Examining system dynamics models together: Using variation theory to identify learning opportunities in online collaboration

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Abstract: This study applies variation theory to examine the discourse of three online groups learning about the structure and behavior of simple population models. Students' discussions were examined to reveal whether the discussions provided opportunities to become aware of possible variations corresponding to those critical dimensions. The findings indicated that only in Group 1 did the discussion open variations corresponding to critical dimensions of the model structure and growth patterns. We propose that variation theory is useful as an analytic lens for researchers interested in collaborative learning particularly in online environments, and also as an instructional design tool for teachers in designing collaborative tasks.

The goal of this paper is to examine how to identify what the students may have learned (about a given topic) from their online collaboration. The process of online collaborative learning can be analyzed from many perspectives. With regards to making claims about learning from group interaction data, one common approach is to see the collaborative discourse as reflecting cognitive processes, some of which are more germane for learning than others (Hara, Bonk, & Angeli, 2000; Schellens & Valcke, 2006). Another approach to making claims about learning from collaboration discourse is informed by a more socio-cultural view of learning as participating in social practices. This approach is more concerned with the qualities of the discourse at the group level, rather than with learning at the individual level (Kennedy-Clark & Thompson, 2011; Stahl, 2006).

These two approaches to analyzing online collaboration discourse have their own limitations. The cognitive approach allows inferences about individual students' relative *amounts* of learning (or potentially germane cognitive processes). However, it provides little insight into what or how students might have learned about the *topic*. The second approach is useful to highlight group-level processes and properties, but it shies away from making inferences about *individual* students' possible learning outcomes. We propose that variation theory (Marton & Pang, 2006; Marton, Runesson, & Tsui, 2004) offers an approach to analyzing collaboration discourse that complements the two approaches above.

Variation theory has been successfully applied to analyze classroom discourse (Ling, Chik, & Pang, 2006; Pang & Marton, 2003; Runesson, 2005), but has not been widely used to examine collaborative learning, particularly in an online learning environment (for exceptions, see Aditomo & Reimann, 2009; Booth & Hulten, 2003). The theory is rooted in phenomenography (Marton, 1981, 1992), which asserts that awareness always has an object, and hence knowing or learning is always knowing and learning about something. Phenomenographic studies have shown that objects (both material and conceptual) can be understood, experienced, or conceived in several qualitatively different ways (Marton & Booth, 1997). Learning, in this view, is becoming able to see, understand, or experience an object in a new and more powerful way. The central tenet of variation theory is that to discern an aspect of something, a person needs to experience *variation* corresponding to that aspect (Marton & Pang, 2006). It is the awareness of *possible* variation in certain aspects of an object that enables one to discern those aspects. In this study, we apply variation theory to examine the discourse of three groups learning about system dynamics modeling.

Method

Participants
Data were obtained using a tool called Snooker (Ullman, Peters, & Reimann, 2005) from a postgraduate class. The students worked in groups: Group 1 consisted of two female students and one male student, Group 2 two males and one female, and Group 3 two males and one female.

Topic and task
Students were learning about the structure and behavior of complex systems. Features that distinguish complex systems include emergence, feedback, time-delays, and non-linear cause and effect relationships (for further explanation of these features, see (Sterman, 2000)). The topic addressed in this session was a population model that included the carrying capacity and the model's behavior (which was an S-shaped growth pattern). Upon

completing the task, students were expected to understand the relationship between the structure of a system and its behavior: that a model with a carrying capacity produces an S-shaped growth pattern. Implicit, but crucial, in this outcome is the understanding that carrying capacity is an *emergent* property, one which arises out of the interaction of several components of the model: the birth rate, habitat size, density, and death rate. In the example in Figure 1, the carrying capacity is 200; that is where the population stabilizes. This specific carrying capacity is a result of the specific birth rate, habitat size, density, and death rate values in the model; altering any of these would change the carrying capacity in ways that are difficult to predict.

Rather than a fixed value, the death rate is formulated as a function of density (i.e. death rate increases as the habitat becomes more dense or populated). Hence, in the first phase of the system's growth, density was low and the death rate was lower than the birth rate. This produced exponential population growth. However, as the population and density rose, the death rate also rose, which slowed the population growth (the system still grew, but not exponentially). When the density reached a certain point (the carrying capacity), the death rate was equal to the birth rate and that is why the population stabilizes. Phrased differently, this type of growth is the result of a non-linear relationship between the system's positive loop (in this case, the birth cycle) and negative loop (in this case, the death cycle).

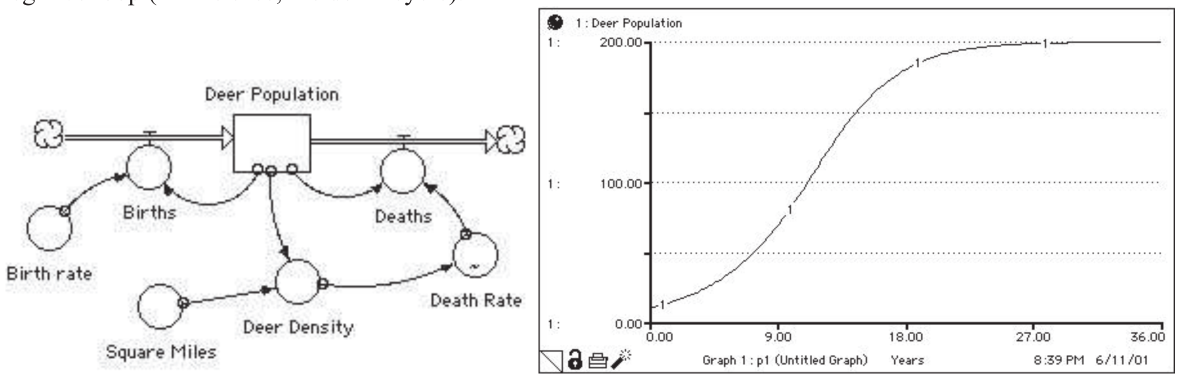

Figure 1: The deer population model (left) and the S-shaped population growth (right).

Students in our course were given a task with the aim that they would learn about several key features of system dynamics models and complexity; features that they could then apply to other models. These were short tasks undertaken in class time. Students were split into groups and asked to discuss three questions, followed by a larger group discussion, facilitated by the lecturer. They were asked to download a simple population model from an external website. In the chat, the students were asked to discuss three questions: (1) This model includes a carrying capacity. What are the implications of this for the behavior of the model? (2) Change the birth rate and death rate in order to find a combination that will result in a decline in the deer population despite unlimited habitat; (3) In real life, there is a limit to` the size of the available habitat. Choose a size of the habitat. What kind of growth does this illustrate? What is the carrying capacity of your habitat?

Analysis and findings

From a variation theory perspective, analysis of learning opportunities starts with the identification of critical aspects of the *intended* object of learning (i.e. the aspects of the topic which students need to discern, to be able to see it in a way intended by the instructor). The intended object of learning was to understand that a system dynamics model that includes a carrying capacity produces S-shaped growth. To achieve this, students needed to discern two broad aspects simultaneously: *structural components* of the model, and the corresponding *behavior* of the model. The *structural* components were: (1) the death rate formula, which depends on density and area (this is the part of the model which embody the system's carrying capacity), and (2) the relative strengths of the birth and death rates. Aspects of model *behavior* relevant to this task were: (3) the shape of the population growth (S-shaped vs. exponential), and (4) the phases in an S-shaped growth (increasing in the first phase, and decreasing in the second).

Did the students enact the task in a way which made possible the discernment of critical aspects of the topic? (There are issues related to the establishment of a common ground necessary for online communication to occur, but we have analyzed this elsewhere (Reimann, Aditomo, & Thompson, 2009)).

Enactment of Problem 1

"This model includes a carrying capacity. What are the implications of this for the behaviour of the model?"
In discussing this problem, Group 1 discussed the meaning of carrying capacity in a qualitative sense, rather than the formal sense represented in the model. For example, Christine started the discussion by saying "the

point of carrying capacity is that the land can only support so much life" (Line 46[1]), and "so if there are too many deer, there won't be enough food for them all and some will die" (Line 47). Judy, also offered her general sense of carrying capacity by saying that "it have a limition of carrying how much dear in the same area" (Line 50), and "if the Habitat Area is wilder, then the dear can live longer" (Line 60). In this group, only Christine related carrying capacity to the model, by mentioning "death rate" and "density" in Line 51, and again mentioning "death rate" in Line 62. The remainder of Group 1's discussion of Problem 1 (Lines 63 to 76) centered on whether it was better to have a higher or lower carrying capacity.

In Group 2, Problem 1 was discussed in the presence of the lecturer (Lines 47-61). As in Group 1, Group 2 focused on the concept of carrying capacity in a qualitative sense. Geoff (Line 48) asked the lecturer what carrying capacity meant, and the lecturer answered "carrying capacity is the amount that the system can cope with" (Line 53), and provided an analogy with the computer room they often used that has a carrying capacity of X number of students. Geoff indicated he understood, and said that it was "straightforward" (Line 57). Another member, Teresa, also indicated that she understood (Lines 58). After the lecturer left, the students began Problem 2, indicating that they felt Problem 1 to have been adequately addressed.

In Group 3, discussion of Problem 1 began with each member offering their interpretation of the problem. Luke asked, "Are we surpposed to explain the model?" (Line 31). Anne, responded "the first question means how does the carrying capacity of the area affect the model, i think" (Line 32). To this, Paul responded with a qualitative definition of carrying capacity: "In farming terms we have a carry capacity of so many sheep per acre" (Line 34). Anne also offered her definition: "yes, so there must be a limit to the number of deers" (Line 35). Subsequently, only Luke referred to the model itself, or what it meant for a model to have a carrying capacity. Luke described the relation between density and death: "if density is over the carrying capacity, then death rate will rise" (Line 36), "which in turn lowers density" (Line 47). Anne added that "in addition to increasing death rate, carrying capacity also decreases birth rate" (Line 45), which indicates a potential misunderstanding because in the model, the concept of carrying capacity was embodied in the variable death rate (it is a function of density and habitat size).

Enactment of Problem 2

"Change the birth rate and death rate in order to find a combination that will result in a decline in the deer population despite unlimited habitat."

Group 1's discussion started when Frank said that it fixes the death rate, and hence they can only manipulate the birth rate (Lines 79 to 81). Frank's statement indicated he was examining the Stella model, unlike Judy, who was using an online simulation. Judy responded by saying she had already obtained a correct combination: "just put 3% for birth rate and 50% for death rate" (Line 82). The online simulation, which was introduced in a previous task by the lecturer, allowed users to manipulate the death and birth rate in percentage forms (not decimals, as in the model). Furthermore, the simulation did not represent a model with a carrying capacity. This caused obvious confusion, as Christine and Frank tried to understand what Judy meant by "3%". The group began Problem 3 without resolving this communication problem. Hence, for Christine and Frank, but not Judy, addressing Problem 2 enabled the discernment of the difference between constant converters (the birth rate) and graph function converters (the death rate).

Group 2's discussion started with Geoff's comment "wouldnt we just have to increase the death rate above the birth rate to have a decliing population?" (Line 93), which was approved by the other two members (Lines 94 and 95). Geoff continued: "because it doesnt really matter how big the area is...if births are less than deaths...or the ratio is leaning that way...its pretty logical" (Line 97). Here, Geoff made sense of Problem 2 in a qualitative way; population size is simply a function of the relative sizes of the birth and death rates. This is qualitatively correct, but it trivialized the problem and diverted attention away from the components of the model that formally represented the system's carrying capacity (i.e. the area, density, and death rate converters). Without attending to these components, students would not have the opportunity to discern that the death rate could be represented in different ways (as a fixed value or as a function of density). Furthermore, without examining the density and death rate components, it would be difficult to guess the birth rate that would decrease the population, as Nathan discovered. Approximately 30 seconds later, Nathan said "but my numbers dont seem to change the graph" (Line 98). This indicates that Nathan was examining the model. This prompted Geoff to think about how density affects the system, as reflected in his next utterance, 40 seconds later: "a higher deer density can mean both less food and more protection in numbers from hunters etc" (Line 99). This move could have directed the group's attention to how carrying capacity is represented in the model, however the group decided to end their discussion due to time considerations.

In Group 3, discussion of Problem 2 started with Anne expressing her puzzlement about the problem's suspicious simplicity: "i dont understand the second question? because whenever the birth rate is smaller than death rate, it will decline. there must be a catch that i dont get … despite unlimited habitat" (Lines 52 and 53).

[1] Due to space limitations, the data to which this line number refers are not included in the paper, however the line numbers were kept in the paper to allow the reader to have a sense of the order in which statements were made.

The discussion then focused on what model should be examined. When they returned to Problem 2, Luke reported that he didn't succeed in lowering the population, despite having specified a very small birth rate (Line 70). Surprised, Anne reported "oh. i just put 25% brith and 30 % death - for example-" (Line 71). This statement indicated that Anne was examining the online simulation, instead of the Stella model, without a carrying capacity. After Luke elaborated what he was seeing in his model (Line 75; that death rate is determined by density), Anne realized that she needed to examine the model (Line 79), at which point the discussion of Problem 2 ended due to time constraints. Overall, enacting this task enabled Group 3 (or at least the students who examined the model) to discern the model components that represented carrying capacity.

Enactment of Problem 3

Specify the habitat size (choose a specific value for the "Square miles" converter), "What kind of growth does this illustrate? What is the carrying capacity of your habitat?"

Only Group 1 had enough time to discuss this problem. The group agreed to try 600 as the habitat size. Christine then said that the system produced an S-shaped growth (Line 114). Judy, on the other hand, said that the population would *increase* if the birth rate were more than 10% (Lines 112-113). Christine expressed her confusion at Judy's prediction (Line 116). This exchange indicates that Judy was still looking at the online simulation, whereas Christine was examining the Stella model. The group ended their discussion without clearly resolving this issue, and without examining the carrying capacity of their system.

Did this brief discussion above open a critical dimension of variation? It is possible that the students who manipulated the model were able to perceive the contrast between a model with unlimited habitat (from Problem 2) and one with a limited habitat (in Problem 3), and potentially with the corresponding growth patterns (exponential vs. S-shaped). The students, however, only tried out one habitat size (set to 600, see Line 110). In other words, the habitat size was not varied. Had the students entered other sizes, they would have had the opportunity to see that changes in habitat size correspond to changes in the slope of the S-shaped growth pattern.

Summary of learning opportunities

Table 1 summarizes the learning opportunities that were opened in the groups' enactment of the task. If a student stated a variation of an aspect of the topic, or referred to an outcome or event (e.g. model behavior) that requires the discernment of that aspect, these were taken as evidence of a learning opportunity for that student (but not necessarily for other students in the group). Hence, Table 1 lists the names of each student whose utterance provided evidence for the learning opportunity.

Critical aspects of the intended object of learning	**Learning opportunities (variation which enabled discernment of each critical aspect)**		
	Group 1 (Christine, Frank, Judy)	**Group 2 (Nathan, Geoff, Teresa)**	**Group 3 (Luke, Anne)**
a. Death rate formula (fixed vs. varying as a function of density and habitat size)	Christine (in Problems 1 & 2), Frank (in Problem 2)	-	Luke (in Problems 1 and 2)
b. Relative strength of birth and death cycles	Christine, Frank, and Judy (in Problem 2)	Nathan (in Problem 2)	Luke and Anne (in Problem 2)
c. Population growth (exponential vs. S-shaped pattern)	Christine and Frank (in Problems 2 & 3)	-	-
d. Phases in an S-shaped growth (exponential increase vs. decrease)	-	-	-

Discussion and Conclusion

The groups' enactment of the task did not open the complete set of variations necessary to understand the intended object of learning. In discussing the model, Groups 2 and 3 focused on the model's structure (aspects (a) and (b) in Table 1), but did not mention any aspect of the model's behavior (aspects (c) and (d) in Table 1). Only members of Group 1 discussed an aspect of the model's behavior (exponential and S-shaped growth), but not even this group examined the properties of the growth pattern in more detail.

The activity did enable students to discern the meaning of carrying capacity in a general sense. For students who examined the model, the activity presented an opportunity to discern the model component that represented carrying capacity: the type of death rate (constant vs. function of density). For students who examined the online simulation, the activity presented an opportunity to simultaneously discern the relative magnitude of death and birth rates, as well as the resulting exponential growth pattern. Students did not have the opportunity to simultaneously discern the critical or defining structural feature of population models with and without carrying capacity, along with their associated growth patterns (exponential vs. S-shaped).

The most obvious challenge in this task was that of communication. Establishing adequate common ground is a well-known problem for online chat groups (Reimann, et al., 2009). In this case, the difficulty was due to one member in both Groups 1 and 3 looking at an online simulation, while other members examined a Stella model. Only the Stella model included carrying capacity. Communication problems do not, however, explain Group 2's enactment of the task, in which the evidence suggests that members were examining the same model. We propose that another important challenge for students was concerned with the dual meaning of "carrying capacity". This concept can be understood at a general, commonsense level, as members from all groups expressed in this task. However, the objective of the task was to understand carrying capacity in a formal sense, as it was represented in the model; as a property of the model's behavior that emerges from the interaction of the model's structural components. Group 2 almost exclusively focused on their discussion on the general meaning of carrying capacity, and did not inspect the Stella model. Members of Groups 1 and 3 also expressed this confusion, although in these groups, some of the members did inspect the model.

To conclude, using variation theory allowed us to examine online group interactions to make inferences about individual learning opportunities. This gave us useful insights into the design of the task that were implemented in subsequent years. This paper illustrates the utility of variation theory as both an analytic lens and as a conceptual tool for teachers, who often feel that learning theories are too abstract, too complex, while offering few practical guidelines (Yanchar, South, Williams, Allen, & Wilson, 2010). One feature that makes variation theory a potentially practical tool is that it focuses on the subject matter or topic itself, which is something that teachers are familiar with.

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