Failures and Successes in Collaborative Inquiry:
Learning the Physics of Electricity with Agent-Based Models

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Abstract: This paper presents a process-oriented case study of successes and failures in collaborative inquiry. The interactions of pairs were recorded and transcribed while they were engaged in learning activities, mediated by agent-based NetLogo electricity models. Transcripts of learner interactions were coded for engagements in science inquiry. The purpose of this paper is to articulate the dynamics of collaborative science inquiry approach resulting from varied scaffolding and consistent scaffolding in learning activities. Our findings indicate that students under a varied scaffolding approach were more deeply engaged in inquiry process and performed better on model-based explanations.

Introduction

Traditional pedagogical approaches that focus on algebraic models for teaching the topic of electricity are common practice in schools. Some research shows that even after extensive instruction, students do not grasp some of the very basic characteristics of an electric circuit (e.g., Mulhal, Mckirrick, & Gunstone, 2001). Students often conduct laboratory-based electricity experiments that typically involve activities leading to collection of data to verify, for example, Ohm's Law or the formula for effective series resistance; nonetheless, the curricula materials or real laboratory experiments about electricity seldom engage students to understand underlying physical phenomenon. The cognitive processes needed to succeed at many school-related tasks are often qualitatively different from the cognitive processes needed to engage in real scientific inquiry (Chinn & Malhotra, 2001). The use of technology such as computer models and visualization has been the focus of recent research to support model-based inquiry (Edelson,, Gordin, & Pea, 1999). An important issue in science education today is how to design curriculum and instruction that will enhance authentic scientific inquiry and promotes ability to apply the knowledge in novel problem-solving situations.

Curriculum and Instructional Approach

In this study, we developed learning activities for four NetLogo Agent-based models: Coulomb's law, Ohm's law, series circuit, and parallel circuit (Wilensky, 1999). Each model had three learning activities. The NetLogo models allow students to view microscopic physical phenomenon aggregating to macro-level outcomes over a period of time. The NetLogo electricity models have been used in the United States with the scaffolded activity sheets, which prompts them with logging observations, reflective tasks and questions, and relevant content knowledge (Sengupta & Wilensky, 2008). We incorporated a Productive Failure (PF) approach (Kapur, 2008) and a traditional approach (Non-productive Failure: N-PF) to design and sequence the NetLogo mediated learning activities, both approaches targeted at model-based problem solving. All the activities for PF as well as N-PF group include model-based problem. The N-PF group receives the design of the experiments in NetLogo environment, in activity 1 as well as activity 2, similar to traditional laboratory instruction. The PF group receives the design of experiments only in activity 2. Activity 3 is envisioned as an alternate assessment tool (Zhang, Jacobson & Kim, 2006). The PF approach postulates that appropriately designed *non-scaffolded* initial learning activities may eventually lead to more productive learning gains than scaffolded early experiences that do not allow students to fail.

Table 1: Sequence of Activities

	Activity 1 (20 min)	Activity 2 (20 min)	Activity 3 (20 min)
PF	Not Scaffolded	Scaffolded	Not Scaffolded
N-PF	Scaffolded	Scaffolded	Not scaffolded

In this paper, we will provide a process oriented qualitative description of interaction of two student pairs, one using the PF approach and the other using N-PF approach, to explore the relationship between the scaffolding approaches and NetLogo mediated collaborative learning of physics of electricity. Building on the

idea of productive failure, we argue that the productive success in model-based explanation comes from cycle of failures and successes.

Selection of Cases

Six pairs of participants from each condition (PF and N-PF) from two schools were selected based on their previous school test scores (high, medium, and low) to collect process data as they worked together. We captured their computer screen along with webcam videos and audio recordings. Clarity problems with the audio and other technical mishaps during recordings limited our choice to have a complete data set for students with similar abilities. As a result, described below are the collaborative inquiry processes and performance on activity 1 and 2 of two pairs: Jian and Mick represent the N-PF group, and Ben and Ruo represent the PF group. Jian and Mick were categorized as having overall high academic achievement by the teacher whereas Ben and Ruo were regarded as medium achievers.

Collaborative Inquiry Process in Two Cases

The test performance indicated the PF group's significant better improvement compared to the N-PF group (see, Pathak, et. al. 2008; Jacobson, Kim, Pathak, & Zhang, 2009). Our hypothesis was that PF group would struggle to explore different ideas and approaches for solving the non-scaffolded initial problems for each of the four NetLogo models during first activity. In doing so, they might cognitively explore a wider range of ideas and concepts than N-PF students who are likely to follow the scaffolded set of tasks as is generally done in traditional laboratory settings. The following questions guided our research inquiry into the processes of two groups (PF and N-PF):

1. What different variable spaces have students explored?
2. How do exploration patterns change as a result of two conditions (PF and N-PF) within the model and over a set of models?
3. How do PF and N-PF conditions affect the process of scientific inquiry?

We conceive of model-based learning as a subset of science inquiry. We coded students' conversations and performance in activities based on their engagements in the following four components of science inquiry (adopted from White & Frederiksen, 1998). In our understanding, engagements on all the components over cycles of failures and successes should lead to a successful model -based learning.

1. *Generation of predictions (GP):* Students make educated guesses on possible outcomes of inquiry cycle.
2. *Design and execution of experiments (DEE):* Designing and conducting experiments with the NetLogo models for electricity require three main aspects of scientific experimentation: Convert the question in measurable attributes; Limit the predictors; and Collect and process the data accurately in presentable and analyzable formats.
3. *Experiment-based inference of relationships (EIR)*: Analyze and interpret data and their representations and look for relationships and patterns.
4. *Model-based explanations (MBE):* We define model-based explanations in electricity NetLogo model as student's ability to model and explain the phenomenon in terms of component of model (i.e., number of electrons, time, and distance).

We present below some excerpts of two pairs on Model 2: Ohm's law and Model 4: parallel circuit to discuss the dynamics PF and N-PF approaches. We first discuss N-PF group learning to understand what kind of interactions are achieved by providing scaffolding activities with NetLogo models, which might look similar to our typical classroom and laboratory practices, followed by PF group, whose interactions contrasts with those of N-PF group.

Model-Based Activities by Jian and Mick (N-PF Group)

Working with the two models, the initial scaffolded activity resulted in students setting their immediate goal to filling in the table with numbers. In both activities 1 and 2, Jian and Mick immediately focused their attention on the accurate measurement techniques (see Table 2).

Success in Collaborative Measuring (Model 2: Ohm's Law)

The pair carries out each measurement twice, take the average as done in a conventional measurement experiment. They are scaffolded through the table and the variables—the table and the first column and first row are given and students filled out the rest (in italics). Here, Jian and Mick successfully carried out the measurements but failed to discuss the microscopic patterns from the model (MBE) during their conversations

and their answers to the activity questions in both activities (Table 2, B and D). By design, this pair's variables and space manipulations were limited to the table in the initial activity. There might be a conflict (between observation and equation-based conclusion as they are using mathematical form of Ohm's law (see, excerpt in Table 2, C) and Jian believes in manipulating it, so as to reach an answer. Though faced by apparent cognitive conflict, they did not change their belief about model function and purpose (i.e., not engaged in MBE).

Table 2: Jian and Mick's conversations and responses during Model 2 and Model 4 activity

	Model2: Ohm's law			Model 4: parallel circuit	
	Conversations/Worksheet Responses		Engage-ment	Conversations/Worksheet Responses	Engage-ment
A. working with worksheet and model			Nil	Mick: 0.5 Jian; No, I don't think so, 0.2… it's in between (raising his hand to gain attention from Ms. Tan) Jian: (Pointing at graph, to Ms. Tan) Do I need to be exact?	Nil
	Collision rate with nuclei	Time taken to reach battery negative to battery positive	Current		
	0.5	$(4.28+ 4. 06) 2 = 4.11$	1.19		
	0.7	$(6.57 + 6.34) \div 2 = 6.46$	0.87		
	1.0	$(9.17+8.72) \div 2 =8.75$	0.7		
B. Activity 1 questions	Q. How would you describe effect of collisions on current? Why is it so? As the collision rate increases, the current in ampere decreases. The collision rate is inversely related to the current.		EIR (partial)	Q. What is your observation about current in both the wires? Explain why it is so. The current in the top wire is half the current in the bottom wire us the resistance of top wire is twice that of the bottom. The higher the resistance, the lesser is the current flowing through	EIR (partial)
C. Discussing the question for Activity 2	Jian: …according to Ohm's law… "why is it so?" (reading from the worksheet) … according to Ohm's law, it states that RI=V, right? Mick: Yes, RI=V Jian: Hence we can reach that conclusion… current goes up, you see…can manipulate Mick: Oh…		EIR (partial)	Ms. Tan: Did you write anything about voltage? Jian: Higher the voltage higher the current, it's about ohm's law… directly related. Ms. Tan: So you are using ohm's law? Jian: Yes. Ms. Tan: Ok, plays…but there are two variables.	EIR (partial)
D. Activity 2 questions	How are three values of time related to voltage? Why is it so? The higher the voltage, the lower the time taken to reach battery negative to battery positive the voltage is inversely related to the time taken.		EIR (partial)	Q. Explain even if the charges are same why the current is different in both the wires. The current in both the wires depends on the collision rate wire nuclei in both wires. The higher the collision rate, the higher the resistance in the wires.	EIR (partial)

Success in Collaborative Measuring (Model 4: Parallel Circuit)

By now they have gone through three NetLogo models with scaffolded activities. However, their interaction and inquiry patterns look quite similar to their earlier engagement as in model 2, which focus only on macroscopic ideas—they are focused on exacting their measurements. They also made inferences based on mathematical forms of circuit laws (partial EIR) without much explanations based on model observations as can be seen in excerpts Table 2, B. Here we see the teacher prompting (Table 2, C) that there are two variables involved, but their answer to the activity question (Table 2, D) does not reflect explanation with the two variables.

Model-Based Activities by Ben and Ruo (PF Group)

In the following excerpts and sample work from Ben and Ruo, we can see that they struggled and had short-term failures on aspects of science inquiry through the PF approach. However they were able to deepen their understanding and scientific inquiry through interacting with the NetLogo model and with each other after working together on a few NetLogo models.

Failures and Successes in Collaborative Inquiry (Model 2: Ohm's Law)

According to the video analysis, Ben and Ruo changed (Table 3, A) number of electrons, voltage, and collision rate to know the effect of collisions on current (engaged in DEE). It was done in a random manner by engaging in predictions as they did not have any prescribed settings as did the N-PF group.

Table 3: Ben and Ruo conversations and responses during Model 2 and Model 4 activity

	Model 2: ohm's law				Model 4: parallel circuit				
	Conversations/Worksheet Responses			Engage-ment	Conversations/Worksheet Responses				Engage-ment
A. Activity 1 working with the model	No of electrons	Voltage	Collision rate	DEE GP	No of electrons	voltage	Collision rate R1	Collision rate R2	DEE
	500	*1.5*	*0.5,0.8*		*500*	*1.0*	*0.5*	*0.5*	
	500	*0.5*	*0.7, 0.2, 1.0,*			*0.5*	*0.45*	*0.9*	
	2000	*0.5*	*0.1*			*0.5*	*0.45*	*0.45*	
	5	*0.5*	*1.0*			*1.0*	*0.45*	*0.45*	
B Activity 1 question	Q. How would you describe effect of collisions on current? Why is it so? The current is more constant when the collision rate is low. When the electrons collide, the current drops due to resistance. When there is lets say, a numbers of about 10 electrons colliding with the nuclei at one time, the current drops by a lot. However, when there is only about one or two particles colliding with the nuclei at one, the current barely falls or the drop the current is negligible as abscond from the model.			MBE GP	Q. What is your observation about current in both the wires? Explain why it is so. When the resistance in one wire is half of the other wire, the current in this wire is about two times the other wire, both have the same number of electrons, with equal voltage. The wire with half the resistance compared to the other will have two times the current compact to the other wire, wire, as the electrons have move about two times faster than that of the other wire.				MBE EIR
C. working with activity 2	Ruo: How are the three values related to voltage? Ben: Want to use this one? (pointing to stop watch) Ruo: Try, try. Let's check time. Ben: Try this one (referring to the current model setting)			DEE	Ben: Due to collision rate. Ruo: Are you sure, it's due to collision rate? Everything goes with V=RI Ben: Yes, the whole essay is about ohm's law.				EIR MBE
D. Activity 2 question	Q. How are the three values of current related to voltage? Why is it so? As the voltage increases, the current increases. When the voltage increases the time taken for the electrons to reach battery negative to battery positive decreases and as the collision rate with nuclei is constant and as the velocity so the electrons increases and as V = RI and thus current increases as the role of collision remains constant.			MBE EIR	Q. Explain even if the charges are same why the current is different in both the wires. Despite number is electrons being the same, the current is determine by the equation V = IR, thus voltage and resistance also affects the value of the current thus even if both charges are the same. If the voltage and resistance is different the current would not be the same.				MBE EIR

In addition to the random exploration of the model, the main struggle during this activity for Ben and Ruo was about the meaning of the different representations. For example, they did not know changing the number of electrons represented a change in the material. They were also unable to attribute the collisions to an experimentally measurable form, such as collision rate (failure in the form of understanding the deeper form experimentation techniques/methods, measurements) and to make experiment-based inferences of relationships (i.e., not engaged in EIR) (see, Table 3, B). However, there is a hidden efficacy in such explorations that may manifest in "knowing" more about interrelated components of NetLogo model. Ruo tries to understand the relationships (Table 3, C) that bring both of them to engage in experimentation with prescribed settings. Working with activity 2, unlike their first activity, they are able to articulate the relationships based on the model observation as well as mathematical formulation (Table 3, D).

Successes in Collaborative Inquiry (Model 4: Parallel Circuit)

The analysis of their interaction with NetLogo shows that Ben and Ruo did the minimal number of settings needed to arrive at a meaningful functional relationship (i.e., engaged in DEE) by constraining the variable

space (see, Table 3, A). It is important to note that the PF students could interpret the two-variable (see, Table 3, B) on the output current, unlike N-PF group (see, Table 2, B). Even in the non-scaffolded activity, students are able to explain their observation in terms of NetLogo based explanation taking into consideration the effects of three variables: voltage and two resistance (see, Table 3, A). Working on activity 2, (engaged in EIR) students have figured out that there is a two-parameter simultaneity that determines the output current (see, Table 3, D). They are also evoking a voltage-centered scenario in their explanation (MBE).

Conclusion

In this study we focused on failures and successes in science inquiry in the specific context of problem solving activities that required engagement with the NetLogo electricity models. In our experimental set up, we used two independent treatment conditions that differed in scaffolding approaches. The PF pair received cycles of *varied* scaffolding while N-PF pair received *consistent* scaffolding. Our results showed that in the case of the PF pair, the cycles of varied scaffolding resulted in engagement on different aspects of inquiry cycle; failing on some while succeeding on others. There seems to be a cumulative efficacy of cycles of failure and successes that resulted students performance in data-based explanation of the behavior of electricity models. The scaffolded experiences consistently engaged the N-PF pair in measurement activities and were successful in generating the data. However, interactions over the set of models did not engage them in all the aspects of science inquiry. We did not find any evidence of attempts at model-based explanation. The results clearly show the varied scaffolding approach to have significant potential in engaging students in various aspects of science inquiry in the context of a model-based learning environment.

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