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Prairie Protector: Systems thinking and STEM-informed decision-making in agroecosystems through game-based learning

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Abstract

The Nebraska Sandhills represents one of the world's last remaining intact grasslands. However, the Sandhills and other grasslands in the Great Plains are currently threatened by "the green glacier"-- a slow but steady encroachment of invasive tree species into ecosystems which have historically been dominated by grasses and wildflowers. These invasive species not only threaten the habitat of native wildlife but also threaten the livelihood of ranchers who depend on the vast grasslands to feed their livestock.

To address this complex agroecosystem issue, there is a need to prepare a science-literate citizenry equipped with systems thinking and STEM-informed decision-making skills. Game-based learning offers an educational approach for players to practice working cooperatively, building empathy for diverse stakeholders, and enacting cooperative strategies and policies. Game-based learning opportunities provide distance between players and the issue to circumvent emotional responses, while empowering learners to test different strategies in a low-stakes and fun way.

Using a game-based learning approach, our team created a digital game, Prairie Protector. Supporting instructional materials were also developed including lesson plans and game tutorials targeted for use at middle school and high school grade levels. Prairie Protector allows players to build empathy for ranchers and other landowners who are faced with difficult land management decisions given the constraints of limited time, money, labor, and other resources. The learning experience supports students in designing successful land management strategies to mitigate spread of Eastern Redcedar, analyzing gameplay decisions to compare outcomes of competitive and cooperative management strategies, and recognizing long-term economic and ecological value of cooperative management strategies.

Prairie Protector has received enthusiastic reception from science and agriculture education teachers. After experiencing Prairie Protector at a game-based professional development workshop in 2020, all 21 participants reported plans to integrate the game into classroom instruction. In this paper, we evaluate the impact of Prairie Protector and associated standards-based learning activities on middle school student development of on systems thinking and empathy building in a formal science classroom.

Introduction

Temperate grasslands are the most threatened and least protected ecosystems globally [1]. Currently, the Nebraska Sandhills represents one of the largest remaining intact grasslands in the US Great Plains [2]. However, the Sandhills and other Great Plains grasslands are currently threatened by "the green glacier"-- a slow but steady encroachment of tree species into ecosystems which have historically been dominated by grasses and wildflowers [3]. Woody

encroachment not only threatens the habitat of native wildlife including small mammals [4]–[6], grassland birds [3], [7], and insects [8], but also threatens the livelihood of ranchers who depend on the vast grasslands to feed their livestock [9], [10].

Given that 98.9% of Nebraska lands are privately owned [11], addressing the issue of grassland conservation in Nebraska depends on voluntary and collective conservation action of current land managers. Developing a land management strategy to combat woody encroachment is no small feat. Land managers must select from a variety of tools, such as mechanical removal, chemical treatment, and prescribed burns, to combat the spread of Eastern Redcedar and other woody tree species [12]. However, each of these strategies comes with unique costs, benefits, and risks. Further complicating the land management decision-making process is the fact that the decisions of neighboring landowners also impact overall strategy effectiveness.

The scale and severity of woody encroachment in the Great Plains will also require equipping today's K-12 youth with the science literacy skills to take future grassland conservation action. Developing science literacy skills requires an individual to have scientific understanding that enhances the capacity for complex decision making (systems thinking), awareness of self and social relationships, and real-world application. Scientific understanding is the most developed in the current educational system as it entails the theoretical principles required in science, technology, engineering and mathematical (STEM) courses. Systems thinking, self and social awareness, and real-world application are more difficult to transfer as they require Bloom's highest orders of cognition including application, analysis, and evaluation [13].

Game-based learning (GBL) shows potential as a vehicle to achieve learning outcomes related to science literacy and broader STEM capabilities [14]. GBL is characterized as a type of game play with defined learning outcomes [15], [16]. In the field of systems thinking, Adachi and Willoughby [17] performed a longitudinal study that found playing slow-paced strategic video games improved student problem solving skills. Similarly, Grund and Meier [18] showed that GBL could be used to improve decision-making skills for most of the capabilities required for effective managerial decisions. GBL has also shown strides in improving student understanding of sustainability issues [14], [19].

Based on the benefits that GBL affords, our team sought to examine if a GBL approach could be used to introduce the complex and likely unfamiliar ecological issue of woody encroachment, support learners in developing and testing land management strategies in a game-based simulation, build empathy for diverse grassland conservation stakeholders, and develop systems thinking skills.

Methods

Game and Instructional Materials Development

Our team consisting of undergraduate software developers, education researchers, and content specialists contributed to decisions related to game design elements (as defined in [15]). First, our team convened to outline game mechanics and subject matter content and skills. Consultation

with content specialists allowed the game designers to identify relevant research models to guide the development of gameplay mechanics while consultation with education researchers resulted in the outlining of key learning objectives.

With select game design elements in place, game designers moved forward with design decisions related to visual aesthetics (i.e. graphics to represent key information in the game), an incentive system (i.e. a scoring system to encourage players to continue their efforts and to provide feedback to modify their in-game behavior), narrative design (i.e. text introducing the issue of woody encroachment), and musical score. The final step of the game development process involved game designers creating levels that allowed players to adjust gameplay difficulty and more carefully consider the underlying mechanics of the game to "win". On-going gameplay assessment ensured the key learning objective goals were maintained while improving the gameplay experience.

The learning objectives for Prairie Protector are to develop decision making skills and a systems thinking mindset by experiencing the spread of invasive species in an ecosystem and analyzing the effects of various mitigation strategies. To achieve these learning outcomes, Prairie Protector was built on an algorithm modeled after the actual spread of invasive species. Players choose from a toolbox of mitigation strategies with varying costs and impacts to manage their land. Within gameplay intended for beginners, systems thinking concepts of recognizing the impact of time delays in cause/effect relationships (spread of invasive species over time) and assessing system structure to identify leverage points (choosing where to apply limited mitigation efforts to have the intended effect) were highlighted. In advanced levels, neighboring lands may be added to the gameboard with these lands being managed by computer artificial intelligence. Neighboring land managers can be assigned different "personalities" including Preventionist, Good Neighbor, Selfish, and Pyrophobic. With the addition of neighboring land managers, the game encourages players to reflect on the impacts of individualistic and cooperative land management strategies.

After game development, instructional materials were created to support teachers in enacting a GBL experience in formal or non-formal education settings. Instructional materials included compiling relevant videos, essays, and age-appropriate summaries of research literature, and writing lesson plans to encouraged gameplay reflection.

Participants and Implementation

Student Participants. Middle school students were recruited during the spring 2022 semester. All students were in 7th grade and provided informed assent to be included in the study. Student parents received information emails and provided informed consent to allow their student to participate in the study. The study was given expedited status by University of Nebraska – Lincoln Institutional Review Board (IRB #: 20211121464EP). A total of 8 students assented to participate in the session survey.

The intervention consisted of four, 35-minute instructional periods during which students played Prairie Protector (https://www.prairieprotector.com/) and engaged with a selection of instructional materials (e.g. lessons providing direct instruction, research prompts, reflections, discussions, videos, and game tutorials).

Data collection
Eligible students were invited to participate in focus group discussions after playing the game, participating in associated teacher-guided instruction, and providing assent. Focus groups followed a semi-structured interview format with questions focused on game play strategy, decision making, and the student experience playing the game (see Supplementary Materials for focus group prompts and associated questions). Focus group discussions were digitally recorded.

Data analysis
Qualitative analysis of the data consisted of reading the focus group discussions and using a basic qualitative approach. Analysis was conducted in two key phases: open coding and analytical coding [20]. During open coding, meaningful data segments were identified in the interview transcripts and codes made up of the participants' exact words, the investigators' words, or concepts from the literature are assigned to the data segments [20]. During the subsequent phase of analytical coding, codes were sorted into related themes or categories [20].

Results & Discussion

Broad public awareness of woody encroachment and its threat to grassland conservation is limited as evidenced by the continued planting of Eastern Redcedar and other invasive trees throughout the Great Plains. The public's lack of awareness or concern regarding woody encroachment may be due in part to the fact that areas most at risk are also some of the least populated in the state. Our results suggest that the Prairie Protector game and associated instructional resources successfully introduce key concepts underpinning this conservation issue to middle school learners in a formal education setting in a rural locale. Student responses during the focus group discussion indicated that their GBL experience successfully supported students in developing and testing land management strategies in a game-based simulation, building empathy for diverse grassland conservation stakeholders, and developing systems thinking skills.

Student discussion suggested an understanding of the game objective (i.e., "try to manage the forest") and a growing awareness of different land management tools. Students admitted to being more aware of mechanical methods for removing trees (such as with an ax or skidloader) and explained that the game presented "new methods" (i.e., prescribed fire). The game's presentation of a novel land management tool piqued students' interest with one student saying they "thought it was interesting—[learning] all of the methods".

Students' responses also indicated successful engagement in both development and testing of land management strategies during the GBL experience. Students recounted an iterative gameplay experience which involved "lots of trial and error" and explained that developing an effective strategy "took time to figure out". Some early strategies that students described involved "just burning everything" and "tackling big trees first". Students indicated that over time they "eventually learned to take care of the young trees first" and "start on the perimeter and work in toward the center". Students shared that even though early attempts resulted in losing the game that playing was "fun after learning to tackle the hard levels" and they admitted being eager to start another game if they failed to complete a level.

Social interaction and communication among players appeared to be fundamental to students' ability to test and evaluate different land management strategies. Students discussed communicating with other players about the success or failures of different strategies in the game. Some students enjoyed "sharing ideas" because this "helped to learn what worked for others".

The GBL experience allowed students to effectively engage in STEM-informed decision making. Students described trying out more than one strategy. Through reflection and comparison, they evaluated the relative success of different strategies. Students were able to highlight factors that influenced their decisions in the game. Cost was perceived as especially important with students reporting that cost "was a big factor", "saving money" was important, and that "limited budget levels were hard". In addition, students were able to articulate trade-offs of different land management strategies. For example, students explained that while mechanical tools could effectively remove trees in the game, they lamented the fact that there were drawbacks including that "seeds still spread" and that "more time and money" were needed when using these methods. Students went on to explain that the most successful strategies were based on using prescribed fire.

Student discussion also suggested an ability to see similarities and differences between their GBL experience and real-world grassland management decisions. Students pointed out parallels between the value of communication with other players and the value of land managers sharing their land management successes and failures with one another. Students explained that shared communication with classmates resulted in more effective strategies in the game and suggested that similar communication between land managers might also result in better outcomes in the real world such as "saving everyone time and money".

In addition, students' comparison of gameplay to the real-world suggested an understanding that land management decisions are not made in a vacuum and instead are part of a much larger, interconnected system of interactions. For example, students explained that land managers' decisions were impacted by personal factors such as their "knowledge and skills" in "planning and preparing to manage a burn" as well as social, political, or environmental factors such as "the government and certain restrictions on land" and 'drought conditions".

Student discussion indicated an empathetic view for real-world stakeholders with students expressing that land management is a "stressful thing" that is "kinda hard to deal with". Students felt that land managers might struggle with "too many options" and "not enough money" to implement successful strategies, but also that not acting might lead to loss of usable lands leading to "less farms, less animals, less vegetables" and "if a ton of farms go out because of cedar trees, it could hurt the economy". Students also demonstrated understanding of perspective taking by wondering how animals within the prairie ecosystem would be impacted by the various land management strategies.

Our study is limited in several ways. The qualitative nature of this study limits our ability to generalize the findings to broader educational contexts. While our findings suggest that GBL offers a promising approach, we acknowledge that this study may be considered a "best case scenario" for several reasons. First, the teacher participating in our study has family ties to

agriculture and was both interested in and familiar with rangeland conservation issues and effective land management strategies. Next, the student population in our study lives in a rural locale and while it is unknown if they have direct family ties to agricultural lands, their responses suggested some prior knowledge of ranching and land management practices. Finally, due to Covid-19 pandemic impacts, we were limited to conducting our focus group discussion via Zoom video conferencing which may have limited participation of quieter or less knowledgeable students. The combination of factors that either participating students 1) have an elevated existing level of understanding or 2) our focus group interview responses are biased toward students who are more outspoken (potentially because of their increased level of understanding) potentially contributed to the elevated level of understanding some students expressed during the focus group discussion. Future studies will focus on increasing student response numbers, recruiting students with less pre-existing knowledge of the prairie ecosystem, and refining focus group methods to ensure representation of all participants.

Conclusions

This paper presented analysis of the effectiveness of game-based learning to meet the need of preparing a science-literate citizenry equipped with systems thinking and STEM-informed decision-making skills. Prairie Protector provides a flexible way to introduce the issue of woody encroachment in many different educational settings (formal, non-formal, and informal). In this study we explored the impact of the game and associated learning materials on middle school students in a formal classroom. Student feedback indicated that playing Prairie Protector allowed meaningful interaction with land management practices through making informed decisions, identify differences between game-play and real-world decision process, and explore the larger interconnected system of interactions involved in prairie ecosystems. Future work will focus on analyzing the educational impact of Prairie Protector with other learning contexts and audiences.

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Supplemental Materials

Focus Group Prompts and Associated Questions

- Please introduce yourself to the group.
- What did you learn by playing [specific game name] for class?
- How did you feel while playing the game? Did you feel differently when you were winning or losing?

[Prompt] I want you to think back to a time in the game when you played by yourself (no neighbors).

- Tell us about your game play strategy. Did your strategy change as you played the game more times? If yes, how did your strategy evolve?
- What information did you use to make decisions in the game?

[Prompt] How we think about the world (our mental models) are influenced by past experiences. These experiences shape our perceptions, beliefs, and assumptions about how a system works currently and how we think it will function in the future.

- What knowledge or past experiences, if any, do you have with the system presented in the game?
- What perceptions, beliefs, or assumptions do you think influenced your decisions in the game?
- Do you think differently about the issue of woody encroachment now that you have played the game?

[Prompt] The situation presented in the game is a real issue impacting the Great Plains.

- How do you think the game is like real life and how is it different?
- In the game, you get a certain number of treatment coins to use each year and this limits the land management action you can take each year to combat woody encroachment.
    - In real life, what do you think are some of the limitations that land managers and ranchers face when deciding on their land management strategy?
- Now that you have played the game, how do you feel about land managers who are dealing with the issue of woody encroachment?