Sharing is Caring in the Commons – Students' Conceptions about Sharing and Sustainability in Social-Ecological Systems

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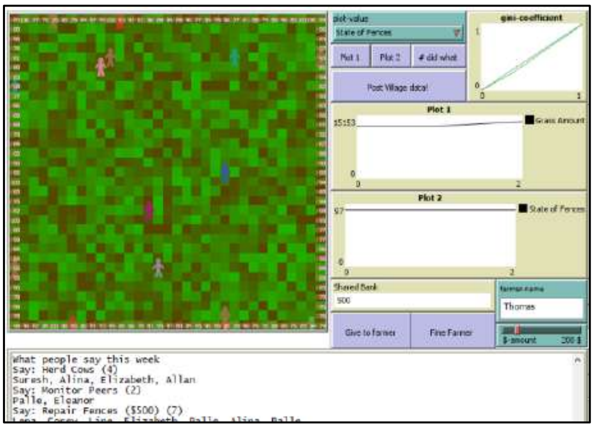
Abstract

In this paper, we present the design and analysis of a high school environmental science participatory simulation-based activity about sharing natural resources. In particular, we focus on this activity's utility in surfacing students' diverse ways of thinking about Social-Ecological Systems, offering entry points for Constructionist design. The activity was implemented as part of a three-week unit in an environmental science AP class. At the core of the activity was a participatory NetLogo simulation in which students played the role of dairy farmers. Through their interactions with the simulation and collective and individual decision-making, students struggled to reason and argue productively about the difficulties involved with sharing natural resource systems.



The virtual grazing ground and accompanying data interface gives students insights into how their individual and collective decisions affect the ecosystem.

We gave students two written assignments, in which they were asked questions about true, historical descriptions of communities sharing natural resource systems. Here we analyse the responses, identifying four distinct 'thinking patterns' across student responses. We discuss how these four patterns were productive in so far as they helped students to reason about the historical cases, but also how these patterns in their thinking restricted them from thinking productively about the full nature of the case studies. Finally, we discuss how future designs might address the less productive aspects of these patterns.

Keywords

NetLogo; agent-based modelling; HubNet; participatory simulation; social studies; complex systems

Abstract

This paper presents data from a high school implementation of a unit on common-pool resource sharing dilemmas in Social-Ecological systems. We designed and implemented a computer-simulation-based classroom activity in a high school Environmental Science course. Students took on the role of cattle farmers who had to maintain and share a virtual grazing ground and prevent a "Tragedy of the Commons." We present an analysis of students' responses to questions about how best to coordinate collective action and ensure sustainable utilization of the commons. We identify four patterns in students' thinking and discuss how these patterns were simultaneously productive and a hindrance to reasoning about different aspects of this complex problem. Finally, we discuss the impact of our findings on our own iterative design-based research, as well as wider implications for future learning design and research on social-ecological systems and sustainability.

Introduction

The United States' National Council for the Social Studies' recent C3 framework (NCSS, 2013) proposes a new set of standards for Social Studies, including the use of computer simulations to test and understand the effects of policies and collective action. Despite decades of using computer modelling in science education (Wilensky & Jacobson, 2014), there have been relatively fewer applications in social studies classrooms. In this paper, we present data from a 3-week high school classroom implementation of activities focusing on the challenge of sustainable food production and featuring computer-based network-supported participatory simulations, or PartSims (Klopfer, Yoon, & Perry, 2005; Wilensky & Stroup, 1999b). Our core PartSim activities took Hardin's (1968) seminal Tragedy of the Commons paper as a point of departure. Hardin argues that collectively shared resource systems are doomed to end in "tragedy" because individual actors within the system will act in their short-term interest to the detriment of the collective. However, Elinor Ostrom's Nobel Prize-winning work (Brondizio, Ostrom, & Young, 2009; Ostrom, 1990, 2007) has shown that while true under certain conditions, other conditions make it possible for communities to sustainably share and maintain resource systems. In such contexts, collectives can work to discover and sustain solutions to common-pool resource sharing problems. Ostrom and colleagues thus refer to a *drama* of the commons (*The Drama of the Commons*, 2002), which may end either in "comedy" or in "tragedy" depending on policies and practices adopted by participants.

Given the societal importance of the sustainable use of natural resource systems like oceans, aquifers, and populations of fish or game, it is critical to prepare students to envision and engage the potential impact of policies oriented towards addressing the drama of the commons. In this paper, we present an analysis of a study in which we designed and implemented a 3-week PartSim-based unit on sharing natural resource systems in a high school Environmental Science class. Our focal PartSim activities, and our unit as a whole, gave the classroom group the opportunity to role-play a village of cattle farmers. Together, they collaboratively explored possibilities for sustainable growth and for collectively maintaining a "virtual commons" in a simulated world. Our analysis focuses on students' written responses to two sets of questions on this topic. We identify four patterns in student thinking, explain how they both helped and hindered students in making sense of the topic, and discuss why future learning design and research would benefit from addressing these thinking patterns.

What is hard about sharing

Following Hardin (1968) and Ostrom (1990), we can think of the difficulties of sharing a resource system from the perspective of an individual, and from the perspective of an individual's larger community. From the perspective of an individual, the dilemma is a classical free-rider problem: the long-term benefits of collaboration are *shared* between all community members, whereas "cheating" benefits only the *individual* cheater. This leads to an individual-centred logic which dictates that cheating creates a net gain for the cheater. From the community's point of view, the difficulties of sharing stem from the very nature of conditionally self-replenishing resource systems:

> *Resource systems can best be thought of as stock variables that are capable under favorable conditions of producing a maximum quantity of a flow variable without harming the stock or the resource system itself. (Ostrom, 1990, p. 30)*

To exemplify, let us imagine a shared fishing pond: the *stock variable* is the amount of fish in the pond, and *flow variable* is the amount of fish being "produced" in the pond (through reproduction). *Favourable* *conditions* include natural or anthropogenic factors like weather or nutrition levels in the water that affect how much flow the system produces. Finally, the last part of the quote alludes to the fact that these systems are often fragile and can be harmed or even driven to collapse if not cared for properly. The challenges facing communities who depend on sharing sustained access to these systems are then two-fold: First, how does a community collectively manage a system in order to create and sustain the set of 'favourable conditions' that optimize the amount of *flow* resource? This difficulty is exacerbated by the fact that the cost to maintain favourable conditions sometimes cannot be spread easily among community members. (For instance, while the community could decide to share the costs associated with feeding the fish, the time-cost involved in physically feeding the fish or measuring current nutrition levels will fall on one or a few individuals.) Second, and related, how does a community set up a system for sharing the produced resource that makes individual community members feel that their efforts are rewarded fairly? This difficulty involves a number of social challenges: for instance, establishing a means to ensure compliance with group norms that enables members of the community to "rest easy" that their fellow citizens are not cheating.

Research questions

In this paper we offer a preliminary analysis, through which we aim to better understand how students reason about communities that share resource systems. We ask,

1. How do students reason about the problems facing communities who rely on shared natural resource systems?

2. What kinds of community rules do students imagine would help address these problems, and why?

Design, Implementation, and Data

The study presented here emerged from the first year of a multi-year design-based research project (Cobb, Confrey, Lehrer, Schauble, 2003) in partnership with a classroom teacher at a suburban high school in the US Midwest. Together, we collaboratively designed a unit to run over 15 periods in a high school Environmental Science classroom. The 22 students in our partner teacher's class were consented, and all chose to participate in the study. In addition to fitting into the larger themes of the course, we designed the unit to target the NCSS's standards for social sciences (NCSS, 2013), and the NGSS science standards (NGSS Lead States, 2013), focusing on the use of computer simulations of ecological systems, to test the viability and effectiveness of policy interventions and collective action. Seven periods out of 15 during the first two weeks of implementation revolved around PartSim activities and are the focus of this study.

The Virtual Commons Sharing Activity

PartSims are socially shared computer-mediated simulations in which a group of students takes on the role of agents in a system whose aggregate behaviour emerges in real time as the students interact. As such, PartSims provide a means for a group of learners to experience a phenomenon from both the micro-level (as individual participants) and the macro-level (as a collective group experiencing the emergence of these outcomes). PartSims have a long history in the design of Constructionist learning activities, and have been used to teach topics as diverse as chemistry (Brady et al, 2015), geography and policy decision-making (Gilligan et. al, 2015), and as a tool for teaching complex systems principles (Brady et al, 2017; Guo & Wilensky, 2016).

From a Constructionist perspective, the purpose of a HubNet activity is to give a group of students a shared, manipulable object with an underlying set of complex systems interactions, and a socially meaningful purpose for these manipulations. Our PartSim was programmed in NetLogo (Wilensky, 1999) using the HubNet (Wilensky & Stroup, 1999a) architecture. The purpose of the PartSim was to give students the experience of sharing a "virtual commons" with collective responsibilities. The Virtual Commons HubNet activity began on day 3 of the unit. During the first two days, we ran two activities focusing on the Tragedy of the Commons. In the first, a non-virtual activity, students had to share a fishing ecosystem consisting of candy fish. In the second, students had to share a grazing ground in a HubNet NetLogo model. Both of these activities were designed with Hardin's original constraints in mind: students were not allowed to speak or coordinate with each other, nor were they permitted to share responsibilities. In both of these activities, students inevitably "crashed" the ecosystem and enacted the Tragedy of the Commons.

In contrast, and reflecting an important difference between Hardin's *thought experiment* and Ostrom's *empirical research*, our subsequent Virtual Commons PartSim was designed to give students incentives to work together to maintain their resource systems: Students played the role of dairy farmers who relied on a shared grazing ground. For each "week" (turn) of the activity, students held a town hall meeting in which they assessed the state of the commons by looking at data together, and agreed on what tasks would need to be done in the following week as well as, *by whom*.

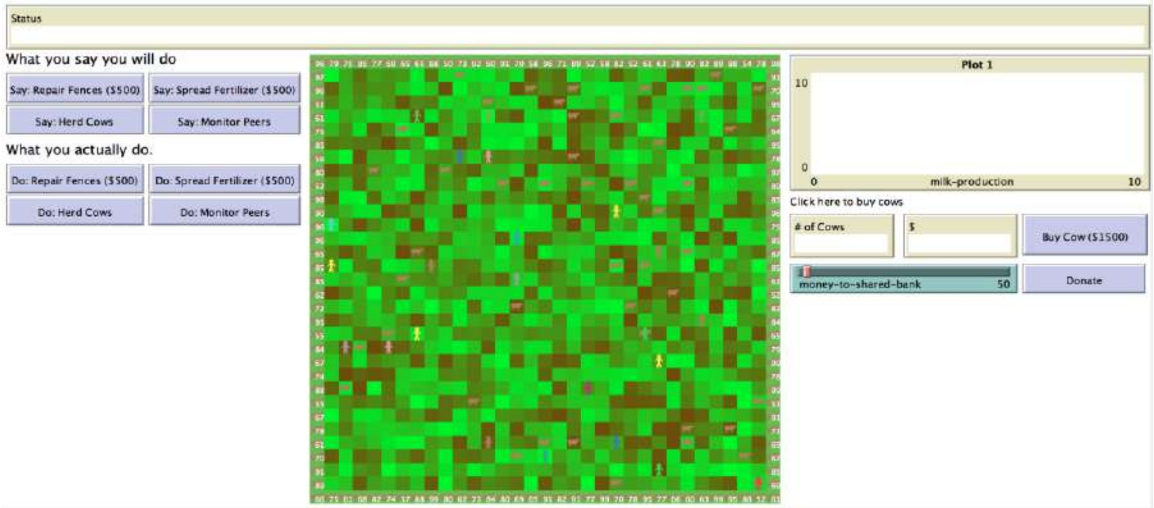


Figure 1. Each student's private view of the Virtual Commons PartSim model.

Each student could take on one of four tasks (see Figure 1): (a) spreading fertilizer (accelerating the regrowth of grass on the commons); (b) repairing fences (ensuring that the village's cattle do not escape); (c) herding their own cattle (increasing their own milk production for the week); or (c) monitoring their peers (confirming that they were doing what they promised to do). Importantly, the simulation allowed students to "cheat" – by promising to engage in one task, while secretly doing another. This made monitoring an important task, as monitors enabled the village to catch cheaters.

During the town hall meetings, students gathered around the shared view (Figure 2), which displayed relevant information, including the number of cows on the field, the amount of grass on the grazing ground, the total milk production, the Gini coefficient for the farm community, and the general state of repair of their fences. Based on these data and their shared experiences up until this point, students discussed the dilemmas they faced, both as individuals and as a group, and devised means to address them through collective action. In addition to pursuing collective farming goals, they also conducted "experiments" to learn information about their environment. These included varying the number of people who spread fertilizer (to assess how quickly grass grew back on its own or to estimate "carrying capacity") or repaired fences (to assess the rate at which fences deteriorated).

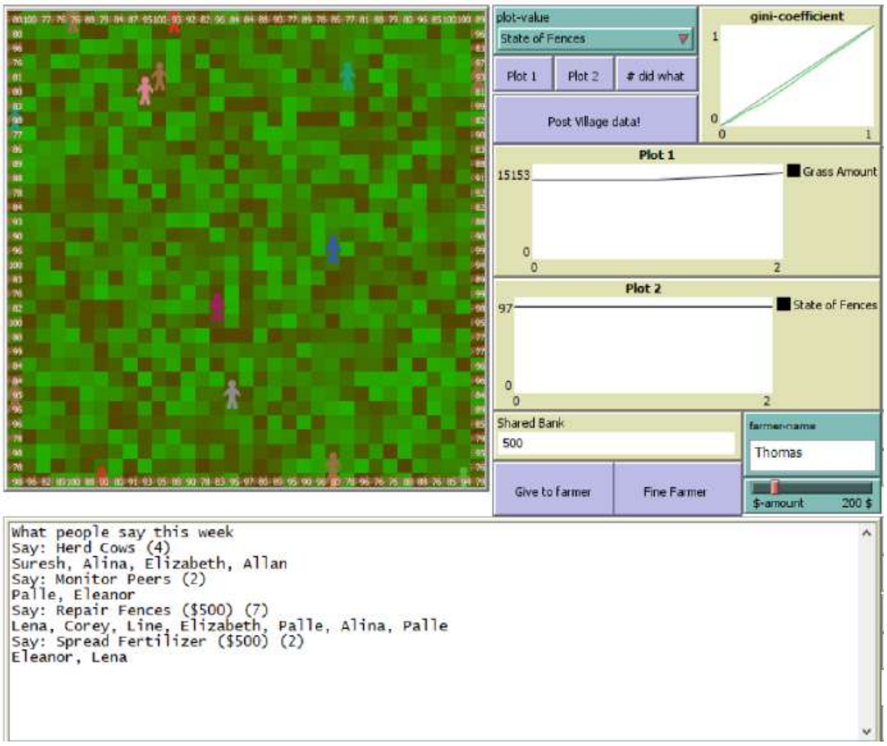


Figure 2. Students' collective view of the grazing ground.

Our aim with the Virtual Commons PartSim activity was to give students a contrasting experience to the Tragedy of the Commons, so that they might come to understand problems facing sustainable sharing as well as to explore the viability of potential solutions. By exploring the aggregate outcome of their collective choices, students experienced the potential problems that commons-sharing communities face, while also confronting the strengths and weaknesses of different solutions. We hypothesized that this activity would support students in reasoning about other, similar, situations in which social collectives share a commons.

The Elicitation: Two Real Cases of Resource Sharing

At the end of each of the three weeks of the unit, students were asked to respond individually to questions about written case studies in which communities share resource systems. These assignments were given as homework over the weekends, and questions were distributed via Google Forms. The data presented in this paper come from the first and the second of these assignments. As mentioned above, our purpose analysing these data is more to identify *patterns in students' ways of thinking* about resource systems, than to argue for the effectiveness of our unit in creating conceptual change or learning in this area.

These two homework assignments presented students with historical cases from Ostrom's (1990) work. We decided to use these two cases for a variety of reasons: first, because Ostrom's own treatment of them provided us with an "expert analysis" with which we could compare student responses. Second, both these cases took place years ago before technological innovations would offer easier solutions to some of these problems. By taking out technical solutions, we forced students to reason about the social and ecological aspects of the dilemma, instead of coming up with intricate technical solutions like satellite surveillance or GPS tracking. Finally, these cases involved self-replenishing but fragile resource systems with similar features to the one that students experienced in the Virtual Commons, but were still different enough that we could see whether students would reason about these systems by drawing on their experiences from the Virtual Commons.

The first case described a community of farmers outside of Valencia, Spain who shared an irrigation canal system in the Middle Ages. Maintenance of the canals relied on the coordinated effort of many people and more resources than any one farmer could afford. Additionally, the amount of water fluctuated each year due to differences in precipitation.

The second case described a community of fishermen in Sri Lanka living by a bay, whose livelihood depended on the use of large *seine* nets. These nets were so costly that seven families typically had to co-own each one, and so large that only one boat could fish in the bay at a time. The nets, then, posed both financial and logistical constraints, forcing people to cooperate. In addition, maintaining the health of the bay (a fragile ecological resource system) was yet another factor requiring community collaboration.

Analysing the Responses

The questions (9 questions for the first case and 8 for the second), probed student thinking about the difficulties that these communities might face, and asked students to think about what rules the community could instate to address the difficulties, and probed their thinking about why those rules would help. We changed the number of questions between the two cases as part of our iterative design process, because a preliminary look at student responses after the first week of implementation suggested to us that two of the questions overlapped in a confusing manner. Our second iteration of questions collapsed these two questions into one and rephrased the prompt.

Because we were still in the exploratory stages of our research, we took an open-ended approach to coding students' responses. We used "ways in which students identify challenges at the community or individual level" as "sensitizing concepts" (Miles & Huberman, 1994) in our initial coding. The first two authors coded all student responses individually, and we then converged on four interesting patterns that both researchers noticed across many student responses.

Findings

In this section, we will describe four patterns in students' thinking that emerged from our open-ended analysis, and that we believe future learning design and research should focus on. We describe each pattern and how it relates to the specific details of each of the cases; provide examples of student responses that exemplify each pattern; and, finally, discuss how each pattern seemed to participate in the broader reasoning of the students who exhibited it. These patterns proved to be two-sided in their effects on student reasoning about common-pool resource sharing. On one hand, they acted as productive tools to support students in thinking and in articulating ideas; on the other, they seemed to foreground particular aspects of sharing dilemmas at the cost of backgrounding other features, thus tending to limit student thinking in some ways.

The "Fixed Flow" Pattern

We found that when asked to identify a potential tragedy of the commons in each of the two cases, it many students reasoned primarily about short-term aspects of sharing the *flow* resource. In contrast, very few students mentioned long-term, *stock*-related aspects relating to optimizing the yield of the system.

For example, consider this typical *flow*-focused response to Case 2 (fishing):

> *By cheating […] that group would get the most fish and […] affect the other groups by forcing them to split a smaller number of fish and depriving them of equal opportunity. (S12)*

Compare this thinking with the following typical *stock*-focused response, also to Case 2. (Note: Here and elsewhere students' spelling and grammar are maintained.)

> *If one of the fisherman caught more than assigned then the it effects the rest of the community because thre wouldn't be enough fish to reproduce and have enough for next 'harvest.' (S21)*

Interestingly, both students are talking here about overfishing. But the *function* of overfishing is different and reflects the distinction between fish as *stock* and fish as *flow*. In the former response, the student identifies the problem with overfishing as there being an immediately lower number of fish to split between the rest of the fishermen at that moment. In the latter, the student identifies the problem with overfishing as diminishing or threatening *future* yield.

This illustrates the importance of thinking about both stock and flow. However, we often saw that students focused only on flow. In Case 1 (irrigation), 21 students brought up potential *flow*-related problems with people taking too much water and not leaving enough for the rest of the community, and 14 students brought up potential rules to address these problems. In contrast, only 10 students mentioned *stock*-related problems, and only four students mentioned solutions to them. Likewise, in Case 2, 20 out of 22 students mentioned potential *flow*-problems - relating to taking more than one's share by fishing too much - and 12 brought up rules to prevent them. In contrast, only 3 student responses brought up problems relating to stock – the maintenance of the system and its ability to produce future fish – and only 2 identified potential rules to address these problems. Moreover, those who did reason about long-term stock issues were very likely *also* to reason about short-term flow issues, but not vice versa: of the 10 students who mentioned stock problems, 8 *also* mentioned flow problems.

We call the thinking pattern that attends to flow-aspects *at the expense of stock-aspects* the "fixed flow" pattern, because responses exhibiting this pattern treat the shared resource as an invariant quantity of flow – water in the canal, or fish in the bay. That is, this thinking pattern attends to "fair sharing" of the flow, possibly making a hidden assumption that the group's access of the resource will not damage the system's capacity to produce future flows. This pattern of thinking can be problematic if it prevents students from considering how to preserve the "favourable conditions" that optimize the long-term availability of flow resources to be shared, either through maintenance of the stock or the system's infrastructure.

The "Social, Not Ecological" Pattern

We also observed a pattern of thinking in student responses that emphasized solving the social problems of freeloading, at the expense of considering ecological problems. Students' responses exhibiting this pattern often assumed that if the community managed to collaborate, then everything would be fine. For example, consider the contrast between this response to Case 1:

> *If the farmers collaborate, they ensure some level of food security and economic security. (S7)*

…and these responses (to Case 1 and Case 2, respectively):

> *If they collaborate, each farmer will have enough for his on family. (S16)*
>
> *If the fishing groups cooperate then they will each get some fish and there will be a sustainable population (S20)*

In the first response, the student explicitly reasons that while collaborating will ensure some level of food security, it will not absolutely *guarantee* it. In the last two, the students seem to assume that if the farmers or fishermen prevent each other from cheating, everything will be fine. But there are no guaranteed 'happily ever after' scenarios in the commons, even for communities that share resources equitably. Even if everyone gets their fair share, a community can run out of fish or grass if they do not solve the long-term, yield-related *stock* problems. Because of its emphasis on the social dimension of the sharing dilemma, we described this pattern as a "social, not ecological" way of thinking. We saw this pattern in 9 responses in Case 1, and 8 in Case 2, with four students exhibiting the pattern in both their responses to both cases. These responses suggest that students may forefront the social coordination problems without taking into account the ecological dimensions of the system. While the social side of problems *is* important, it cannot stand on its own, and future design iterations of our unit will try to forefront the ecological side more in an attempt to address this pattern.

The "Social, Not Ecological" pattern and the "Fixed Flow" pattern share similarities in the features of common-pool resource sharing that they background. In particular, both are focused on concerns about equal access to flows at the expense of questions about the sustainability of stocks. However, for us they represented different ways of thinking, because of the way they engaged with social dynamics and norms. As we seek to engage groups of learners in broadening their perspectives, these ways of thinking represent different entry points and leverage points for the design of activities and learning environments.

The Profit and Competition Pattern

As we have noted, our student responses focused on short-term, *flow*-based problems, with almost all students in the population mentioning these challenges. One pattern in students' *characterization* of these problems had to do with an interpersonal source or motivation for cheating in the commons. This pattern grounded reasoning about why people cheat in an implicit or explicit belief that people in groups are *competitive*, such that community members compete over the commons and attempt to generate the most individual profit. Responses exhibiting this pattern focused on motivations for cheating that pertain to people's *desires* rather than their *needs*. Consider these three responses:

> *Farmers would [cheat] to get ahead and water more and more crops to make money. (S12)*

and,

> *They want to produce the most and be the best farmer. They want to be known as having the best most consistent product. (S6)*

and,

> *By cheating in a way like going out to fish earlier than everyone, that group would get the most fish and be the most wealthy and profitable. (S13)*

Twelve responses to Case 1 and twelve to Case 2 brought up a competitive profit motive for cheating, with 7 students responding in this way to both cases. However, Ostrom's research shows that community members may cheat for a wide variety of reasons beyond the desire to profit over others. For instance, community members experiencing temporary financial or health-related difficulties may cheat out of necessity. Alternatively, community members may feel an incentive to cheat if they perceive that others are cheating and getting away with it. Thus, preventing cheating can be a very complex matter. But students exhibiting the "profit and competition" pattern tended to reduce this problem to an interpersonal competitive dynamic.

Ostrom's work suggests that designing collaboration rules for preventing cheating requires a deep understanding of the underlying reasons for why people cheat, as these motivations are what the rules must target. Thus, while the "profit and competition" pattern may be productive for reasoning about preventing one kind of cheating, it may draw students' attention away from solutions to other manifestations of *flow*-sharing problems.

The "Fixed Human Nature" Pattern

Another prominent pattern in student responses that addressed *flow*-sharing problems appeared to be based in an image of human nature as having essential qualities independent of context or situation. This pattern was distinguishable from the "profit and competition" pattern in which the competitive nature was seen as coming out of the *interactions* between people. In contrast, in the "fixed human nature" pattern, students downplayed the impact of social arrangements and conditions in preventing cheating, and instead saw rule-breaking as inevitable. Humans (or some types of humans) were seen as essentially predisposed to pursue antisocial behaviour that would benefit them individually. We provide examples of this pattern of thinking from responses to Case 1.

In some instances, students posited essentialized features of human nature in particular individuals or types of individuals within the broader population. For example, the following response indicates a belief in the existence of an antisocial element:

> *A few rotten apples out of the farming bunch may misuse the water and everyone's fields would collapse. (S10)*

In other responses, students expressed essentialized understandings of human nature in general, or they bridged from behaviours exhibited by individuals to traits of all people. Consider the following response:

Certain farmers will always ask for more than they need due to the selfish nature of humans. (S22)

Here, while the phrase “certain farmers” suggests a conception about a *subset* of the population, “the selfish nature of humans” points toward a more general human trait. Similarly, in reflecting on the impact of variability in the flow resource of water in Case 1, another student remarked:

I think this because people worry about themselves first and foremost, then secondly comes the idea of sharing. (S18)

Under this conception of human nature, it is possible to make context-independent statements about how humans will behave and interact. This pattern in student thinking stands in contrast to an alternative conception of human nature, which holds that it is malleable, and that human behaviour is highly context-dependent. A “fixed human nature” pattern tends to underestimate the potential for policies, rules, and information to alter collective patterns of action. Thus, this pattern may hinder students’ ability to conceive of creative responses to the dilemmas and challenges that constitute the “drama of the commons,” limiting their capacity to imagine solutions for sustainable common-pool resource sharing and management.

Discussion, Limitations, and Conclusion

This paper has presented an analysis of high school students’ reasoning about communities sharing natural resource systems as part of a 3-week unit on sustainable food production featuring participatory simulation activities. Based on our analysis, we identified four patterns across students’ responses. These patterns proved to be productive for students to reason about some aspects of the cases, but we speculate that they also hindered students in reasoning about other important aspects.

We have taken a design-based research approach to the iterative construction and implementation of this unit, and the design changes to our subsequent iterations have aimed to better identify and address the problematic aspects of these thinking patterns. We have implemented the activity sequence analysed here two additional times, including the following refinements, responsive to our analysis of patterns of thinking.

In order to address the “fixed flow” pattern, our current design gives students increased access to the *data* produced by the model in order to provide the classroom group with opportunities to explore how their behaviours, both as individuals and as a community, effect changes in the “*size* of the pie” from which they are taking equal or unequal shares.

To address the “social, not ecological” pattern, we have made two changes to the simulation itself. First, we reduced the carrying capacity of the system, and second, we have sped up how quickly the simulation runs. Both of these changes increase the likelihood that student villages will experience a crash, even with a modest number of cows. Our aim with this is to let students discover that even a well-coordinated community can experience crashes because of scarcity.

Finally, in order to address the “profit and competition” pattern and the “fixed human nature” pattern, we have developed a set of activities within and around the PartSim experiences, in which students run collective self-defined “experiments” in and on their commons. While the groups spontaneously thought of some of their actions as providing information about their environment even our first-year implementation, our subsequent design refinements have amplified this tendency. Data from these experiments have allowed student groups to make better decisions about how many cows should be allowed to graze, and how many people should repair fences or fertilize the grazing ground each week. In addition to serving the more general learning goal of using computer simulations and data to make decisions, our hope with these activities is that students can experience both the challenges and benefits of working together to manage shared resources and to gauge their success in doing so.

An important limitation of our study is that our sample of students comes from a predominantly white, private, suburban, parochial high school from which 99% of graduates go to college. Importantly, this study focuses on reasoning about sharing, and we believe that these students who often come from very high-resource homes will have a particular set of experiences of sharing as a result of their upbringing, not representative of the high-school aged population as a whole. To address this limitation in the makeup of our population, we hope soon to implement our unit in other socio-economic settings.

In analysing student response data, we identified substantial variation not only across students but also within students across the two cases that students reasoned about. However, it is important to keep in mind that the two cases are quite different, exhibiting distinctive features of the natural resource systems that communities share. In order to tease apart (a) how differences in students' responses to the cases stem from genuine differences or changes in *thinking* about the cases on the one hand, from (b) substantive differences between the social-ecological systems in the cases on the other hand, we are varying the order in which students experience each of the two cases.

Finally, we believe that participatory simulations offer a particularly powerful approach to learning about common-pool resource sharing dilemmas in a classroom setting. PartSims give students the dual perspective of individual and group in experiencing social-ecological dilemmas and allow them to engage in deliberation about resource systems sharing. Given the importance of this topic to the survival of our species and planet, we feel that collective resource systems sharing and maintenance is an important area of focus for education research and design. In this paper, we have presented what we see as early educational research on this topic.

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