Strategic game moves mediate implicit science learning

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ABSTRACT
Educational games have the potential to be innovative forms of learning assessment, by allowing us to not just study their knowledge but the process that takes students to that knowledge. This paper examines the mediating role of players' moves in digital games on changes in their pre-post classroom measures of implicit science learning. We applied automated detectors of strategic moves, built and validated from game log data combined with coded videos of gameplay of 69 students, to a new and larger sample of gameplay data. These data were collected as part of national implementation study of the physical science game, *Impulse*. This study compared 213 students in 21 classrooms that only played the game and 180 students in 18 classrooms in where the players' teacher used game examples to bridge the implicit science learning in the game with explicit science content covered in class. We analyzed how learning outcomes between conditions were associated with six strategic moves students made during gameplay. Three of the strategic moves observed are consistent with an implicit understanding of Newton's First Law, the other three strategic moves were not. Path analyses suggest the mediating role of strategic moves on students' implicit science learning is different between the two conditions.

Keywords
Game-based science learning; Discovery with models; Automated detectors; Predictive modeling;

1. INTRODUCTION
Digital games are garnering increasing attention as potential learning environments as the volume of research increases indicating games may foster scientific inquiry, problem-solving, and public participation in breakthrough scientific discoveries [1]. Because nearly all youth and many adults participate in Internet-based games [2], educators and researchers are trying to tap this pervasive vehicle for learning and assessment environments for the 21st century [3].

Our research group studies how games can be used to improve learning of fundamental high-school science concepts (e.g. Newton's laws of motion). Our games use popular game mechanics embedded in accurate scientific simulations so that through engaging gameplay, players are interacting with digitized versions of the laws of nature and the principles of science. We hypothesize that as players dwell in scientific phenomena, repeatedly grappling with increasingly complex instantiations of the physical laws, they build and solidify their implicit knowledge over time.

It is not our intent that these games *teach* science content explicitly, but rather that they engage the learner with scientific phenomena allow them to build their implicit understandings about these phenomena through gameplay. To measure implicit learning in games, we built automated detectors of strategies we saw players using in the games [4, 5]. Thus, we address the question: *Do learners' strategic moves in the game correspond to increased implicit understanding of the science content outside the game?*

We also examine the role of the teacher in game-based learning. As Jim Gee points out, games rely on what he refers to as the Big "G" Game – the surrounding interactions that arise because of and support the game [6]. Post-game debriefing and discussions connecting gameplay with classroom learning are critical in helping students apply and transfer learning that takes place in games [7]. Our research attempts to capture the strategies players develop during gameplay that may reveal implicit knowledge, so that we can help educators seize and leverage that implicit learning to support explicit classroom learning.

Success in this approach will result in a new way to think about game-based assessments, starting not from prescribed learning outcomes, but from watching what types of strategy development actually take place. The final step of this research, reported in this paper, is to examine the extent to which strategic moves used while playing *Impulse* mediate changes in classroom measures of students' understanding of the same science content.

2. THE GAME: *IMPULSE*
The game *Impulse* is built for the web and wireless devices. Impulse challenges players use an impulse (a click or touch on the screen) to move their ball to a goal without crashing into any other (ambient) balls on the screen. All the balls have mass and obey Newton's laws of motion. As the levels of the game increase, more ambient balls are introduced, with varying mass.

Impulse is an attempt by designers to immerse a player in what is known to physicists as a n-body simulator. We hypothesize that by having to predict the motions of the particles, and their reactions to the force imparted by the impulse, the player will build implicit knowledge of forces and motions (Figure 1) that we could measure through data mining.

The first 20 levels of the game introduce players to 4 particles of different mass, providing 5 levels of experience with each of the 4

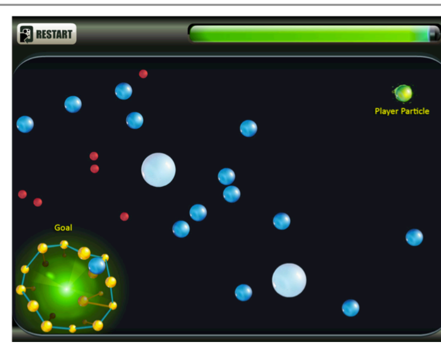

Figure 1: Impulse game

particles; across these 5 levels, the number of particles in the game space increases from 1 to eventually 10. Beginning in Level 21, players encounter particles with different masses simultaneously. As players reach higher levels with greater numbers and variety of masses of particles, they need to "study" the particles' behavior to predict the motion of particles so that they can guide their particle to the goal, not run out of energy, and avoid collision with other particles.

3. STRATEGIC MOVES

Our research attempts to capture and automatically assess the range of strategies players develop during gameplay. We identified a set of 6 strategic moves that we observe players making in the game *Impulse* (Table 1). Three of these strategic moves are theorized to constitute evidence of implicit understandings of Newton's First Law: each particle will keep moving on its path without an impulse or force from another particle. The remaining three strategic moves reflect an understanding of the game mechanic, but are not considered strong evidence of implicit understanding of Newton's First Law.

Table 1. Strategic moves and coding definitions

Strategic Move	Coding Definition
*Float	The player particle was not acted upon for more than 1 second
Toward goal	The learner intended to move the player particle toward the goal
*Stop/slow down	The learner intended to stop or slow the motion of the player particle
*Player path clear	The learner intended to move non-player particles to keep the path of the player particle clear
Goal clear	The learner intended to move non-player particles to keep the goal clear
Buffer	The learner intended to create a buffer between the player and other particles to avoid collision

*Evidence of implicit understanding of Newton's First Law

Video data was collected from 69 high school students, to develop automated detectors of these strategies. Every click in randomly selected, three-minute video segments, one per student, was coded for these strategic moves, with every player action in these video segments coded as to which strategy it represented. Two coders coded ten videos with Kappa values exceeding 0.70 for all of these strategic moves [4, 5].

We built classifiers to infer the ground truth labels created by the video coders. For each player action a set of 66 features of that action were automatically distilled, including the time since the last player action and the distance between the player particle and goal. These features were then aggregated at the click level to map to the labels provided by the video coders [6]. Classifiers were created using J48 decision trees within RapidMiner 5.3 that mapped the student behaviors in the features distilled from the clickstream data to the training labels, cross-validating at the student level. All detectors discussed here had cross-validated Kappas between 0.51 and 0.86 and A' between 0.78 and 0.97 [6].

4. IMPLEMENTATION STUDY

Having developed these detectors of student strategic moves, we then collected a much larger data set to be able to study the relationship between in-game strategic moves, pedagogical practices, and learning outcomes. To this end, we conducted an implementation study [8] to examine the conjecture that implicit learning in game play can help prepare students for classroom learning.

Forty-two teachers were assigned to one of three groups (14 per group). Teachers could include a maximum of three sections of an individual class. Of the 42 teachers who initially agreed to participate, 23 teachers completed the study (55 percent), resulting in this final sample with complete data:

Bridge: 180 students in 18 classes in which 8 teachers incorporated game examples to bridge game play and science content

Game Only: 213 students in 21 classes in which 10 teachers encouraged students to play the game, but provided no in-class interaction around the game

Control: 108 students in 11 classes in which 5 teachers taught the science content as they normally do, without games.

Students took pre-post online assessments with six items, three dealing with Newton's First Law and three dealing with Newton's Second Law. All items were written to be answerable with an intuitive understanding of the physics concepts and were piloted with think-aloud interviews. Both assessments had a maximum of 10 points possible. Assessment scores were standardized as Z-scores and all coefficients are reported in effect sizes.

Hierarchical linear modeling of data from the 23 teachers (50 classes) shows a significant positive effect of the Bridge and Game Only groups compared to the Control group on student's post-assessment scores after accounting for pre-assessment scores [8]. This group effect, however, was significantly moderated by whether or not the class was a Honors/AP class (Figure 2). There was also a significant main effect for gender, with female students receiving lower post-scores than male students.

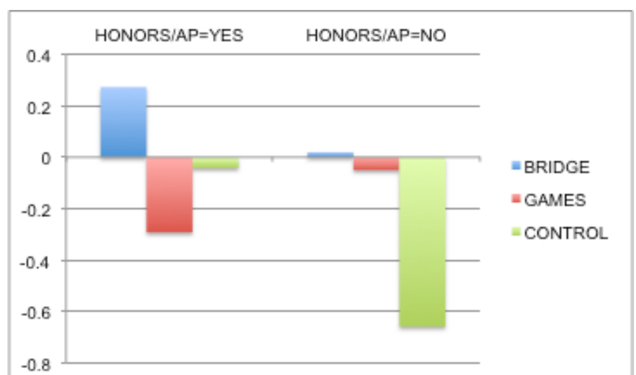

Figure 2: Predicted post-assessment scores across study conditions in Honors/AP classes versus non-Honors/AP classes (y-axis=standard deviations from the mean post-score, accounting for all components of the HLM model) [8].

The group effect was significant among students in non-Honors/AP classes. Among students in Honors/AP classes, Bridge students performed better than Game only students but not Control students. These results, while intriguing, tell us that the Bridge condition was generally best, but do not explain why Bridge was better. Did the teachers in the Bridge condition promote learning separate from the game? Or did it actually drive different behavior within *Impulse*, making the game a more valuable learning experience?

5. THE ROLE PLAYED BY IN-GAME STRATEGIC BEHAVIOR

The final step in this research, and the specific contribution novel to this paper, is to connect in-game measures of implicit science learning with external measures of those concepts. Specifically, we hypothesize that strategic moves consistent with an implicit understanding of Newton's First Law will mediate changes in these external assessments, whereas the other strategic moves will not be associated with changes in the pre-post assessments.

5.1 Apply Automated Detectors

We applied the automated detectors built with the sample of 69 students to this larger sample of gameplay data from 393 students to detect when learners used each type of strategic move. The detectors were applied to every student action during the entire duration of gameplay, 1.01 million actions in total. The same log data features were automatically distilled for this entire data set as for the initial creation of the models. Then this data was inputted into RapidMiner 5.3, along with the previously generated W-J48 decision trees model files, in order to apply the trees to the data. The result was a prediction for every click, for each of the relevant strategic moves in Table 1, of the detector's confidence that strategy was being used. Every learner action in this game was thereby annotated with an estimated probability that the learner was using each of the strategic moves.

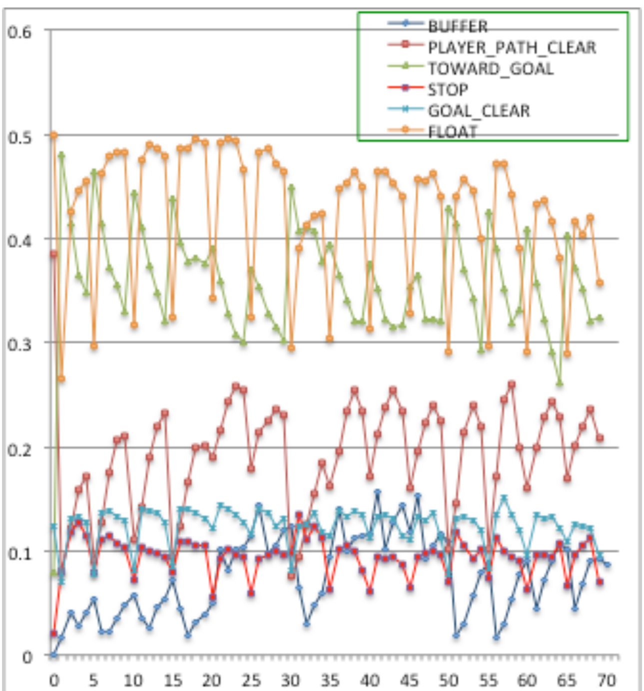

Figure 3: Average probability for each strategic move (y-axis) by game level (x-axis)

Figure 3 shows the average probability for each strategic move at each game level. The most prevalent strategic moves were Toward Goal and Float, with Float being evidence for implicit understanding of Newton's First Law. The least common strategic moves were Stop/Slow Down (evidence for implicit understanding) and Buffer. Float reflects the absence of activity (on the player particle in the time prior to the click and can co-occur with any other strategic move. Stop/Slow Down, in contrast, reflects a deliberate attempt by the player to stop or slow down the motion of the player particle. Float and Stop/Slow Down both reflect understandings of Newton's First Law e.g., a mass will keep moving until acted upon by a force, but the float strategy is a passive move and the stop strategy is an active move.

Figure 3 also shows evidence of shifts in behavior every 5 levels. The cyclical patterns in this data correspond with the planned transitions in the game. Every 5 levels, the game reduces the difficulty level of the game when a new challenge (e.g., particle with a different mass, two particles with different masses) is introduced, by decreasing the number of particles in the space (a decrease in gameplay challenge which balances for the increase in conceptual challenge). However, the reduction in the number of particles makes it more likely a player will simply push the particle toward the goal, leading to corresponding declines in all of the other strategies. Overall, as the number of particles in the game space increases, the average probability of using the simple Toward Goal strategy declines while the probabilities of using the other strategies increase.

5.2 Path Models

Path models were built to estimate the mediating role of each strategic move between prior achievement and post assessment scores using SmartPLS [9]. As pre-assessment scores and Honors/AP enrollment were significantly correlated, they were combined into a single latent variable labeled 'Prior Achievement'. Separate path models were created for the Bridge and Game Only conditions (Figures 4 and 5). The standardized coefficients appear on the paths and the adjusted R^2 values appear in the circles. T-values were calculated using a bootstrapping process with 1000 samples.

Among students in Bridge classrooms, the use of the Buffer strategy significantly mediates the impact of prior achievement and gender on post-scores (adjusted $R^2 = 0.151$, p=0.005). This suggests using the Buffer strategy enhanced Bridge student's understanding of the concepts, beyond what is accounted for their prior levels of achievement. In Game Only classrooms, student use of the Buffer (adjusted R2 = 0.095, p=0.018), Stop (adjusted R^2 = 0..149, p<0.001), and Float (adjusted $R^2 = 0.109$, p=0.031), strategic moves significantly mediate the relationship between prior achievement & gender on post-scores. In these classes with no teacher scaffolding of the gameplay, use of the Buffer and Float strategies enhanced student's understanding, but use of the Stop strategy diminished their understanding.

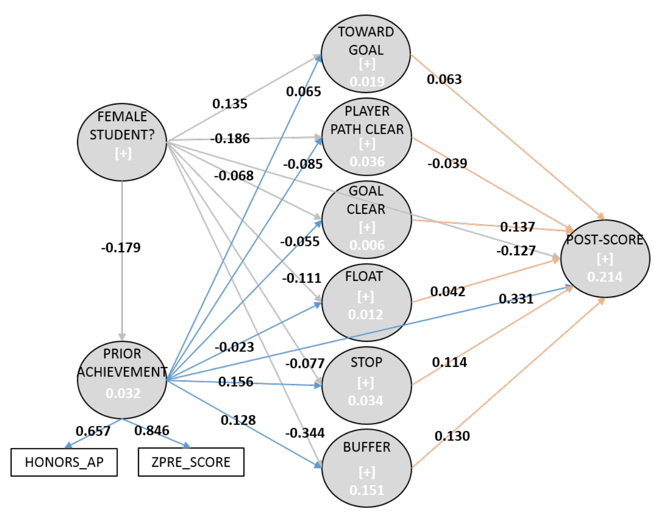

Figure 4: Full path model—Bridge Classrooms

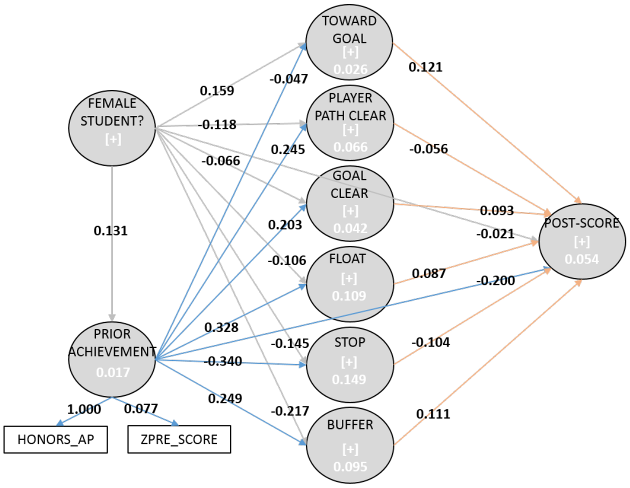

Figure 5: Full path model—Game Only Classrooms

In Bridge and Game Only classrooms, once gender differences in strategic moves are taken into account, the impact of being a Female student on post-scores is no longer significant (coeff=-0.127 in Bridge classrooms, p=0.108; coeff=-0.021 in Game Only classrooms, p=0.759). This suggests the gender main effect found in the HLM analyses may be entirely attributable to gender differences in gameplay. One potential explanation is that while females play games at equal rates as males [2], the types of games they play and the amount of time they spend doing so may vary. Success in a rapid-fire, reaction time educational game like *Impulse* may require gameplay skills more congruent with games more popular among males (e.g, first person shooters) than the social, puzzle, and role-playing games females tend to prefer [2].

6. DISCUSSION

It is noteworthy that two of the three strategies we anticipated reflecting an implicit understanding of Newton's First Law were significant mediators in Game Only classrooms. Player Path Clear, a strategic move applied to non-player particles, may not have been a significant mediator because it is likely to co-occur with Float, a strategic move applied to the player particle. By contrast, the other strategies were not significant mediators with one exception: Buffer, the simultaneous use of force on more than one particle when the particles were in close proximity to each other. Sometimes those forces were in direct opposition to the other particles (i.e., simultaneous use of the Stop strategy), while other times they were not. While Buffer was not a strategic move we a priori identified as consistent with an understanding of Newton's First Law, these results suggest it plays a mediating role similar to Stop and Float. Use of the Buffer strategy was associated with higher post-scores in Bridge and Game Only classrooms.

The negative mediating relationship of the Stop strategy in Game Only classrooms is consistent with the HLM findings shown in Figure 2, where students in Honors-AP classes did not perform on the post-assessment as well as students in non-Honors/AP classes [8]. This lack of use of the Stop strategy is consistent with the lack of understanding of Newton's Laws exhibited on the pre-post assessments. This suggests that learners who already have a basic understanding of the scientific concepts may not be aided by the game as a sole intervention. Their improvement in science understanding is enhanced when the game and the teacher bridge materials are used together. These results reinforce the importance of teachers providing bridges between gameplay and science content.

This paper also makes an important contribution to the space of problems that can be addressed by EDM. Many projects have attempted to detect strategic behavior in online learning. This project, by detecting strategic behavior explicitly connected to core concepts, and modeling how different classroom activities influence in-game behavior, shows how EDM methods can bridge understanding of the relationship between what students learn in class, and how they behave online. As such, we are able to see the concrete impact of classroom activity on gameplay behavior, and to measure its scope and manifestations.

In the long term, then, this combination of methods – automated detectors, path analysis, and classroom studies – creates the potential to make EDM useful for investigating interventions not just online, but in classroom settings as well.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] Cooper, S., et al. (2010). Predicting protein structures with a multiplayer online game. *Nature, 466*(7307), 756-760.

[2] Lenhart, A., et al. (2010) *Social Media & Mobile Internet Use Among Teens and Young Adults*. Washington, DC: Pew Internet & American Life Project.

[3] National Research Council. (2011). *Learning Science Through Computer Games and Simulations. Committee on Science Learning: Computer Games, Simulations, and Education*. M. Honey & M. Hilton (Eds.). Washington, DC: National Academies Press.

[4] Rowe, E., Baker, R., & Asbell-Clarke, J., Kasman, E., & Hawkins, W. (2014). Building automated detectors of gameplay strategies to measure implicit science learning. *Proceedings of the International Conference on Educational Data Mining*, 337-338.

[5] Rowe, E., Baker, R. & Asbell-Clarke, J. (in press). Serious games analytics to measure implicit science learning. To appear in C.S. Loh, Y. Sheng, D. Ifenhelter (Eds). *Serious Games Analytics*. New York: Springer.

[6] Gee, J. (2008). Learning and Games. In K. Salen (Ed). *The Ecology of Games: Connecting Youth, Games, and Learning*. Cambridge, MA: The MIT Press. 21–40.

[7] Ke, F. (2009). A qualitative meta-analysis of computer games as learning tools. In R. E. Furdig (Ed.), *Handbook of Research on Effective Electronic Gaming in Education* (pp. 1–32). New York: IGI Global.

[8] Rowe, E., Asbell-Clarke, J., Bardar, E., Kasman, E., & MacEachern, B. (2014, June). *Crossing the Bridge: Connecting Game-Based Implicit Science Learning to the Classroom.* Paper presented at the 10th annual meeting of Games+Learning+Society in Madison, WI.

[9] Ringle, C. M., Wende, S., & Becker, J.M. (2015). SmartPLS 3. Boenningstedt: SmartPLS GmbH, http://www.smartpls.com.