Playing and Designing Games for Systems Thinking: A Design Based Research Project

Amanda Bell, Vanderbilt University, amanda.m.bell@vanderbilt.edu

Abstract: Systems thinking (ST) is an important skill for making sense of the complex systems in our world. This design-based research study tested conjectures around students' understanding of ST in elementary grades. We tested how students learn ST skills through designing and playing digital and board games. We looked for students to identify components of a system, describe interconnections, and explain how those interconnections affect the outcomes of the overall system. We discuss changes to our designs and conjectures over two large design cycles. We hope findings from this study can inform research examining how games support the development of ST and other critical thinking skills.

Introduction

Systems thinking (ST) is an important skill for making sense of the complex systems in our world, including navigating everyday professional and social life (Hogan, 2000). Systems thinking helps people see and experience the relationships "between the various physical and social subsystems that make up our reality" (Richmond, 1993, p. 113). It is considered an important 21st century skill for generating solutions to increasingly complex and interconnected problems (Boardman & Sauser, 2008; P21 Framework Definitions, 2009). ST has received increased attention in educational research (e.g. Goldstone & Wilensky, 2008; Jacobson & Wilensky, 2006; Sweeney, 2010). However, there are few studies focusing on students' ST learning trajectories, especially in elementary grades.

Hmelo-Silver, Marathe, and Liu (2007) articulated the main aspects of ST that we focus on in this study: components or structures - the elements of a system, behaviors - features of components or descriptions of what they can do, and interconnections or functions - the ways components or behaviors interact and how that impacts the system. Ideally, we're looking for students to identify components, describe how components and behaviors interconnect, and explain how those interconnections affect the outcomes of the overall system.

We chose to approach ST through designing and playing games for several reasons. First, research clearly demonstrates the benefits of playing games for learning (Barab et al., 2007; Gresalfi & Barnes, 2016; Pareto et al., 2011; Squire, 2006). Research also shows the value of learning through design (Harel & Papert, 1991; Haury, 2002; Kafai & Resnick, 1996), including designing games (Kafai, 1996; Marchetti & Valente, 2014), but more research is needed to unpack how playing and designing games impacts ST (Squire, 2002).

Context and methods

Study context

The data for this project was collected at a summer camp at a southeastern U.S. university during summers 2013 and 2014. Year 1 of the study included two rounds of implementations. There were some revisions to the design between rounds 1 and 2 based on initial findings, then more revisions before year 2.

In year 1, our workshop focused on designing and playing digital games to learn about ST. The workshop lasted one week, followed by a second week with another group of students. The first week had 25 students, and the second week had 23 students including 4 who repeated the workshop. In year 2, our workshop involved designing and playing digital and board games to learn about ST and ratio. We again taught the same week-long workshop for two weeks to two different groups of students. There were 15 students in week 1 and 15 in week 2, with no repeaters. The workshops lasted all day with short breaks for lunch and exercise.

Participants

The students in this study were rising 4th and 5th graders from across the U.S. To qualify for the program, students had to perform at or above the 95th percentile on standardized achievement tests. Once accepted to the camp, students chose to participate in workshops based on their interests and areas with strongest test scores. Therefore, students in our workshops had some interest in games and mathematics. The research team designed, taught, and analyzed each of the workshops.

Data collection

During year 1, we focused data collection on the development of students' ST skills. We designed and collected pre and posttests for ST, kept copies of the digital games students designed, and took videos of whole class discussions. From year 2, we have copies of students' digital games and videos of the board games students designed, videos of whole class discussions, and copies of students' "let's play" videos, described below.

Analysis

We used the ST framework from Hmelo-Silver, Marathe, and Liu (2007) to code students' pre and posttests and discussions for evidence of components, behaviors, and interconnections. Test questions and student talk in discussions were coded on a three-point scale. Responses received a 1 if the student only mentioned components, a 2 if he/she talked about behaviors or one interconnection, and a 3 if the solution included multiple interconnections or their impact on the system. We also used the ST framework to count the number of components and connections in students' digital games. In the digital game designs, each different kind of block or character counted as a component. We then counted connections necessary to win the game. For instance, if there were many enemies in the game and the student chose an avatar (the character the player controls) with a gun, we counted that as one connection because the player needed a gun to get past all the enemies.

Starting points and conjectures

The students in this study identified as "gifted" and tested about two grade levels ahead. They also chose to participate in this workshop, so they were already interested in games and motivated to participate. However, they had very few prior experiences with formal ST skills. Informal interviews indicated students had not spent much time playing or designing games in school. Although all of them played games at home, only a few students had experience designing games.

To understand students' starting points with ST, we gave pretests in year 1. We coded the tests for evidence of thinking in terms of components, behaviors, and interconnections. The average score on the pretest in the first week of year 1 was 42.8%, and the average score (without the repeat students) in the second week was 45.9%. Students were able to identify components of different systems, but they didn't understand how those components interacted to affect outcomes of the overall system.

Our initial designs were informed by several conjectures. We thought playing some digital games first would help students generate ideas for their own designs. We planned to talk about the digital games in a whole class discussion, which focused on identifying components in each of the games students played. Next, we wanted students to design their own digital games, which gave them opportunities to plan and explore systems. Students designed in Gamestar Mechanic (https://gamestarmechanic.com/) because the program allows students to easily start the game design process. We also thought that giving students an open goal, such as making the easiest or hardest game in the world, would allow them to explore many different aspects of the game system.

Findings and revised conjectures

Year 1, Week 1

The results after week 1 revealed some limitations of the initial designs. The average pre to posttest change was only 1% (increase from 42.8% pre to 43.8% post), so the tests didn't reflect any ST learning. In whole class discussions, students mentioned an average of 5 components, 8 behaviors, and 4.7 interconnections per discussion. That means that in each discussion led by a researcher involving all 25 students, only 5 components and about 5 interconnections were mentioned. The numbers are low considering the number of students, the amount of student talk, and the length of whole class discussions (30 minutes or more). We also saw few connections in the games students' designed. On average, students' digital games included 7.4 components and only 1.5 connections. A game with 7 components and 1 connection implies there were extra components that didn't affect the outcomes of the game system. These results led to some changes in the designs for week 2:

- Researchers used ST vocabulary during whole class discussions to help students develop a shared language and understanding of basic ST skills. Researchers used the vocabulary to organize discussions, but students were not required to use the terms in their talk.
- We changed the game design prompt to be "design around an avatar or enemy." Each student chose an avatar or enemy in Gamestar Mechanic and designed his/her game around that character. This allowed students to think specifically about how components and their behaviors interact with the chosen character to help players win or lose the game.

Year 1, Week 2

Results from the second week of the summer camp revealed some learning gains. First, students' posttests increased an average of 10% (from 45.9% to 55.9%, ignoring students who repeated the workshop). Looking at students' talk, we saw an average of 8.7 components, 25.3 behaviors, and 16 interconnections per whole class discussion. This is a large increase from 5 interconnections in week 1. We also saw an increase in the number of connections students used in their designed digital games. Students used an average of 9.1 components and 3.2 connections per digital game.

Year 2

In year 1, we thought the quality of whole class discussions improved when teachers used ST vocabulary to organize discussions. Therefore, in year 2, we added ST terms to the worksheets students used to guide their game designs. We also had students design math board games, and we gave students cards with mathematics problems to use in their games.

While we have not yet completed a retrospective analysis of year 2, I can point to some initial findings based on videos and my own participation in the workshops. First, we found that giving students math cards constrained their game designs. All the student groups incorporated math cards into their board games in a similar manner: a player lands on a particular space that requires them to pick up a math card, and if they get the answer correct, the player collects points or money.

Second, a few students asked to design their digital games in pairs instead of individually. Designing in pairs helped students articulate their ideas and talk more clearly about how the pieces in the games interconnected. In future iterations, we'd like all students to work in small groups.

Third, students created "let's play" videos of the games. "Let's plays" are videos people post online showing themselves playing games and talking about strategies to complete difficult sections. Thinking about an audience encouraged students to analyze the difficult parts of the games and how the player interacted with components to win the game. It also forced students to make their thinking explicit. In future workshops, we want to keep using "let's play" videos as a way to engage students in articulating their ideas.

Discussion

After two years of studying games for ST, we have made some important changes to our conjectures and designs. We now have a better idea of what we can expect from students' ST skills during each activity and how we can support their learning. I've adjusted the hypothetical learning trajectory to build in ST skills more gradually. Rather than expecting students to go from identifying important components to talking about outcomes of a system, the trajectory now includes a set of activities that supports students to think about components, then behaviors, then interconnections and system outcomes. Our findings also point to some ideas about how to support students' design processes, including using designer worksheets with systems vocabulary, having students play many different games and brainstorm ideas, letting students think creatively about how to use math in their games, and designing digital games around a specific character or component. Table 1 summarizes the updated learning trajectory with design changes to explore in future iterations. We hope findings and design changes from this study can inform research examining how games support the development of ST and other critical thinking skills.

It is important to remember that the context of this study was special: all the students tested above the 95th percentile on state tests, students chose to participate in this workshop, and the workshops lasted all day for a week. However, our designs could be implemented in a regular classroom over a longer period of time. Instead of one week devoted to playing and designing games, the activities could be dispersed over a month or a semester of instruction. As we continue to refine our designs and learning trajectory, it will be interesting to explore how teachers might use these activities to improve students' ST skills in more diverse classrooms.

Table 4: Updated learning trajectory and designs

Systems Thinking Learning Goals	Activity
Recognize important components of the games students play	Students play math board games and digital games. Teachers lead a whole class discussion of the games using systems thinking vocabulary.
Articulate important components and their behaviors in the games students play	Students make "let's play" videos about some of the digital games they played.

Recognize important components and how they interconnect to make a game work (focusing on the games students played and their game design ideas)	Teachers lead whole class discussions brainstorming ideas for math games. Students plan their board game and digital game designs by answering questions (written with systems thinking terms) on a worksheet.
Talk with peers about components and interconnections in students' designed games	Students work in groups to design math board games.
Think about components, their behaviors, and how they interconnect in the digital games students make	Students work in pairs to make digital games in Gamestar Mechanic using the prompt "design around an avatar" or "design around an enemy."
Talk about components, behaviors, interconnections, and game system outcomes (in terms of digital games, board games, and students' designs)	Teachers lead a whole class discussion wrapping-up students' game playing and designing experiences. They discuss playing versus making games, the different features of digital versus board games, and how digital and board games help people learn or practice mathematics.

References

Barab, S., Dodge, T., Tuzun, H., Job-Sluder, K., Jackson, C., Arici, A., ... & Heiselt, C. (2007). The Quest Atlantis Project: A socially-responsive play space for learning. *The design and use of simulation computer games in education*, 159-186.

Boardman, J., & Sauser, B. (2008). *Systems thinking: Coping with 21st century problems*. CRC Press.

Goldstone, R. L., & Wilensky, U. (2008). Promoting transfer by grounding complex systems principles. *The Journal of the Learning Sciences*, *17*(4), 465-516.

Gresalfi, M. S., & Barnes, J. (2016). Designing feedback in an immersive videogame: supporting student mathematical engagement. *Educational Technology Research and Development*, *64*(1), 65-86.

Harel, I. E., & Papert, S. E. (1991). *Constructionism*. Ablex Publishing.

Haury, D. L. (2002). *Learning science through design*. ERIC Clearinghouse for Science Mathematics and Environmental Education.

Hmelo-Silver, C. E., Marathe, S., & Liu, L. (2007). Fish swim, rocks sit, and lungs breathe: Expert-novice understanding of complex systems. *The Journal of the Learning Sciences*, *16*(3), 307-331.

Hogan, K. (2000). Assessing students' systems reasoning in ecology. *Journal of Biological Education*, *35*(1), 22-28.

Jacobson, M. J., & Wilensky, U. (2006). Complex systems in education: Scientific and educational importance and implications for the learning sciences. *The Journal of the learning sciences*, *15*(1), 11-34.

Kafai, Y. B. (1996). Learning design by making games. *Constructionism in practice: Designing, thinking and learning in a digital world*, 71-96.

Kafai, Y. B., & Resnick, M. (1996). *Constructionism in practice: Designing, thinking, and learning in a digital world*. Routledge.

Marchetti, E., & Valente, A. (2014, October). Design Games to Learn: A new Approach to Playful Learning Through Digital Games'. In *Proceedings of the European Conference on Games Based Learning* (Vol. 1, pp. 356-363).

Pareto, L., Arvemo, T., Dahl, Y., Haake, M., & Gulz, A. (2011, June). A teachable-agent arithmetic game's effects on mathematics understanding, attitude and self-efficacy. In *Artificial Intelligence in Education* (pp. 247-255). Springer Berlin Heidelberg.

P21 Framework Definitions (2009). *Partnership for 21st Century Skills.* Retrieved from http://www.p21.org/storage/documents/P21_Framework_Definitions.pdf.

Richmond, B. (1993). Systems thinking: critical thinking skills for the 1990s and beyond. *System dynamics review*, *9*(2), 113-133.

Squire, K. (2002). Cultural framing of computer/video games. *Game studies*, *2*(1), 1-13.

Squire, K. (2006). From content to context: Videogames as designed experience. *Educational researcher*, *35*(8), 19-29.

Sweeney, L. B. (2010). Systems thinking: A means to understanding our complex world. *Pegasus Communications*.