International Society of the Learning Sciences

Pandemic Board Game Redesigned: How Learners' Decisions Enable Emergent Learning Possibilities

Reyhaneh Bastani, University of Calgary, reyhaneh.bastani@ucalgary.ca
Beaumie Kim, University of Calgary, beaumie.kim@ucalgary.ca

Abstract: This paper discusses a study on students' exploring and creating emergent systems using mathematics and science while redesigning the cooperative board game, *Pandemic*. Grade seven students participated in the game redesign project co-developed with a teacher in an art immersion school in Western Canada. Their work was collected through video recordings, photos, and interviews. The analysis shows how the game redesign activities supported the divergence and convergence of ideas and group decision making. It highlights how learners' interests and choices acted as frames that enabled their ongoing inquiry and expanding their use of learning topics in creating a working system.

This paper describes a design-based research project on using a board game redesign approach to learning. It aimed to support students to engage with emergent systems and to imagine and model new possible structures using mathematics and science topics. Relying on a complexity perspective, we follow a notion of learning as an emergent phenomenon that involves expanding capacities to adapt to and participate in novel situations (Davis et al., 2015). Complexity perspectives propose learning designs that attend to creating a balance between setting constraints and stimulating learners' diverse responses. In this paper, we discuss how the board game redesign approach, and the materials and activities involved, not only set some structures, but also enable students' collective decisions that could expand their design space and engagement with math and science topics. Our analysis attends to the critical episodes of divergence and convergence of ideas in the groups and the role of structured and self-imposed constraints in supporting this process, using a frame informed by design and creativity research. The following questions guided our analysis: (1) How do the co-design spaces evolve through the redesign process? (2) How do the project structure and learners' decisions frame their design directions and use of math and science topics in creating their game system?

Perspectives

This study draws on a complexity perspective of knowledge and learning that address the emergent nature of learning and its nestedness (Davis et al., 2015). That is, individual understanding and collective knowledge are emergent learning systems at different but interwoven levels. Complexity views, therefore, seek for the conditions that could stimulate more emergent learning possibilities for learners. They use the notion of enabling constraints to indicate how design for learning should attend to a balance between enabling learners' idiosyncratic responses and setting structures that would limit the vast possibilities of approaching learning topics to support learners' shared goals and language (Davis & Simmt, 2003). Classroom structures that engage learners in design practices have showcased their potential to support collaboration based on their interests and skills toward shared goals (e.g., Kim et al., 2019). Design practices support learners to engage in intentional interactions with their peers, teachers and learning topics, using design materials and their developing artifacts. Approaching learning topics through balanced design practices with structures and openness speaks to the notion of enabling constraints, allowing learners to iteratively challenge their own assumptions of problems at hand and explore possible solutions and thus emergent learning possibilities.

Games have the potential for embodying disciplinary and interdisciplinary knowledge. Some studies have explored how designing board games, as models of systems, could support students' engagement with mathematics and science (Kim & Bastani, 2017; Ke, 2014). The present study was a design iteration of a previous learning design for supporting mathematics learning through collaborative re-design of a board game (Kim et al., 2021). The previous project indicated structuring game design projects as re-designing board games (rather than starting from scratch), in which learners play a common board game and change its elements to create their own games, enabled learners to creatively engage with disciplinary ideas. The common starting point and physical material (e.g., the components from the board game to be redesigned) could function as enabling constraints that help learners develop shared communication channels and collective goals, which supported their collective decision making. In the iterative process of design and getting feedback, learners' evolving decisions shaped and acted as frames that direct their further

inquiry into design problems and possible solutions. This could stimulate unique paths of using disciplinary knowledge in learners' groups (Bastani & Kim, 2020; Kim et al., 2020).

Research design and data sources

We conducted this design-based research with grade seven students in Fall 2018 and early 2019. It aimed to engage students with mathematics and science through exploring emergent phenomena, in an art-immersion school in Western Canada. The school's approach is to deliver the subject matters not in isolation, but as connected and as the content of the problems that students can creatively engage with. We developed the activities with the math teacher who is also a game designer. The project mainly focused on engaging students with the math topics of numbers, statistics, and probability and the science topics of interactions and ecosystems and human impact. The cooperative board game *Pandemic* (Z-MAN Games, 2007; Figure 1), which models disease spread across the world, was selected as the game to be redesigned. We expected that the theme and the system of this board game could engage students with exploring emergent phenomena, connected to grade 7 math and science topics. Importantly, the game's inherent complexity could also engage learners' diverse interests and stimulate various ideas and viewpoints, as learners explore its multiple components and possibilities of changing them. In the game *Pandemic*, players take different roles and work together to treat infected populations to buy enough time to complete the ultimate objective which is the discovery of the cures. The main stages of the project included playing *Pandemic* and mastering the rules, brainstorming possible new game theme, narrowing down ideas for using math and science with the teacher, and designing and playtesting the game. We collected ethnographic data through field notes and video-recordings of students' in-progress and final designs. We also had a 30-minute interview with each group on their experience with their redesign project.

Figure 1

a) Pandemic board game, Z-MAN Games (Retrieved from http://bitly.ws/ji22)

Analysis

This analysis aims to explore learners' game redesign processes and the underlying elements that stimulated learners' collective idea development and engagement with learning topics, using the data from two groups in this classroom. In framing our analysis of the groups' design practices, we draw on how the design and creativity research view the design practices' value in supporting learning. They include decision making, adapting to evolving goals, and imagining and examining various alternatives. Importantly and in line with the notion of enabling constraints addressed by complexity perspectives (Davis & Simmt, 2003), the design literature signifies how constraints in the process of design could prompt a pathway to creativity and innovation. They include external constraints such as materials and time limitations, and self-imposed constraints that emerge as designers' ideas interact and lead to design decisions. The design process is a continuous space of experimentation and reflection (Schön, 1992). With every decision, designers impose constraints on their work that not only restrain the next actions but also become tools to think with and to explore new possibilities (Biskjaer & Halskov, 2014).

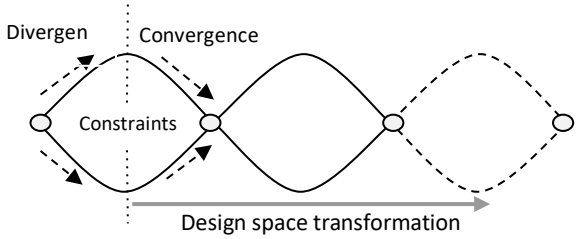
Divergence and convergence of ideas in the transformation of the design space

Exploring the design process, scholars point to the cycles of divergent thinking, i.e., exploring various possibilities, and convergent thinking, i.e., choosing from alternatives to come to a more focused understanding of a problem or arriving at a solution. Our analytic frame (Figure 2) attends to divergence and convergence of ideas that happen iteratively in the design process (Norman, 2013) and the role of constraints (Biskjaer & Halskov, 2014) including the activities' structure and learners' self-imposed constraints in transforming the design space. Self-imposed constraints are evolving frames that could open the space for designers' further exploration. Through identifying the critical

episodes of divergence and convergence of ideas, we investigate how learners' interests and intentional choices enabled them to develop their designs and expand and deepen their use of learning topics.

Figure 2

The analytic framework model adopted from the double diamond model of design (Norman, 2013)



The process of interpreting data

Our coding of data was informed by Barab et al.'s (2001) process for identifying the critical episodes in which learners' ideas and practices evolve, through their interactions with one another, tools and activities. It also attends to the links among these episodes to address the research questions. The analytic frame was used in chunking the data from the groups, identifying the critical episodes and the elements of divergence and convergence of ideas (Table 1). This analysis sought the temporal links among the critical episodes, i.e., how learners' co-designs evolved. It also attended to the students' interim decisions that contributed to developing their designs.

Table 1

An example of the identified critical episodes (Reverse Pandemic)

Episode	Divergence Elements	Supporting Interactions	Convergence Elements	Supporting Interactions
Taking the perspective of bacteria and viruses	Exploring how bacteria and viruses spread and how they act in different environments	Discussing their game story with their science teacher/ using Pandemic to discuss their ideas	Discussing the mechanisms that could strengthen or weaken players (i.e., diseases)/ deciding what diseases they want to use	Researching bacteria and viruses/ drawing diseases' cards/ making parallels between their intended game components and the original game components

Findings

In the following, we discuss the redesign effort of two groups, whose redesigned games were named *Reverse Pandemic* and *Pandemic Theatre Edition*. Elaborating on the identified critical episodes of students' design practices, we address how learners could expand their ideas over time, transform their conceptions of problems and design possibilities, and find opportunities to research on and use learning topics.

Reverse Pandemic: Players acting as viral diseases

The first group developed the idea of reversing the *Pandemic* game story, i.e., creating a cooperative game in which players would act as diseases to overtake the cities and spread around the world. One significant aspect of this group decision was their building on the original game's narrative, and not changing the game's theme completely. The *Pandemic*'s game materials, e.g., the cubes representing viruses, board map, and infection and role cards, mediated the group discussions on their game's aspects and implementing their ideas. Notably, they initially tried to implement their idea of reversing the *Pandemic*'s story by defining opposite functions for the original game's components (e.g., cubes representing cures instead of diseases). This approach might not have been helpful in reversing the dynamics of a game system. For example, in *Pandemic*, the cubes represent the number of infected areas and possible outbreaks. Therefore, simply using them to represent cures would not make meaningful dynamics in the redesigned game. This step was still significant in realizing the need for a deeper exploration of the original game system.

Taking the perspective of bacteria and viruses: Developing the game's backstory and system

The students' focus and practices became more purposeful as they started evaluating the possibilities of implementing their initial ideas while using and creating different game components and rules. A transforming event happened for the group when they shared their ideas with their science teacher. They had a conversation about the theme and rules of *Pandemic,* including the idea of reversing the theme. It started with a question by Jess, one of the group members,

"how players (diseases) could move ((on the board)) and overcome the cities in their game" and led to elaborating their game backstory and system. Their chosen game theme, as a self-imposed constraint, encouraged them to take the perspective of bacteria and viruses, exploring the mechanisms that players could progress through spreading the diseases. They discussed how bacteria could develop resistance against antibiotics and mutate and evolve. The teacher talked about how diseases spread as the group explained how the original game worked, showing the teacher the original game's elements and their own game ideas. The teacher built on Elaine's discussion on players' (diseases) moving between the cities, using the *Pandemic* game board, and explained how a disease could spread to far away locations due to international travels: "one of the biggest issues with our global community is we travel a lot. An infection that happens in Chicago can easily end up in Jakarta in a day. And then you will have two outbreaks ((pointing to the map))" (Figure 3a) (it should be noted that this project happened before the spread of Covid-19 and the widespread knowledge about pandemics). Taking the diseases' perspective, they then talked about how travelling between cities could advantage players. Discussing the possible defence mechanisms against diseases for cities, they also talked about how making new vaccines could cause widespread and long-term immunity.

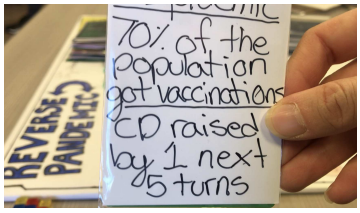
We observed an intentional interaction between the students and teachers mediated by the game materials, e.g., the board map, which supported the integration of learning topics. Their design space with the goal of reversing the theme of *Pandemic*, therefore, changed to include more scientific exploration. Taking viruses' perspective supported their design of game components in a connected way (e.g., how players -- diseases -- could take advantage of moving between cities, and, at the same time, how it could be disrupted by other mechanisms such as vaccination). After these discussions, they did research on different viruses and bacteria and decided which one to use in their game. They worked on their idea of overcoming the cities based on their protection level and developed their player cards (i.e., diseases cards- Figure 3b), their infection cards, and the rules of spreading among the cities.

Numbers, percentages and probability as a tool in materializing ideas

The group found that to reverse the *Pandemic*'s story, they needed to understand this game's system deeply. They evaluated how infection cards, which determined the cities to be infected based on designed probabilities, work and how epidemic cards trigger an outbreak. Put differently, their choice of reversing the *Pandemic*'s story became about reversing the logic of the game, rather than reversing the role of the elements in the game. This self-imposed constraint involved exploring new possibilities of using math in creating a playable game. This exploration converged into using numbers to compare players' power (disease spread) against cities' defence (CD) in their own game. They also designed vaccination cards (Figure 3c), using probability (one out of ten players' cards were vaccination cards), which made cities' defence dynamic: "The city defence changes when 70 percent of the population get vaccination" (Jess).

Figure 3

a) discussing emergent outbreaks in distant location, b) player(diseases) cards (c) vaccination cards

(a)  (b)  (c) 

Incorporating the feature of their interest into the game

The group decided to have six players (diseases) to differentiate their game from *Pandemic* that has four diseases. They, then, needed to categorize the cities differently as hotbeds for the six different diseases. Grouping the cities, they also engaged with the geographical aspect of *Pandemic*, locating the cities on the map, discussing how to scale down the map and create one for their own game. After exploring how to have a 6-player game, their ideas, then, converged into drawing their own map. This became a challenge of how to connect the cities based on their game goal and designed system. They, therefore, faced a "graph" problem in creating their cities' network (Figure 4a).

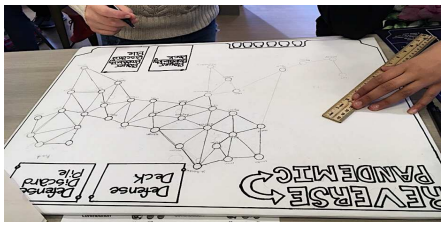
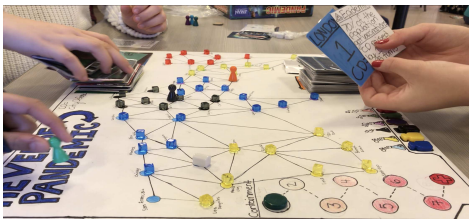
Encountering complexities in balancing the game

Having a draft in time, the group could playtest their game. During playtesting (Figure 4b), they found that in their design, diseases (players) couldn't win. They re-evaluated *Pandemic* and noticed how the Event cards, which would give players random advantages, created a power balance (e.g., the ability to predict which cities will be infected next).

They had created vaccination cards that would give advantage to the cities against players (diseases), but they hadn't used enough mechanisms to give players random advantages. They then designed their own event cards that would randomly allow players (diseases) to make "virus bases" in other countries to travel between them and spread. The group's intention of having a balanced and playable game, therefore, led to make a better sense of the interconnection of different elements in the original game and incorporate their understanding in their own designs, in a way that was meaningful to their redesigned game's narrative. Similar to what Kim et al. (2019) argued, as the students shared their work and confronted their own designs with their applications in the world, they could experience the problems in context and attend to further possibilities. Their more complex understanding was specifically supported through the exchange of group members' viewpoints on different aspects of their game, e.g., how to create a balance, how to modify the graph on their board according to their game goal, and how to make their game meaningfully more complex.

Figure 4

(a) Designing the board, deciding how to connect the cities b) playtesting their game

(a)  (b) 

Pandemic Theatre Edition: Imagining a world balanced through science and art

The other group, *Pandemic Theatre Edition*, initially thought of the game theme of eradicating diseases, similar to *Pandemic* but using different mechanisms. After a few sessions of playing the original game, the teacher asked the students to specify their main ideas and the math and science topics they aim to use. As the students mentioned, this encouraged all the group members to put their ideas together, revisit their initial decisions. They chose to develop a new backstory about making a balance in the world in terms of people's happiness, connecting it to climate conditions. Their game backstory included hot and cold places impacted by climate change and areas with sad and "overly happy" people who would destroy the environment. They decided to have research stations, which could help people in hot and cold areas, and theaters, which could balance people's mood. It was notable how they separated the regions impacted by climate change and the regions that worsen the environmental conditions, and how they considered the role of both science and art in creating a balanced world.

Using Pandemic's components to create a form for their game and enact its story

Focusing on how to enact their game backstory, they evaluated how they could use or modify *Pandemic*'s components in their own game. Their ideas converged into using the cubes (representing diseases in the original game) as symbols of the populations moving among the cities. After considering possible geographical scopes for their game, using *Pandemic*'s board, they decided to use the map of the whole world and to not limit their scope. They also modified the infection deck in *Pandemic*, which added cubes to the board, to tell players how to move people between areas to make the intended balance in their game world. In moving people, they used the concept of percentages. Each player needed to calculate a specific percentage of the cities' total population to determine the number of people to be moved. They also talked about how their game represented the concept of negative numbers in a way, as players needed to move people between the cities with opposite conditions. Their developing game theme also allowed them to connect their game more to the science topics of interactions and ecosystem in a symbolic way. For example, they created a "world climate health meter" for the environmental condition. As the condition gets worse, moving between cities becomes more difficult: "when the world health meter gets to like a certain point, … you can no longer fly unless it's a shuttle flight at the research stations" (Ethan).

The group also decided to have different roles for players for creating the intended balance in the world, e.g., a director to "move people on their turn" and an actress to "cure depressed people", and an environmentalist who could "discard a card in research stations or theatre (and) move the climate health meter up." They also discussed these roles' gender and power, questioning perceived boundaries around gender roles. This led to an emergent discussion on politics and how gender played a role in the Clinton-Trump battle, referring to the 2016 US presidential elections. Such interactions suggest that the human aspect of the game theme provided the space

for the students to relate more with the task. In modeling their imagined world, symbolic representations of human actors became a venue for learners to express their perspectives as if they saw themselves in relation to others.

Engaging with complexities in materializing their imagined world

The group's decision on using the whole world as their game scope was an important self-imposed constraint that needed them to specify "too hot" and "too cold" areas and the overall "happiness" of people living in different cities and countries. Creating the actual game elements, then, needed them to explore deeper their idea of imbalances in their game world and the possibility of categorizing the countries based on opposing conditions. This encountered complexity encouraged the students' exchanging their viewpoints, exemplified in the following:

1. Eva: Oops! People in California are sad ((talking about their initial categorization)).
2. Ema: Why? It's so nice out there. There's Disneyland there!
3. Ethan: Yeah! No, the happy people are in California ((pointing to the map to show it))
4. Eva: Russia is sad.
5. Jacob (from another group): Russia is not that sad.
6. Ethan: It is sad in our game. Although if you say Russia is sad out of nowhere then you are kind of a hatist.

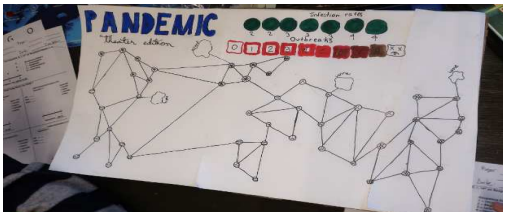
The group also discussed a possible destructive human impact on the environment in the areas where people are "overly happy" because they would not care enough about the impact of their actions on the environment. The decision of having a broad geographical scope for their game did not seem to be significant at the time. It, however, became decisive when interacted with the goal of designing a game with multiple interconnected elements. The group members engaged with complex issues that challenged their simplistic assumptions (e.g., with regards to "sadness" or "happiness" of different regions). Ethan's last utterance (Turn 6) presents a dilemmatic situation for him: although he implied that they would need to make simplifying decisions in modeling their game story, he challenged groundless assumptions. The group's emergent discussions also showcase how addressing a seemingly scientific issue, i.e., climate change in their game, entails attending to social and political factors. This signifies the complexity of the problem the students were engaged with in the context of designing a game system.

Envisioning and moving towards further developments in their game mechanics

Developing their game (Figure 5), the group thought of other design possibilities that could facilitate moving between cities and create "a new way for interaction" (Ethan). Although they could not use all these components in their final game, it was notable how their design process enabled them to expand their view of what would be possible in terms of game dynamics (and the supporting mechanics) and their use of learning topics.

Figure 5

a) The Pandemic Theatre Edition game board, b) Final role cards

(a) 

(b) 

Adding chaos and an element of luck. One of these design ideas was adding "immigration cards" to the game to specify what cities players should move between. This might not be in line with what players need in terms of moving people on the board and could add an element of "randomness" and "chaos" as "things would be moving across the board" (Ethan). The group started by evaluating the mechanics of *Pandemic* and explored the possibilities of transforming their initial design to fit their complex backstory and make their game playable and more meaningful.

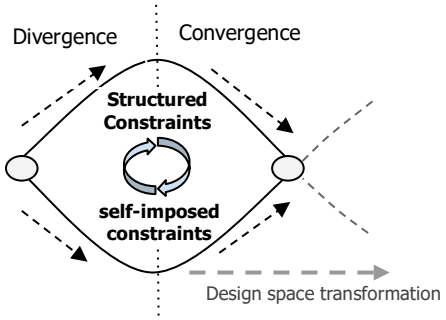
Using more science. The group used interactions and ecosystems through their "world health meter" marker on their board: as the environmental conditions get worse in the world, going forward would be more challenging for players. However, as Ema reflected, a deeper connection to science was missing. They aimed to use the heat and temperature topic, but it became limited to specifying hot and cold regions. Although it could be a good start, they envisioned possibilities of better connections between their game system and the learning topic.

Discussion: the groups' evolving designs and the role of constraints

Our analysis explored the divergence and convergence of ideas and the supporting settings in which learners' design goals and conceptions of solutions evolved (Biskjaer & Halskov, 2014). Here we discuss how the game redesign's structured constraints and the emergent constraints from the groups' interests and decisions enabled them to expand their use of learning topics, adopt new goals, and progress in their design. It also highlights a continuity between structured constraints and learners' self-imposed constraints emerging through the process (Figure 6).

Figure 6

Structured and self-imposed constraints in an evolving design



Structured constraints and tentative boundaries: Foundations for an open-ended task

The project stages aimed to provide a structure within which student groups could develop common languages and collective purposes as underpinnings of group interactivity and idea exchange (Davis & Simmt, 2003). The project structure, mainly starting from a selected common game and the groups' goal of redesigning it, acted as constraints for the broad range of possible design approaches the groups could take at the starting point. In the following, we discuss these structured constraints and how they could enable the groups' focus and progress in their designs.

Playing the original game to decode and destruct what is at hand. The groups started with playing *Pandemic* and, as they engaged with their designs, they needed to further decode this game's system. This, in turn, supported their idea development and decision making as they progressed in their design. The shared understanding of what is at hand and the agency to restructure it could stimulate their imagining of possibilities within the frame of the task. As the teacher put it, there is a mutual relationship between creation and destruction of what already exists, which could be supported in this game redesign project.

Using the original game's components as tools for communication and materializing ideas. The group discussions showed the original game's components acted as tools for students to interact and come up with the elements that would enact their game story. Notably, this supported the groups' focus on the core elements of their own design. The groups had the opportunity of modifying the existing components, i.e., using what already existed in a way that would fit their game (e.g., *Reverse Pandemic*'s use of a similar map as *Pandemic*), while creating what they needed for their unique game (e.g., changing the cities' grouping to have a 6-player game). This signifies an enabling aspect of redesign and its involved constraints, compared to designing from scratch where the broad scope might hinder the groups' focus and translating their ideas into sharable artifacts (Kim & Bastani, 2017).

Attending to project goals and deadlines: Staying within the boundaries of the project. The project had goals and limitations which set overall boundaries for the groups' work (Davis et al., 2015). They mainly included incorporating math and science topics in their redesigned game, the project deadline, and having a shareable game to be played with other groups and students. This overall framework supported students' shared understanding of expectations (Davis & Simmt, 2003), the convergence of ideas in groups, and the groups' making sense of other redesigned games' goals and systems. On the other hand, there were variations in how the groups approached these constraints. For example, the goal of having a balanced game by the deadline encouraged the group *Reverse Pandemic* to have early game drafts, which they could test and get feedback from. This is while the group *Pandemic Theatre edition* focused more on developing their game backstory making it more complex and meaningful, but less on playtesting before the deadline. We observed the important role of the groups' interim decisions as self-imposed constraints in shaping their emergent design process (Biskjaer & Halskov, 2014), which we discuss next.

A continuity between the structure and what emerges through learners' participation

The open-ended process of design entails iterative goal setting and designers' revisiting their conceptions of problems and solutions, as designers get feedback from their prototypes (Norman, 2013). This could create the setting for learners to adopt intentions in approaching the problems and in using learning topics. The critical episodes of the groups' design practices showed how as learners participated in this design project, structured as redesigning a particular board game, they engaged in intentional interactions with their peers, teachers and learning topics, using design materials and their developing artifacts. It showcased an interconnection and continuity between structured constraints and learners' self-imposed constraints emerging through the process.

Learners' expanding and deepening the use of learning topics building on their design decisions. The groups' interim design decisions were self-imposed constraints, which acted as dynamic frames that not only structured their work but also became tools for idea development (Biskjaer & Halskov, 2014). Students' use of science and math topics emerged and expanded throughout the project. This was intertwined with learners' seeing more possibilities to expand their game backstory and implement their ideas to create a working system. As an example, the group *Reverse Pandemic* incorporated numbers, percentages and probabilities as they went through materializing their ideas and creating a balanced game. Their exploration of the possible mechanisms that could enact their game story helped them make a better sense of the emergent process of disease spread at the global scale.

Engaging with complexities in developing the imagined backstory and turning it into a playable game. The game redesign project was a context for modeling an imagined world developed by students. The groups iteratively developed the backstory of their interest to make it more meaningful. This became a self-imposed frame that triggered their design trajectory. The sophistication of *Pandemic-Theatre Edition*'s backstory encouraged divergent ideas through the design process. This included both adding details to their game story and goal and the design ideas that attended to the possible dynamics and mechanics in their game to enact their story. The groups engaged with emergent discussions on the multiple aspects of their game theme and making a better sense of the complexities involved as they intended to create a modeled world through different signs and symbols.

References

Bastani, R., & Kim, B. (2020). Learners' emergent designs for play: Game design as mathematical modeling practices. In M. Gresalfi & I. S. Horn (Eds.), *The Interdisciplinarity of the Learning Sciences*. ISLS.

Barab, S., Hay, K. E., & Yamagata-Lynch, L. C. (2001). Constructing networks of action-relevant episodes: An in Situ research methodology. *Journal of the Learning Sciences*, *10*(1–2), 63–112.

Biskjaer, M. M., & Halskov, K. (2014). Decisive constraints as a creative resource in interaction design. *Digital Creativity*, *25*(1), 27–61.

Davis, B., & Simmt, E. S. M. (2003). Understanding learning systems: Mathematics education and complexity science. *Journal for Research in Mathematics Education*, *34*(2), 137–167.

Davis, B., Sumara, D., & Luce-Kapler, R. (2015). *Engaging minds: Cultures of education and practices of teaching*. Routledge.

Kim, B., & Bastani, R. (2017). Students as game designers: Transdisciplinary approach to STEAM education. *The Alberta Science Education Journal*, *45*(1), 45–52.

Kim, B., Bastani, R., Rahimi, F. B., & Dadkhahfard, S. (2020). Finding opportunities to pursue interest in the classroom: Contrasting two cases of redesigning tabletop games. In Gresalfi, M. and Horn, I. S. (Eds.), *The Interdisciplinarity of the Learning Sciences* (pp. 1613-1616). ISLS.

Kim, B., Bastani, R., & Takeuchi, M. (2021). Embodied mathematical practices in (re)designing board games in a linguistically diverse classroom. *Pedagogies: An International Journal*.

Kim, B., Rasporich, S., & Gupta, D. (2019). Imagining the sustainable future through the construction of fantasy worlds. In *Critical, transdisciplinary and embodied approaches in STEM education* (pp. 61–82). Springer.

Ke, F. (2014). An implementation of design-based learning through creating educational computer games: A case study on mathematics learning during design and computing. *Computers & Education*, *73*, 26–39.

Norman, D. A. (2013). *The design of everyday things* (Revised and expanded edition). Basic Books.

Schön, D. A. (1992). Designing as reflective conversation with the materials of a design situation. *Knowledge-Based Systems*, *5, 1*, 3–14.

Z-MAN GAMES (2007). The world of Pandemic. Retrieved from https://www.zmangames.com/en/games/pandemic

