From Science Student to Conceptual Agent: Examining the Individual Shifts in Engagement during Scaffolded Instruction

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Abstract

In this qualitative study we examine individual student engagement during implementation of an instructional scaffold for critical evaluation of scientific models during earth and space science lessons. We coded dialogic interactions of one student group in a sixth grade science classroom across three observations, wherein we analyzed the trajectory of engagement for a single student - Ray *(a pseudonym)*, within the co-constructed learning of the group. The first of these observations involved implementation of pre-constructed Model Evidence Link diagram on the topic of fracking, wherein students use evidence to compare a scientific model to an alternative model. In the second two observations students used a more agentic variation of the activity called the *build-a-*MEL, to study the topics of fossils and freshwater resources respectively. After three observations, we transcribed and coded each interaction of students in the group. We then categorized and identified emerging patterns of Ray's discourse and interactions with group members by using both a priori engagement codes, and open coding.

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Earth and space science topics present many teaching and learning challenges. For example, the underlying scientific principles are complex, the magnitude of process timescales are not easily observable, and students may have difficulty understanding how scientifically accurate explanations are constructed. Therefore, students need assistance in developing their scientific thinking and knowledge to gain a deeper understanding of Earth and space science topics (Authors, 2018).

Students may be curious about scientific topics, but they are not necessarily evaluative as they consider hypotheses and theories. Critical evaluation in science learning situations can involve judgments about the relationship between evidence and alternative explanations of a particular phenomenon (McNeill et al., 2006). Through critical evaluation, an individual seeks to weigh the strengths and weaknesses in the connection between evidence and explanations. Mere critique is not sufficient, because critical evaluation involves gauging how well evidence potentially supports both an explanation (e.g., an argument, a scientific model) and its plausible alternatives (e.g., a counterargument, a contrary hypothesis). In this way, critical evaluation embraces the criterion of falsifiability, where evidence may invalidate one explanation in favor of an alternative (Popper, 1963; Stanovich, 2007).

Students who engage in critical evaluation understand that scientific knowledge emerges from collaborative argumentation, which is a constructive and social process where individuals compare, critique, and revise ideas (Nussbaum, 2008). Chin and Osborne (2010) suggest that argumentative discourse activities can stimulate critical evaluation, when students challenge each other's thinking through questions about the strength of evidence and explanation connections.

Because students may not be critically reflective when engaging in collaborative argument, they may need instructional scaffolds to evaluate the quality of explanations (Nussbaum & Edwards, 2011). The MEL, which assists students in effectively coordinating evidence with scientific explanations (Chinn & Buckland, 2012), is a scaffold that—as shown from the results of our current project—promotes high school students to be more critical in their evaluations, engage in plausibility reappraisal, and construct scientifically accurate knowledge (Authors et al., 2016c). MELs specifically facilitate evaluation by helping students differentiate between evidence and scientific explanations—a scientific reasoning skill with which students often have difficulty (Duschl & Grandy, 2011; Kuhn & Pearsall, 2000).

Background on MEL Suite of Activities

The Model-Evidence Link (MEL) activities are instructional scaffolds that help students evaluate the links between lines of scientific evidence and alternative explanations about a phenomenon. Based on earlier work at Rutgers University (Chinn & Buckland, 2012), a collaborative team of educational researchers and master teachers developed MEL activities designed to promote students' scientific thinking and deep understanding of fundamental Earth science concepts (Authors et al., 2018).

The MEL activities respond to an explicit call in the Next Generation Science Standards for students to engage in critique and evaluation as a foundation for participating in scientific practices, such as engaging in argument from evidence (NGSS Lead States, 2013, Vol. 2, pp. 67–78). MEL activities scaffold explicit and purposeful evaluation when considering alternative explanations about scientific phenomena. Students evaluate lines of evidence that either support, strongly support, contradict, or have nothing to do with the models. Making such evaluations explicit potentially facilitates deeper understanding about Earth and Space science content, especially when students reflect on their judgments regarding competing alternative explanations about a phenomenon in a more scientific manner (Author et al., 2016).

One such judgment that both laypersons' (e.g., students, the public) and scientists apply to explanations is *plausibility*. Authors et al. (2016) characterize plausibility as a tentative and provisional judgment about the truthfulness of an explanation. Individuals often make judgments about plausibility implicitly and automatically without much conscious thought. But individuals can also make judgments about plausibility after more explicit and purposeful evaluations. Recent research shows that students who engage in the MEL activities experience meaningful shifts in their plausibility toward more scientific explanations, which in turn promotes greater understanding of Earth and space science content (Authors et al., 2016; 2018).

Recent theoretical work provides promise for transferring MEL evaluation beyond the context of the activity. Specifically, Nussbaum & Asterhan (2016) suggest that students may become *conceptual agents* (i.e., active and critical evaluators of explanations about phenomena) when they engage in both constructing and using MEL activities. Such construction and use may promote substantial cognitive and agentic engagement (Sinatra et al., 2015), which in turn, could help students internalize the MEL scaffold into a mental representation for application and transfer to real-world situations.

Operationalizing Engagement

Because this was an observational study, we were looking for indications that students were involved in their own learning and academic tasks, thus demonstrating varying dimensions of engagement (behavioral, cognitive, and agentic) (Finn & Rock, 1997; Sinatra et al., 2015). Indicators of behavioral engagement include for example demonstrated effort (e.g., neatness, timeliness), attention (e.g., eye contact, leaning forward during discussions), and self-directed academic behavior (e.g., note taking, asking relevant questions, and exhibiting resiliency despite academic challenges).

Beyond participatory engagement indicators, students may demonstrate a higher dimension of engagement, chiefly, cognitive, wherein they are able to demonstrate complex thinking and understanding in their discourse and interactions. Cognitive engagement may also be identified by evidence of self-regulated learning (which also relates to behavioral components of self-directed learning) (Schunk, Meece, & Pintrich, 2013). Self- regulatory processes include planning, monitoring, and evaluating one's own thinking and learning strategies (Skinner & Belmont, 1993; Zimmerman, 1990) and can be considered a metacognitive form of effort (Cleary & Zimmerman, 2012), and coded along these sub-categories. In the context of the MEL activities, discourse pertaining to argumentation, reasoning, and other critical evaluation practices were demonstrative of cognitive engagement. Furthermore, if it was determined that if the student invested psychological and cognitive efforts to understand, and went beyond the requirements of the activity, used flexible problem solving, and chose challenging tasks, it was assumed that the student was also cognitively engaged (Fredricks et al., 2004).

When students are actively contributing to instructional flow or process, and proactively demonstrating their agency by enriching, personalizing, modifying, or requesting instruction they are enacting agentic engagement (Bandura, 2001; Reeve, 2012; Reeve & Tseng, 2011; Sinatra, Heddy &

Author, 2015). For instance, when a student communicates suggested shifts to class content related to personal interests they are demonstrating agency. An instructor may alter the flow of instruction by providing additional content focus, or activities related to the student's suggestions and requests.

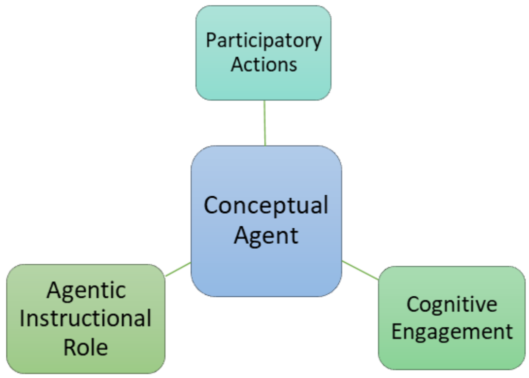

Figure 1. A framework for developing a conceptual agent

Herrenkohl and Guerra (1998) fundamentally connected changes in engagement as changes in discourse within the context of classroom science. Their findings showed that individual students become actively engaged in discussion and argumentation through the process of generating, manipulating, constructing, and monitoring ideas. Engle and Conant (2002) developed the idea of disciplinary engagement by examining discipline-specific discourse and asserted that productively engaging in science means that students' arguments for the methods of seeking evidence, and subsequent claims made, become more sophisticated over time.

Engle and Conant also focused on tracing the moment-by-moment development of argumentation and conceptual understanding as evidence of productive disciplinary engagement. By emphasizing the use of argumentation within the relevant content area, these researchers claimed to be able to unfold and capture how individual students develop cognitive engagement. Of interest, whereas Herrenkohl and Guerra considered agency development to be the result of successful engagement, Engle and Conant viewed being successfully engaged as a condition that results, in part, due to increased agency (i.e., increased responsibility). Alternatively, Gresalfi (2009) conceptualized both disciplinary and interpersonal engagement as classroom practices and characterized discourse changes in the decision-making process for both interpersonal interactions and mathematical thinking and reasoning. Similar to Engle and Conant and Herrenkohl and Guerra, Gresalfi considered establishing the propensity to engage as a result of participating in class- room mathematical practices.

Research Inquiry

When students are operating on the interacting higher levels of conceptual and agentic engagement, they are in essence transforming from a participating student to potentially a conceptual agent, fully immersed in knowledge construction, and in the critical evaluation and explanation of complex scientific phenomena. In the context of the MEL instructional scaffold, it was our intent to examine:

a) To what extent does repeated use of both pre-constructed MELs and baMELs result in student individual engagement of scientific practices (i.e., asking critical questions, using model-based reasoning, planning and analyzing scientifically valid investigations, constructing plausible explanations, engaging in collaborative argumentation, and critically evaluating scientific information)?
b) Whether a student demonstrated varying levels of dynamic engagement over the course of the classroom implementation of one MEL and two baMEL activities?
c) In what ways does the element of instructional choice included in the baMEL result in demonstrably different discourse elevating the student's role to that of a conceptual agent.

Methods

The present qualitative study is grounded in a larger mixed methods research project involving the implementation of the MEL suite of activities in middle and high school Earth and space science classrooms.

From a pool of 36 teachers who volunteered to participate in a summer workshop to learn about the MEL activity suites for science education, five teachers were chosen across a diverse range of factors for the classroom-based research. We aimed to select a heterogeneous sample of teachers across a range of teaching experiences and expertise, student grade levels, and proximity to researcher for some convenience sampling as well due to capacity for data collection.

In their classes, students were exposed to controversial concepts that build upon scientific understanding they may have developed during prior learning and experiences. For example, understanding about climate change involves fundamental knowledge about weather and climate distinctions, energy transfer mechanisms (radiation, convection, and conduction), interactions among matter and energy in ecosystems, etc. Furthermore, the *Next Generation Science Standards* (NGSS) emphasizes these Earth system processes (NGSS Lead States, 2013).

In the present research, we conducted a qualitative case study of a single student randomly selected across the five observed classrooms to analyze their engagement trajectory across the implementation of one MEL and two baMELs. This case study was an inductive exploratory opportunity to examine how the discourse and participation of that single student shifted over time (Stake, 2005).

Materials

Model-evidence link diagrams and activities suite. In the MEL activity suite, students are presented with 2 models, and 4 evidences with corresponding expanded texts. One of the models is a scientifically accurate explanation and the other is a compelling alternative. For example, in the climate change MEL, scientifically accurate explanation of climate change (i.e., human-induced) is Model A. The compelling alternative (increasing solar irradiance) is Model B. After reading through evidence texts, students use the MEL diagram to draw different types of arrows linking evidentiary data to the two models representing alternative explanations of a particular phenomenon.

Students draw arrows in different shapes to indicate the relative weight of the evidence (strongly supports; supports; has nothing to do with; or contradicts).For the baMEL, students construct a

MEL by first ranking the plausibility of three explanatory models of a particular phenomenon. Out of those three, students in their groups or individual must narrow down to two of the models to use on their diagram. Students then individually select four lines of evidence from a group of eight. As with the pre-constructed MELs, each line of evidence will have a one- page evidence text that contains more information. With the two models and the four lines of evidence (including supporting evidence texts), students will construct their own MEL diagram, as well as explain how and why they chose the lines of evidence for their construction. Then students analyze their MEL (i.e., complete the diagram with arrows), as well as at least one other MEL diagram constructed by their classmates. Within the context of the MEL activity, students use critical evaluation in creating their written responses on the MEL explanation task (Figure 3), wherein they justify and explain their most compelling arrows (connections) on the diagram. Students also re-rate their plausibility judgements of each of the models.

Data Collection

We conducted four observations in each classroom. We did a pre-observation of any science lesson of the teacher's choice. Then we made sure the teacher got to implement their first MEL without the researcher present. Next we observed the second MEL implementation, and two baMEL implementations. During data collection we collected field notes into a pre-constructed observation protocol, as well as video and audio recorded each lesson.

Classroom observation and analysis protocol. The observation protocol was a pre-constructed guide to account for classroom characteristics (including diagrams and seating charts), dynamics, and overall sequence of instructional events. The protocol captured the start and end times of all observed lessons, and included time stamps of instructional events and sequences for later video observation analysis, as well as a column for other field notes and observer comments. All researchers attending an observation completed this protocol for that lesson.

Video data. Every classroom visit, the researcher set up one corner main camera (a standard camcorder with tripod) that captured the sequence of the whole lesson, and the visual field of the entire classroom from the back facing the teacher. This main camera largely corroborated the observation protocol, and served as a resource for adding missed events or sequences from the protocol. A second camera (go-pro) was harnessed to the teacher's chest, to provide interactive, dynamic data of the teacher's ongoing interaction with student groups over the course of the lesson.

Audio data. Each student group was given an audio recorder which captured their discourse from generally the start of their reading of the evidence texts to the end of completing their explanation tasks. Of note, because students had access to their group's recorders, there may be the small possibility of students accidentally or intentionally sometimes pausing their recorders, which may have resulted in some missed data, however, this was a fairly rare occurrence, as the researcher would periodically check to ensure the device was recording.

Analysis

All the observations were transcribed, and we selected one of the five teachers to focus on based on our confidence that this teacher had administered all aspects of the activity to accuracy and completion. From the teacher's class, we randomly chose a student group, and a student within that group to follow that individual's discourse trajectory.

To analyze the transcripts we used discourse and conversation analysis to code in depth for indications of participatory behavior, as well as evidence of cognitive and agentic engagement. We developed an *a priori* coding framework based on our research questions examining engagement in its various forms and levels. In our coding framework, these behaviors were coded, and categorized based on whether the student was engaged in basic participation, demonstrating more cognitive engagement, or finally, demonstrating agentic roles in their learning, suggesting the highest level of engagement. The coding process involved identifying key moments in the discourse, that were exemplary of codes, and sorting them under emerging categories (Boyatzis, 1998).

[Insert Coding Schema Table]

For each research question we constructed a separate analytic matrix where we sorted our codes to analyze shifts in forms of engagement. In large part to answer our final research question we examined how engagement shifted towards conceptual agency across all three observations, and described the evidence of those shifts.

[Insert Matrix]

Findings

Our overall results show that Ray was participating throughout all four observations. There was the least amount of demonstrated behavioral engagement in the regular science lesson, with more discourse inputs for cognitive and agentic engagement in both the MEL and baMELs.

[Insert Graph of Discourse Inputs of Engagement Across Each Observation]

Evidence of Student Engagement in Scientific Practices

[Insert table of observation codes indicating various types engagement behaviors]

Shifts in Dynamic Engagement Levels Across MEL and baMEL Activities

Did the student demonstrate more complex and dynamic forms of engagement as they completed more MEL suite activities based on their discourse and interaction levels.

[Provide multiple vignettes and student discourse excerpts to demonstrate these shifts]

The Student as a Conceptual Agent

A thematic summary across engagement categories to draw out narratives of the student as a conceptual agent.