

From Playing a Game to Solving an Equation

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Abstract: Although the potential of digital games as instructional resources is well known, facilitating deeper learning from games is acknowledged to be a considerable challenge. This paper argues that examining transfer from the realm of a digital game to the realm of a discipline as a case of analogical reasoning can be productive when trying to understand and later design scaffolds that connect the knowledge representations embedded in games to formal disciplinary knowledge representations used at school. This claim is supported through (1) an analysis of the design of a multiplatform commercial educational game Dragon Box 5+, aimed at teaching children to solve algebraic equations; and (2) tracking the experiences of several players. The transfer from procedures in the game to algebraic procedures is explored as a case of analogical reasoning, specifically addressing central sub-processes such as retrieval, mapping, evaluation of inferences, and the role of prior knowledge in these processes.

Introduction

Digital games are considered to be a powerful medium for learning (Aldrich, 2004; Gee, 2003). However, some studies of game-based learning as an instructional resource in the formal disciplines suggest that the links between the game world and formal disciplinary knowledge required in a school-based context are not straightforward (Holbert & Wilensky, 2012; Kebritchi, Hirumi, & Bai, 2010).

Clark et al. (2011) and Habgood and Ainsworth (2011) showed that digital games that integrate the subject matter with a game idea in which the external representation of the learning content is explicitly explored through the core mechanics of the game are more efficient in creating this link. Clark et al. termed this "conceptually-integrated games" whereas Habgood and Ainsworth called it "intrinsically integrated games", and both acknowledge the challenge of transfer from the game world to formal disciplinary-based reasoning. Holbert and Wilensky (2012) attributed the transfer problem to the incongruence of the epistemological framings (Hammer, Eleby, Scherr, & Redish, 2005). More specifically, the set of expectations that a student has about a real-world or school-based situation that requires disciplinary-based reasoning is very different from the set of expectations in the game world. Based on this explanation they suggested that when the appropriate formal representations are integrated into the player interface, the likelihood for transfer increases since the players are implicitly encouraged to connect different epistemological framings.

The present paper suggests a complementary explanation. As in Holbert and Wilensky's paper, the theoretical approach employed is the Knowledge in Pieces epistemological perspective (e.g., diSessa, 1993; diSessa & Sherin, 1998; Wagner, 2006); however, following Kapon and diSessa (2012), the transfer from the realm of the digital game to the realm of the discipline is theoretically explored as a case of analogical reasoning. Central sub-processes of analogical reasoning such as retrieval, mapping, evaluation of inferences, and the role of prior knowledge are examined in the context of playing an educational digital game. The theoretical claims will be illustrated through an analysis of an award-winning commercial educational digital game entitled Dragon Box Algebra 5+ (WeWantToKnow), and examples from players' experiences (7 children, 5th, 6th and 7th grades). The 7th graders who played the game played after learning to solve linear equations in school. The 5th and 6th graders played before a formal presentation of algebra.

Theoretical Framework

Analogies and analogical reasoning have been studied from a wide range of perspectives. A core focus of attention has been the ways in which analogies foster understanding in some new situation or domain (the target) by comparing it to a more familiar one (the source/base) (Gentner, 1983; Holyoak & Thagard, 1989). Several models suggest that spontaneous analogical transfer is more likely to occur when the target shares multiple features with the source analogue (Falkenhainer, Forbus, & Gentner, 1986; Holyoak & Koh, 1987) and that this process is mediated by pragmatic goals (Holyoak & Thagard, 1989; Keane, 1996). These models cohere with the design principles of conceptually integrated games, in which the degree of similarity of representations and actions between the realm of the game and realm of the discipline is by definition increased.

The ability to apply relational knowledge across different contexts is a powerful learning mechanism. In analogical reasoning this transfer takes place when relations from a familiar source domain are mapped onto relations and objects in the target domain, allowing the individual to analogically infer new relations or objects in the target domain (Dunbar, 1995; Gentner, 2010; Holyoak & Thagard, 1989). However, spontaneous retrieval of a relevant, appropriate, and productive source for an analogy is not trivial, and often superficial similarity

plays a major role in analogical retrieval rather than deep relational structures (Gentner, Rattermann, & Forbus, 1993; Gick & Holyoak, 1980). The issue of retrieval seems highly germane to the development of links between the game world and formal disciplinary knowledge required in a school-based context. After all, why should a student even consider an activity in a game setting as similar to an activity in a formal disciplinary context?

Studies of students who reason through instructional analogies show that the evaluation of the plausibility and applicability of an analogical inference is not just a question of the degree of similarity and pragmatic considerations. Rather, these studies suggest that the learner's knowledge in the target domain directly affects the acceptance or rejection of this explanation (Brown & Clement, 1989; Kapon & diSessa, 2012). Kapon and diSessa (2012) argued that learning through analogy always involves a bootstrapping process *within* the target domain. Drawing and elaborating on the model of p-prims (diSessa, 1993), they suggested that when reasoning through instructional analogies, students activate particular knowledge elements, termed explanatory primitives, or e-prims, in light of which they assess the plausibility of the analogical inference. Differences between individuals accepting or rejecting the suggested analogical inferences were explained by differences in the repertoire of cued knowledge elements and a dynamic assessment of their applicability to the target domain. Thus, it is reasonable to expect that prior knowledge in general and in the target disciplines in particular will affect the analogical transfer from the realm of the game to the realm of the discipline, not only in terms of retrieval but also in terms of the evaluation of inferences.

The Game

This paper analyzes a commercial educational digital game that aims to teach children to solve algebraic equations. Dragon Box 5+ (WeWantToKnow) is an award-winning multiplatform commercial game. Players start with a two sided game board, a box and some cards. The goal is to get the box alone on one side of the game board by cancelling out negative cards, adding cards to both sides, placing cards below or next to a group of cards. Gradually the cards are replaced by numbers and variables, and actions in the game start to *look* like addition, division and multiplication operations (see Figure 1). The game has 5 chapters with 20 problems ("levels") each. As the game progresses, instead of getting the box alone the player solves (at least in terms of representations) algebra equations for x . During the game the player gets constant feedback.

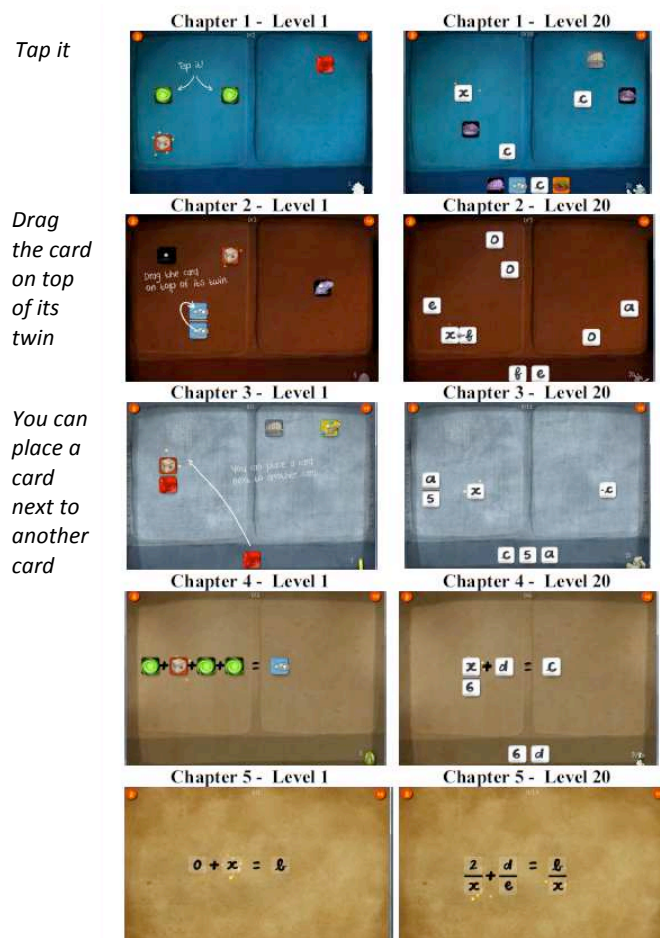


Figure 1. The game board as the game progresses. On the left are the instruction that appear on the screen.

Tracking Players' Experience

Data on players' experience were collected by graduate students enrolled in a seminar taught by the author. A considerable part of the seminar dealt with the notion of transfer of learning from multiple perspectives. Seven graduate students (5 math teachers, 1 science teacher, and 1 psychologist) participated in the seminar. Each graduate student worked with one child (5th-7th grade) who volunteered to participate in the study. Each child ($N=7$) met with the graduate student five times (25-50 minutes each). During each meeting the child played and completed one chapter and the grad student observed. The computer screen (game board and in the corner, a video webcam of the child) and all the conversations were recorded. The students were instructed that if the child asked for assistance during the game they should only use "game language" unless the child explicitly used mathematical terms. A short semi-structured interview took place, after each chapter. The interviewer asked the child to return to one or two levels, solve them again and explain how he or she solved them. No questions were asked during the game to avoid interrupting the flow (Czikszenmihalyi, 1990). Additional questions were asked to probe whether the child made connections to the mathematical meaning. The interviewers also took field notes regarding difficulties on specific levels, requests for assistance, etc. All the sessions (play and interview) were transcribed including a time stamp and a description of the child's actions on each level. Particularly difficult levels were identified based on the relative time spent on the level, the number of repetitions needed to get it right, and explicit requests for assistance.

Analogy from the Realm of the Game to the Realm of Algebra

The next subsections discuss central terms and sub-processes in analogical reasoning, such as mapping, surface and relational similarities, retrieval, the source of the analogy, and the role of prior knowledge in the evaluation of the analogical inference, as they come to bear on the design and player experience of Dragon Box 5+.

Relational Similarities

At the design level, Dragon Box presents an analogy with rich relational similarities. The player's actions in the game as well as the rules that are enforced with the constant feedback given to the player are isomorphic to the actions and rules used when solving linear algebraic equations. (1) When adding a card (equivalent to arithmetic addition) to one side of the game board, the player is graphically reminded to add the same card to the other side. In algebraic equations the rule is to add variables and numbers to both sides of the equation. (2) When placing a card next to (equivalent to arithmetic multiplication) or below (equivalent to division) another card, the player is graphically reminded to do so to all groups of cards on both sides of the game board. Again, when we multiply or divide one side of an equation by a number or variable, we should do the same to the other side of the equation, and this means multiplying or dividing every component on each side of the equation with the same number or variable. (3) The player receives feedback after completing each level: (a) the box is alone - equivalent to success in isolating the variable; (b) right number of moves - equivalent to success in efficiently solving the equation with a minimal number of steps; (c) right number of cards - equivalent to canceling redundant numbers and variables (e.g., cancelling $-2+2$). In fact one might even be tempted to think that the actions in the game and the algebraic actions are isomorphic production rules (Anderson, 1987).

Analogical Transfer

Despite the rich relational similarities in the structure of the actions in the game to algebraic procedures, very few students spontaneously ascribed mathematical meaning to their activities, and those who did so ascribed only partial meaning (e.g., treating the equivalent to addition in the game as addition, but not seeing the equivalent to multiplication in the game as multiplication). The literature on analogical reasoning suggests several explanations for the spontaneous failure of analogical transfer: (1) The students did not understand the source of the analogy (as in Clement, 1993). (2) The students were unable to retrieve the relevant information (as in Gentner, Loewenstein, Thompson, & Forbus, 2009). (3) Based on their prior knowledge about games and algebra the students failed to see the game situation and the algebraic situation as similar, and thus rejected the entailed analogical inferences (as in Brown & Clement, 1989; Kapon & diSessa, 2012). In the following sections I discuss each explanation in the context of the game and its pedagogical implications. Note that the children were fully engaged in the game and enjoyed it. They often wanted to play an extra chapter after each session, they were happy to meet with the graduate student for the next session, and said that the game was fun. Thus the difficulty to ascribe mathematical meaning to the actions in the game cannot be attributed to affect.

An Accessible Source for the Analogy

The game has five chapters, and the rules of the game are gradually presented in the first three. As the students move through the chapters, the symbolic representations gradually transform into formal symbolic algebraic representations (see Figure 1). The fact that the participants completed chapters 4 & 5 relatively quickly compared to the time spent on chapters 1, 2 and 3 suggests that they had mastered the procedures of the game, and that they were almost unaware of the transformation in the symbolic representations. Hence the students

fully understood the source of the analogy. Moreover, the time the children spent playing the entire game and successfully completing all 5 chapters (e.g., 100 exercises) ranged from a total of 1 to a total of 1.6 hours, which is much faster than the time it generally takes students to master the equivalent math rules in a classroom context. This suggests that the procedures of the game can be considered as a productive source of the analogy.

Retrieval

Superficial similarity plays a major role in analogical retrieval; i.e., the retrieval of a base for analogy is easier if it shares similar objects, similar properties, and a similar general theme with the target, although the structure of relations are what makes the analogy a powerful cognitive tool. As the students move through the chapters, the symbolic representations gradually transform into formal symbolic algebraic representations (see Figure 1). The observations indicated that the children were almost unaware of the transformation in the symbolic representations; namely they treated them implicitly without thinking about their mathematical meaning. For instance, in the game each "night card" has a "day card" with opposite coloring. Dragging a night card over a day card cancels it (one gets a green whirlwind card, which when clicked over disappears). During chapter 1, level 12, suddenly instead of a drawing on a card, the player sees the letter "a" on a card and "-a" on another card. All the children treated the "-a" card as a "night card" and dragged it on the "a" card, but the 5th and 6th graders did not use the words "positive" or "negative". For instance one of the children said in the interview afterwards that "it just looked like the most appropriate thing to do", but she did not regard the green whirlwind as "zero". The three 7th graders did better than the younger students in this respect, but the ascribed mathematical meaning was nevertheless limited for them as well.

Scholarly work on learning from games suggests that external scaffolds are required to facilitate deeper learning from games (e.g., Barzilai & Blau, 2014; Honey & Hilton, 2010). The literature on analogical reasoning suggests that explicit alignment may facilitate analogical encoding, and subsequent retrieval of the relevant schema in other relevant situations (Gentner, Loewenstein, & Thompson, 2003). Thus explicitly aligning the actions and rules of the game with the corresponding algebraic actions and rules might prove to be a productive scaffold.

Evaluation of Analogical Inferences

Let us examine two excerpts from the interviews: (1) A 5th grader, who had not been introduced yet to formal algebraic representations, was interviewed after completing chapter 1. He was asked how he knew that if he dragged the "-a" over "a" he would cancel both cards and get the green whirlwind. He pointed to the "-" sign and said: "it symbolizes opposites". After a minute he stopped, looked at the interviewer, smiled and said "well, it doesn't really make sense to put a minus before a letter, why would they do that?" (2) A seventh grader was interviewed after successfully completing all 5 chapters. She was asked by the interviewer who pointed to the fraction line on the game board, "what is the meaning of the line?" Her answer was: "It separates both parts..... at first I thought it was a fraction line." When the interviewer asked why she decided it was not, she answered: "because a fraction line actually contains things, this divided by that, and if you divide them....., it's equal to something, and I cannot see anything here that is a division."

The two examples illustrate how the students' knowledge in arithmetic and algebra affected their evaluation of the analogical inference, a finding that is consistent with prior work on students' reasoning and the evaluation of instructional analogies. This work (Brown & Clement, 1989; Kapon & diSessa, 2012) suggests that a carefully planned discussion of meaning should be integrated into the explicit alignments suggested above.

A Concluding Remark

This paper argues that examining transfer from the realm of a digital game to the realm of the discipline as a case of analogical reasoning can be productive when trying to understand and later design scaffolds that connect the knowledge representations embedded in games to formal disciplinary knowledge representations used at school. The claim was illustrated through an analysis of the design of a commercial computer game (Dragon Box 5+) and the experiences of a few players.

One may question the generalizability of the claim made here. It is possible that the analogical mapping between the procedures in the game and the disciplinary procedures are applicable only to Dragon Box 5+. The strong analogy in the game was indeed what attracted my attention to it in the first place. However, even simulation games do not reproduce an activity identical to what they simulate, and the construction of correspondence relations between the real world and the game requires some degree of analogical reasoning.

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