Extending the Impact of Digital Games by Supporting Analogical Reasoning

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Abstract
The potential of digital games to support learning has been well documented, and yet the empirical evidence on the impacts of digital games on student learning finds varied effects. This paper explores an issue that we believe is central to realizing the potential of digital games for influencing learning: the relationship between games and the transfer of knowledge, and specifically the need to support the meaningful integration of games into instruction. We examine the theoretical and empirical literature on how middle-grade students can transfer knowledge and skills gained from digital gameplay to develop new conceptual models of the science concepts that the games target, focusing on the research on the use of analogical reasoning in science. Finally, we illustrate this approach with an example of using analogies with digital games in middle school science classes.

Author Keywords
Video Games; Science Education; Instruction.

ACM Classification Keywords
K.3.1[COMPUTERS IN EDUCATION]: Computer Uses in Education---Computer-assisted instruction (CAI)

INTRODUCTION
Despite the growing prevalence of the use of digital games in school to support student learning, there is little consensus on the characteristics and conditions necessary for effective use. A key goal of incorporating

gameplay into classrooms is to enable students to engage with digital games and develop flexible knowledge that can be applied to other contexts outside of the gameworld. However, little is known about the specific conditions necessary for students to be able to develop flexible conceptual knowledge through gameplay. In this paper, we describe specific instructional techniques to incorporate gameplay into the science classroom that draw on theory and evidence about how knowledge transfer occurs from a familiar domain, such as a digital gameworld, to a new domain and how teachers can support this process.

This paper explores how particular features of digital gameplay and subsequent instruction for middle-grade science learning can support consolidation and transfer of *conceptual* understanding beyond the gameworld. Specifically, we describe theoretical and empirical literature on how middle grade students can transfer knowledge and skills gained from digital gameplay to develop new conceptual models of the science concepts that the games target. We examine empirically-based approaches to incorporating digital games into instruction and attend particularly to the implications that game design, and representation in particular, may have for learning and instruction. We argue that more research is needed on the interaction between games and instruction, and provide an example of our initial approach to this problem, with the purpose of informing future research.

BACKGROUND

The potential of digital games to support learning rests on two main theories of action. First, games can serve to increase student engagement and motivation. Children can be intrinsically interested in and motivated by media and technology experiences, and this increased motivation is associated with deeper engagement and processing. For example, digital games can provide students with the motivation to repeatedly practice a skill towards mastery, or persist in approaching a difficult concept [12]. Second, games can improve student skills and knowledge directly through interaction with a virtual representation of complex environments and processes. Although digital games and media clearly hold potential for influencing learning, there is less consensus in the literature about the conditions required to support effective use of digital games as part of a longer instructional arc in the classroom.

Games and Instruction

Digital gameplay is widespread in elementary and secondary classrooms—just under three-quarters of K-8 teachers report using digital games in class [14]. However, positive impacts on learning are less widespread. Research on gameplay and learning finds varying results [3, 16, 18]. These inconsistent findings have been attributed in part to lack of attention to the most effective means of incorporating games into instruction [18]. In fact, some research suggests that the ways in which teachers incorporate technology interventions into instruction are more significant predictors of student learning than the quality of the technology intervention itself [15].

An extensive body of research documents the need for going beyond simply incorporating digital game playing into the classroom as an isolated activity. Additional game-related instruction is not enough to affect learning, but rather, the *ways in which* the instruction integrates the game has implications for learning [2, 17]. Studies of game use suggest that students do not spontaneously transfer the knowledge gained from the

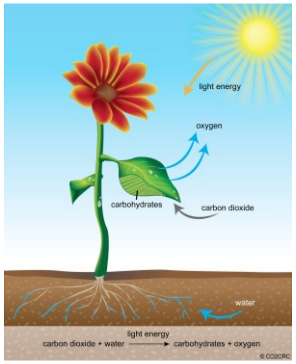

Figure 1: Image of analogy target, photosynthesis

Figure 2: Image of analogy source, Ruby Realm photosynthesis-related game.

game to the target concept in the domain [4]. Although there is little conclusive evidence regarding the features of instruction that mediate the relationship between games and instruction in order to support student learning [2], there is some suggestive evidence that metacognitive strategies related to *evaluation* and *reflection* about the gameplay are essential for students to integrate the new knowledge from the game [1, 18]. Similarly, teachers' guidance and meta-cognitive scaffolding helps ensure students can transfer their knowledge from the game to the target concept, for example, asking students to think aloud about the knowledge they gained from the game as well as how it might connect to real-world concepts [1, 18].

Analogies in Science Learning

Thus, a critical element in the use of games for learning is supporting knowledge transfer: how students can apply knowledge gained from gameplay in a new context to develop conceptual understanding of new content and concepts. To address this problem, our project draws specifically from the research on the use of analogical reasoning in science [8] and frames gameplay as the source for a series of relational analogies, to be mapped to the target concepts during instruction.

Analogies are a foundational process of critical thinking and reasoning in science, used both by scientists to communicate, explain and also guide scientific inquiry and reasoning as well as by science teachers to support student learning [9]. Reasoning through analogies provides a means to build student understanding of new or less familiar topics based on prior knowledge providing a familiar entry point to an otherwise unfamiliar concept. Using analogical reasoning, students apply knowledge of the initial familiar source to reason and develop new inferences about the target concept [8,9]. Research on use of analogies in science instruction suggests it is a particularly effective means to support learning. Comparisons such as analogies and metaphors broadly have the potential to support learning, but the power of the comparisons to create new conceptual knowledge or schema seems to be tied to the use of the specifically relational comparisons of structures and processes that are characteristic of analogical reasoning. Comparisons that rest solely on comparing surface features and physical attributes rather than structural similarities tend to have limited explanatory power [5]. In contrast, comparisons based on mapping correspondences in deep structure and the underlying patters of relations can support more robust conceptual leaps and flexible knowledge. Other central characteristics of the types of analogies that support development of new conceptual schema include comparisons that are novel to the learner rather than conventional, systematically connected to the target concept with clear one-to-one correspondences, and distal from the target domain [6].

Digital Games and Analogical Reasoning

Digital games provide a particularly compelling means to support analogical thinking processes. They can be designed purposefully to provide student with a novel visual and interactive experience that systematically relates to the target context. Digital games and the deep engagement they tend to foster may also provide a particularly effective means to ensure that students with disparate levels of preparation are able to develop a shared understanding of the analogical source and its structures and processes. While a game that functions like a simple metaphor might require comparison of physical attributes between the game and the target concept, a game that supports analogical reasoning conveys a relational comparison, in which there is a

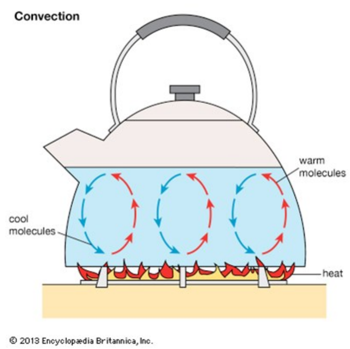

Figure 3: Image of analogy target, convection (heat transfer)

Figure 4: Image of analogy source, Galactic Gloop heat transfer-related game

system of relations between the game and the target concept.

Research on use of analogies in the classroom suggests that students are better able to transfer knowledge between analogical domains when teachers initially provide explicit instruction regarding the corresponding structures and processes between the analog source and target [7, 10]. It seems likely then that students may gain more from gameplay if teachers explicitly map game metaphors or analogies to instructional content [11]. This process is likely to be particularly important for games that do not obviously physically relate to their real-world counterpart [18]. Effective instructional techniques to incorporate analogies and metaphors should include explicit cues that identify which aspects of the source (the game) are critical for the analogy and understanding of the target concept [9]. Additionally, one risk in using analogies is that it can lead to false conclusions. To avoid overextensions of analogies that can lead to misconceptions, instruction that attends to the differences between the game and the target concept and identifies where the analogy breaks down is central to the effectiveness of the mapping [8].

GAMES AND ANALOGIES IN PRACTICE

Although the literature provides compelling rationale for the use of analogical reasoning to incorporate games into instruction, there is little concrete guidance describing instructional practice. In this section, we describe one approach to incorporating digital games in middle-grades classes using analogies to support science learning.

Instructional Modules

Specifically, we developed three instructional modules for middle school science students that incorporate digital games. Each module focuses on a topic related to energy transfer, including photosynthesis, heat transfer and electricity, using three different digital games developed under a grant from the U.S. Department of Education. In each game, an analogy to the target science concept is embedded in a different core mechanic—the actions the player must engage in repeatedly in order to progress through the game. Each game also uses visual contexts that are designed to engage the player through playful narratives and imagery unrelated to the target concepts (Figures 1-4 illustrate images of the games and target concepts). By playing the games students develop shared understandings and mental models of the game processes and mechanics, and this experience can provide a foundation from which to build and frame new knowledge of more abstract science concepts.

For example, in one of the games, players navigate a vast cave in search of missing friends, only to discover that they have entered a hidden, treasure-filled world whose vampire inhabitants do not like intruders. Players have a guide in a robot powered by artificial photosynthesis, who helps them fend off angry vampires. Players must find light sources where the robot can generate the glucose he needs for power. Using the robot’s molecule replicator, they shoot light beams at carbon dioxide and water molecules, breaking them apart and recombining the atoms to form glucose, participating in the process of chemical change.

Instruction to Support Analogical Reasoning

For each of the three target concepts and associated games, researchers designed an instructional sequence in which teachers provide their students with at least 45 minutes of gameplay during one class and then incorporate two associated sets of discussion questions

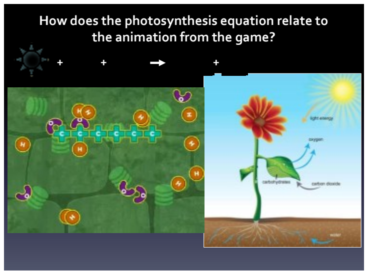

Figure 5: Image of power-point slide asking questions to support students to connect game to photosynthesis

connecting the game to the target science content, designed to complement rather than supplant their existing instruction on the topics. These questions focus first on identifying the mechanical structures underlying the games and second on mapping the mechanics of the game that are the same in the concept of focus and in the process developing new inferences about the concept. The teacher and students also examine where the analogies break down, to prevent over-generalizations to the target concept.

We also provided teacher with specific training on use of research-based cognitive supports for analogies, based on a schema of cues to focus attention on relational similarity developed by Richland, Zur & Holyoak [13] to analyze 8th-grade teachers' use of analogies in mathematics. Richland et al. created the schema based on cognitive science research regarding how students learn mathematics from analogies. The training and materials focus on providing these specific cognitive supports:

1. Attend to relational structures or processes and not solely object attributes
2. Ensure student familiarity with the source—that students have time and support to develop a deep understanding of the digital game and mechanics within
3. Present images of the source analog visually during discussion of the target concept
   a. Use spatial cues to highlight the correspondences such as a parallel diagram
   b. Use comparative hand or arm gestures to mark the relationship between game and target concept
   c. Use mental imagery or visualization
4. Delineate both similarities and differences between source (game) and target concept

The supports are particularly focused on providing visual cues, with the purpose of lessening cognitive strain and to create more opportunities to connect deeper structures. We also provide teachers with PowerPoint slides that include discussion questions with pictures and short animations of the game that correspond to images of the target concept (see Figure 5). For example, in the photosynthesis game, students break apart water and carbon dioxide molecules using a yellow-colored rays. Teachers ask students to explain the role of the yellow rays in the game, and then to explain how it relates to the role of sunlight in photosynthesis. In the game the robot makes glucose, methanol, and tear gas molecules using carbon, hydrogen, and oxygen atoms in different combinations. Another discussion question asks students to identify how this process relates to the products of photosynthesis—namely that plants produce glucose, which they use for food, and further that plants do not produce methanol or tear gas.

CONCLUSION AND NEXT STEPS

Too little is known about how gameplay can support the development of flexible conceptual knowledge, and the role of curriculum and teachers in supporting this process. As an example of how the field should move forward, we describe one approach to incorporating science games into instruction that rests on theory and evidence related to analogical mapping that we hypothesize will result in greater student learning compared to traditional instructional techniques. Our next steps will explore this approach further through a study examining the relationship between student learning and instruction to support analogical reasoning. Results from this study should generate new knowledge about how students draw on games as grounds for analogical reasoning and how their teachers' structuring of that process influences conceptual knowledge.

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REFERENCES

1. Baek, Y., Kim, B., & Park, H. 2009. Not just fun, but serious strategies: Using metacognitive strategies in game-based learning. *Computers & Education*, 52: 800–810.
2. Clark, D., Tanner-Smith, E., Killingsworth, S . 2014. Digital Games, Design and Learning: A Systematic Review and MetaAnalysis. Menlo Park, CA: SRI International.
3. Connolly, T.M., Boyle, E.A., MacArthur, E., Hainey, T., Boyle, J.M. 2012. A systematic literature review of empirical evidence on computer games and serious games. *Computers and Education*, 59(2): 661–686.
4. Culp, K.M., Martin, W., Clements, M., & Presser, A.L. 2015. Testing the impact of a pre-instructional digital game on middle-grade students' understanding of photosynthesis. *Technology, Knowledge and Learning*, *20*(1): 5-26
5. Gentner, D. 1983. Structure –mapping: A theoretical framework for analogy. *Cognitive Science* 7: 155-170.
6. Gentner, D., Bowdle, B., Wolff, P. & Boronat, C. 2001. Metaphor is like analogy. In *The analogical mind: Perspectives from cognitive science,* Gentner, D., Holyak, K. & Koknov, B. (Eds.). Cambridge, MA: MIT Press, 199-253.
7. Gentner, D., Loewenstein, J., Thompson, L., & Forbus, K. 2009. Reviving inert knowledge: Analogical abstraction supports relational retrieval of past events. *Cognitive Science,* 3: 1343-1382.
8. Gentner, D., & Smith, L. 2012. Analogical reasoning. In *Encyclopedia of human behavior,* V. S. Ramachandran (Ed.). Oxford, UK: Elsevier, 130–136.
9. Holyoak, K. & Thagard, P. 1996. *Mental Leaps: Analogy in Creative Thought.* Cambridge, MA: MIT Press.
10. Novick, L. & Holyoak, K. 1991. Mathematical problem solving by analogy. *Journal of Experimental Psychology* 17(3): 398-415.
11. Reese, D. 2007. First steps and beyond: Serious games as preparation for future learning. *Journal of Educational Multimedia and Hypermedia, 16*(3): 283-300.
12. Renninger, K. A. 2000. Individual interest and its implications for understanding intrinsic motivation. In *Intrinsic motivation: Controversies and new directions,* C. Sansone and J. M. Harackiewicz (Eds.). San Diego, CA: Academic Press, 373-404.
13. Richland, L. E., Zur, O., & Holyoak, K. J. 2007. Cognitive supports for analogy in the mathematics classroom. *Science,* 316: 1128-1129.
14. Takeuchi, L. M., & Vaala, S. 2014. Level up learning: A national survey on teaching with digital games. New York: The Joan Ganz Cooney Center at Sesame Workshop.
15. Tamim, R.M., Bernard, R.M., Borokhovski, E., Abrami, P., & Schmid, R.F. 2011. What forty years of research says about the impact of technology on learning: A second-order metanalyasis and validation study. *Review of Education Research* 81(1): 4-28.
16. Tobias, S., & Fletcher, J. D. 2012. Reflections on "A review of trends in serious gaming." *Review of Educational Research,* 82(2): 233-237.
17. Wouters, P., van Nimwegen, C., van Oostendorp, H., & van der Spek, E. D. 2013. A Meta-Analysis of the Cognitive and Motivational Effects of Serious Games. *Journal of Educational Psychology,* 105(2): 249-265.
18. Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullen, G., Lai, B., Simeoni, Z., Tran, M. & Yukhymenko, M. 2012. Our princess is in another castle: A review of trends in serious gaming. *Review of Educational Research*, 82: 61–89.