*N* = 35)		Nigerian Academy (*N* = 28)	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
Game (3)	1.70(1.12)	2.11(1.05)	0.67(0.77)	0.62(0.70)	0.52(0.81)	0.82(0.70)
House (2)	1.41(0.74)	1.06(0.90)	0.62(0.74)	0.37(0.60)	0.21(0.42)	0.40(0.50)
Abstract (3)	1.98(0.90)	2.12(0.85)	1.06(0.89)	0.79(0.81)	0.85(0.93)	0.92(0.80)
Addition (3)	2.14(0.78)	2.26(0.85)	1.03(0.76)	0.56(0.66)	0.67(0.68)	0.89(0.64)
Subtraction (2)	1.09(0.76)	1.33(0.78)	0.44(0.56)	0.47(0.62)	0.29(0.46)	0.82(0.81)
Correction (3)	1.88(1.13)	2.12(1.15)	0.67(0.82)	0.91(1.08)	0.48(0.75)	0.63(0.79)
Total (8)	5.07(2.03)	5.67(2.16)	2.35(1.18)	1.74(1.36)	1.52(1.24)	2.00(1.20)

Table 1. Overview of the comprehension test scores across the different groups, in M(SD).

The results may have been due to a possible *floor effect*. The test may have been too challenging, especially considering that the Nigerian students themselves expressed to have learned from it, and more so than the US participants. In exploring possible relationships with the test performance, we found that age may be a factor in this group, $r = .29$, $p = .023$. In addition, and much surprisingly, it seems that player enjoyment is negatively correlated with how much they improved, $r = -.27$, $p = .043$. Further exploration shows that in particular participants with positive improvements agreed less so with the statement “I thought it was fun”. Based on this, we made a new dichotomous variable distinguishing participants who agreed and disagreed on this statement, and ignored those who chose neither disagree nor agree. We then compared this new variable separately for each Nigerian group because with the Camp participants a decrease was almost observable. For the Camp participants the “disagreers” ($N = 7$; *Mpre* = 1.43, SD*pre* = 0.53; *Mpost* = 2.14, SD*post* = 1.21) improved more so than the “agreers” ($N = 22$; *Mpre* = 2.73, SD*pre* = 1.24; *Mpost* = 1.63, SD*post* = 1.40), $t(27) = 2.71$, $p = .014$, $r = .45$; likewise, for the Academy participants the “disagreers” ($N = 9$; *Mpre* = 0.78, *SDpre* = 0.67; *Mpost* = 2.33, *SDpost* = 1.41) improved more so than the “agreers” ($N = 19$; *Mpre* = 1.95, *SDpre* = 1.27; *Mpost* = 1.95, *SDpost* = 1.03), $t(16) = 2.71$, $p = .016$, $r = .56$. From these results it is noticeable that the disagreers scored lower on the pre-test than their peers. When only considering the disagreers, the game did have a significant impact, $t(15) = 3.45$, $p = .004$, $r = .67$.

Game Data

For the game data we considered what difficulty levels participants played (1 to 11), the time it took them to complete a level, how many times it took them to complete a level, how many actions they needed to take within a level to complete it, and–when playing the PCG version–when participants requested a new level. Regarding the latter, none of the 17 participants made use of the “random” button to get a new puzzle. If this can be generalized to all of 34 participants in this condition then it explains why the PCG manipulation may not have had any effect. For the US pilot study about a third in the PCG condition did not make use of the “random” button. As for the levels played, compared to the 17 (41%) US participants who completed the final level, only two (7%) did for the Nigerian students. Moreover, the US participants were able to complete at least Level 5, for the Nigerian students this was Level 3. In fact, only six (21%) were able to complete a level higher than six compared to the 38 (90%) of the US participants.

In total, the Nigerians (M = 33.4, SD = 25.3) played on average as many levels as the Americans (M = 31.9, SD = 13.0); they just played the earlier levels more so and also needed more time to play these levels. For example, it took the US participants a little over a minute on average to play Level 1 whereas it took the Nigerian participants more than four minutes. A difference in performance is not clearly noticeable until Level 4, where the Americans fail about twice the amount less than the Nigerians, $t(69) = 2.34$, $p = .024$, $r = .27$. Interestingly, unlike with the US pilot no difference is noticeable in the time to play for the collaborative condition.

Discussion

This study has helped to understand the differences in how students of different cultural backgrounds perceive, interact with, and learn from an educational game. After the implementation, the Nigerian students revealed that they wanted inclusion of hints, which is understandable considering their difficulty with progressing in the game. They also wished for a mobile version of the game. This is also not surprising as smartphones have rapidly penetrated Africa, and is arguably a very important tool in the future of education in Africa (Brown, 2003). However, the main take-aways from this study are the performance gap and the performance paradox. Based on these take-aways and the other results, we discuss the implications, also considering the limitations of this study.

Performance Gap

It is clear from this study that the USA students performed much better than the Nigerian students in terms of test scores. However, it is worthy to note that due to the program’s selectivity, there is an inherent bias that may be responsible for the wide margin. The USA students were selected based on high academic performance while the Nigerian students consist of a blend of students with varying academic status. Although for the Science Academy more than 50% of the participants have their own laptops, the majority of the participants from the Camp are from a humble background, with very limited or no access to computers. This tacitly suggests that their level of proficiency with computers is less compared to USA students and this may have impaired their ability to learn from the game, as they have more trouble to learn how to play it. Additionally, the Nigerian students have much varying game experience compared to the USA students, which may have played a role too. Of course, a possible bias may have been the research instruments that we used. Although we modified the language of the test, the test itself may have been too difficult to measure improvement. Regardless of all these possible biases, the performance gap is that significant that it would need to be considered in designing educational games for cross-cultural impact.

Performance Paradox

Overall, the game did not have a significant educational impact on Nigerian students, which is in contrast to the moderate improvement of the USA students. However, a performance paradox became apparent. Those who did not enjoy the game actually made drastic improvements. It should be noted that these students were the lowest performing students at the start, suggesting that they are academically either uninterested or have more difficulty in performing well. This outcome is promising but also discouraging. On the one hand, the game seems to impact those who need it; on the other hand, those who need it may not make use of it as they do not find it enjoyable.

Implications for Cross-Cultural Design

It is clear from the study that the USA and Nigerian students experienced the game in similar ways. The expressed greater enjoyment by the Nigerian students may have been the result that these students receive much less exposure to innovative educational technologies in their classrooms such as games. In fact, in Nigeria a game is still not considered a learning tool in most schools. The idea of a game is even considered a "taboo" in some classrooms. An interesting finding is that Nigerian girls seem more open to games than US girls to games, which is maybe telling about the role of games in both cultures. However, in general it is clear that the Nigerian students experience and play different games, which may have hindered them in accessing the learning content of the game. Both the performance gap and paradox are issues for further investigation but it seems clear that varying levels of difficulty may be necessary to increase cross-cultural usage.

Conclusion

By investigating the same game among middle school students in the USA and Nigeria, this study has enabled us to perform a cross-cultural evaluation of a CS teaching game. Findings from the study have led us to conclude that there is a need to introduce a cross-cultural perspective to educational game design and its evaluation in order to broaden a game's impact. Our results will be used to improve the next iteration of the game and achieve our ultimate goal of broadening the game to be both inclusive to girls as well across varying cultures. We intend to achieve this by integrating adaptive models that will be able to give personalized interactions to players notwithstanding their cultural background.

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