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Discourse and Agency during Scaffolded Middle School Science Instruction

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ABSTRACT

Instructional scaffolds may promote science learning, particularly for topics that are controversial. Scaffolding may also need to be autonomy supportive, particularly for adolescents, and designed to facilitate scientific discourse and agency. The purpose of the present study was to investigate differences in middle school students' discourse and agency across two scaffold forms: one more autonomy-supportive and one less autonomy-supportive. We designed both to facilitate scientific evaluations about the connections between lines of evidence and alternative explanations about two geological phenomena: relations between hydraulic fracturing and earthquakes (less autonomy-supportive) and reliability of fossil evidence for inferring past surface changes (more autonomy-supportive). Integration of qualitative and quantitative findings revealed meaningful differences, with greater collective disciplinary agency expressed during the more autonomy-supportive form. Results support a burgeoning area of research suggesting that productive discourse and agency are necessary to prepare students to participate in a civically minded and inclusive society.

Introduction

Many socioscientific topics, such as the current climate crisis and availability of freshwater resources, are complex and present considerable learning challenges. Further, these topics are often spread across multiple science domains (e.g., biology, chemistry, geoscience, and physics) and are often controversial (see, for example, Dawson & Carson, 2020; Khishfe et al., 2017; Owens et al., 2018; Philip et al., 2018). Controversial socioscientific topics are characterized as issues where conflicting perspectives arise from distinct sources, "each with a distinct set of assumptions, points of view, target audiences, and goals" (Lombardi et al., 2020, p. 330). With such issues, students may encounter alternative but nonscientific claims that conflict with consensus claims held by a particular community of scientists. Such competing, nonscientific claims may challenge students during their science learning (Lombardi et al., 2016).

Instructional scaffolds that promote students' scientific evaluations may be one way to overcome barriers and facilitate students' learning about socioscientific issues. Lombardi et al., (2013a, 2018a, 2018b) developed several Model-Evidence Link (MEL) activities around such socioscientific topics as climate change, hydraulic fracturing (fracking), and water resources. The MEL activities are an instructional scaffold using a diagrammatic framework to facilitate middle and high school students' evaluation of the connections between four lines of scientific evidence and two alternative explanatory

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models (one scientific and one nonscientific). However, students may have considerable difficulty transferring concepts learned through scaffolded instruction outside of the specific context and situation of their science classrooms (Pea, 2004).

Effective knowledge construction and transfer through the process of scientific evaluation may then also require students to engage in discourse processes that promote individual and collective agency and help promote deeper learning. Agency may emerge through externalized and internalized dialogs that occur when instructional scaffolds facilitate self-regulatory processes of students' planning and monitoring of their individual and group learning (Barzilai & Ka'adan, 2017; Greene et al., 2018; Ryu & Lombardi, 2015). These individual and group dialectic and self-regulatory processes are known as conceptual agency (Heyd-Metzuyanim & Schwarz, 2017), disciplinary engagement (Engle & Conant, 2002; Sandoval et al., 2019), and epistemic agency (Miller et al., 2018; Stroupe, 2014). If implemented in the classroom, these processes may model the construction of scientific knowledge, in what Pickering (2010) calls a "dance of agency" (p. 21), where individuals and groups are engaged in an intentional practice involving epistemic construction and manipulation of scientific resources (e.g., data in tables and graphs). This agentic engagement means that students author their own contributions, are accountable to the learning community, and have the authority to solve problems (Nussbaum & Asterhan, 2016). Furthermore, students who are agents of their own and their peers' learning may actively monitor and reappraise judgments about credibility of evidence and plausibility of competing knowledge claims around a phenomenon (Heyd-Metzuyanim & Schwarz, 2017; Nussbaum & Asterhan, 2016).

We enhanced the MEL scaffold with the hope of increasing students' agentic engagement during the learning process. These modified activities, called the build-a-MEL (baMEL), task students to construct their diagrams prior to analyzing and evaluating how well lines of evidence support alternative explanatory models. The purpose of the present study was to compare students' agency between the older version of the activity (i.e., the preconstructed MEL [pcMEL]) and the newer baMEL. The present study is part of a larger 6-year design-based research project examining instructional scaffolds and methods that deepen students' scientific evaluations and discourse about claims related to socioscientific phenomena in earth, environmental, and space science contexts. Although previous studies have revealed that pcMELs were effective in facilitating students' knowledge construction within the classroom context (Lombardi, Bailey et al., 2018a; Lombardi, Bickel et al., 2018), the project's overall purpose is to design and test the baMEL as a more autonomy-supporting form and test whether the baMEL may increase students' agency and strengthen their knowledge construction above and beyond the pcMEL. The present study uses data collected in the second year of the project and specifically focuses on discourse and agency comparisons between the two kinds of scaffolds. A previous study using quantitative data, which were collected at a different time but in the same classroom involved in the present study, suggested that the baMEL was more effective than the pcMEL, specifically in facilitating students' scientific evaluations, shifting their plausibility judgments toward a more scientific stance, and deepening their knowledge about water resources (Klavon et al., 2022). To investigate a potential reason for the baMEL's effectiveness, the present study probed a bit deeper by comparing students' engagement in scientific practices during discourse and their agency when learning about geological phenomena. Prior to discussing the methods, results, and potential implications of this present study, we first turn to the theoretical framework that supported our research design.

Theoretical framework

In developing the present study's theoretical framework, we examined extant theoretical and empirical work related to students' discourse and agency in science learning. Specifically, we examined and melded literature from science education research, the learning sciences, discourse analysis, social network theory, and educational and developmental psychology to support this study's constructs (agency and scientific discourse) and design.

Agency and learning

A report by the National Academies of Sciences, Engineering and Medicine (2020) says that "student sense-making of phenomena or problem-solving help build student agency by engaging them in thinking through and planning instructional sequences" (p. 47). In developing his notion of individual agency, Bandura (2001) said that "To be an agent is to intentionally make things happen by one's actions ... The core features of agency [intentionality, forethought, self-reactiveness, and self-reflectiveness] enable one to play a part in their self-development, adaptation, and self-renewal with changing times" (p. 2). Individual agency may extend toward collective agency when students become learning agents during group work with their peers via a classroom support structure that allows for greater student autonomy (Patall et al., 2019; Roth, 1999). Thus, situations allowing for deeper engagement through autonomy supportive scaffolding may help induce students' individual and collective agency. Furthermore, increased classroom engagement is often associated with science learning and achievement. For example, Lee and colleagues (2016) found that greater amounts of engagement predicted science achievement in adolescents, particularly if students enjoyed mastering the content and believed they could be successful in completing the learning task. Similarly, secondary data analysis by Grabau and Ma (2017) revealed that several indicators of engagement were robustly (medium to large effect sizes) related to adolescent science achievement.

Agency is manifested via engagement in classroom learning. Because of the recent series of global crises (e.g., climate change, the COVID-19 pandemic), education reformers are calling for science instruction to focus on "student engagement with real-world phenomena and problems" (National Academies of Science, Engineering, and Medicine, 2020, p. 9). However, despite being termed the "holy grail of learning," many consider engagement to be a relatively vague construct and realizing meaningful engagement in the science learning context remains elusive (Sinatra et al., 2015, p. 1). Some have viewed engagement in science learning as a multicomponent construct (Sinatra et al., 2015) involving cognitive (Chi et al., 2018), social-behavioral (Rogat & Linnenbrink-Garcia, 2019), and emotional (Geiger et al., 2017) factors. Another component of engagement is directly related to agency: agentic engagement, which "is the proactive, purposive, and educationally constructive action students initiate to catalyze their ... learning" (Reeve et al., 2020). In science classrooms, agentic engagement may emerge through a dynamic interplay of cognitive, social-behavioral, and emotional factors (Patall et al., 2019).

Students' participation in scientific practices may be an effective way to deepen their agentic engagement because these disciplinary practices include cognitive, social-behavioral, and emotional components. For example, the scientific practice of argumentation could involve building students' conceptual knowledge about the nature of science and disciplinary core ideas through cognitive engagement facilitated by critique, reasoning, and conceptual integration (Nesbit et al., 2019; Nussbaum, 2021). Similarly, social-behavioral engagement in scientific argumentation could facilitate students' understanding that "science is fundamentally a social enterprise, and scientific knowledge advances through collaboration and in the context of a social system with well-developed norms" (National Research Council, 2012, p. 27; Roth, 1999). Discourse in collaborative group work may also transfer topic interest between students, thereby potentially deepening emotional engagement (Bergin, 2016; Bohn-Gettler & McCrudden, 2021; Renninger & Bachrach, 2015). Through the dynamic integration of cognitive, social-behavioral, and emotional factors, students may increase their agentic engagement in the science classroom by becoming accountable to the learning community as more autonomous actors of scientific inquiry and problem solving (Nussbaum & Asterhan, 2016).

Agency and scientific discourse

Science classrooms often involve a community of learners (e.g., teachers and students) trying to make sense of phenomena (e.g., addressing if wetlands are a nuisance or benefit to humans). For such a community to promote learning, it should be focused on facilitating scientific knowledge construction and critique in a way that promotes agency through scientific discourse (Lombardi & Bailey, 2020; Ryu & Lombardi, 2015). Such discourse extends the notion of the student as an agent of learning (i.e., *learning agency*) by situating their agency within the context of the scientific discipline (i.e., *disciplinary agency*). In science classrooms, disciplinary and learning agency should go together, but only when instruction effectively allows students to engage in scientific discourse where they propose and evaluate ideas that contribute to the community's collective science knowledge construction (Miller et al., 2017; Roth, 1999). Thus, disciplinary and learning agency may be deepened when students participate in scientific practices that promote discourse where students consider and select appropriate connections between scientific evidence and alternative explanations about phenomena and evaluate these connections consistent with scientific criteria (Bohn-Gettler & McCrudden, 2021; Christodoulou & Osborne, 2014; Trabasso & Magliano, 1996; Trabasso & Wiley, 2005). For example, students may examine and select lines of scientific evidence that support or refute alternative explanations of socioscientific topics, such as biological evolution, vaccination efficacy, and hydraulic fracturing (Hopkins et al., 2016; McCrudden et al., 2021a; Wertgen et al., 2021; Wolfe et al., 2013).

Relatively recent education reform suggests that scientific practices should be incorporated into students' science learning experiences to facilitate both their disciplinary and learning agency. For example, in the United States, *A Framework for K12 Science Education* introduced eight scientific and engineering practices characterizing classroom knowledge building skills where students investigate and develop explanations and solutions about phenomena and problems through evaluative processes involving argument, critique, and analysis (National Research Council, 2012). This framework further suggests that engagement in these practices may develop students' scientific habit of mind and enable them to become disciplinary agents via inquiry and reasoning while deepening their learning agency to actively construct knowledge about both the nature of science and science concepts. For example, when students engage in the scientific practice of evaluating how well lines of scientific evidence support alternative explanations about the availability of freshwater resources, they may deepen their understanding about how technology has made water safer for human use (a fundamental concept about how "Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation [HS-ESS3-4]"; NGSS Lead States, 2013, p. 288).

Scientific practices may help students to become disciplinary and learning agents because they act as authentic epistemic operations performed by scientists but are situated in the science learning context. When students collectively engage in epistemic operations (categorizing and classifying, describing and defining, and critiquing, evaluating, and judging) when using data and models in classroom settings, they may recall, retain, and generate knowledge in a similar fashion to the scientific community (Christodoulou & Osborne, 2014).

Visualizing agency through social networks

Social network analysis (SNA) is ideal for measuring agency by tracking the changes in participation over time. It characterizes interactional features of a lesson and observes the relationships among social entities by monitoring the patterns within these networks (Burt, 1978). SNA focuses on analyzing either the structure of relationships or the positions of individuals in the network, producing diagrams consisting of nodes and ties (Wasserman & Faust, 1994). Each member of the social network is represented as a node, and the line connecting two nodes represents the interaction between two members.

SNA assumes that the individuals who compose the network are influenced by the structure of the network (and other network members). The positions of individuals within a structure are based on tracking and analyzing the number, shapes, and lengths of ties (connections between individuals) and paths, that is, how people are connecting and how information/knowledge/resources are distributed within the network. In this way, researchers can visualize and analyze forms of agency within learning environments, particularly when paired with discourse analysis. For example, if one node has many links to other nodes, SNA assumes that the node has a central role in the network for that activity. Conversely, a node is less engaged, and possibly disconnected from learning, if it has no links to other nodes. When paired with discourse analysis, it is possible to visualize how engaged students are based on their interactive turns, as well as to track how agency becomes distributed over time across learners.

Present study

In the present study, we examined students' discourse for evidence of their disciplinary and learning agency when using MEL diagrams about geology topics. We specifically investigated middle school student group discussions when they were completing the fracking pcMEL and the fossils baMEL scaffolds. In the fracking pcMEL, students are presented with four lines of scientific evidence and two alternative explanatory models about the increased frequency in earthquake activity in the Midwestern United States (Figure 1) Hopkins et al., (2016). In the fossils baMEL, students select four lines of scientific evidence from eight possible choices and two alternative explanatory models from three choices about the reliability of fossil evidence for inferring past paleoclimatic and surface changes (Figure 2) (Governor et al., 2020). We specifically asked, *Would a scaffold that is more autonomy supportive (i.e., the fossils baMEL) facilitate greater disciplinary and learning agency in middle school student groups compared to a less autonomy-supportive scaffold (i.e., the fracking pcMEL)?* We hypothesized, based on our synthesis of the literature highlighted above, that a more autonomy-supportive scaffold, the baMEL, would support students' engagement in scientific discourse that reflected greater disciplinary and learning agency than a less autonomy-supportive scaffold, the pcMEL (Christodoulou & Osborne, 2014; Patall et al., 2019; Ryu & Lombardi, 2015).

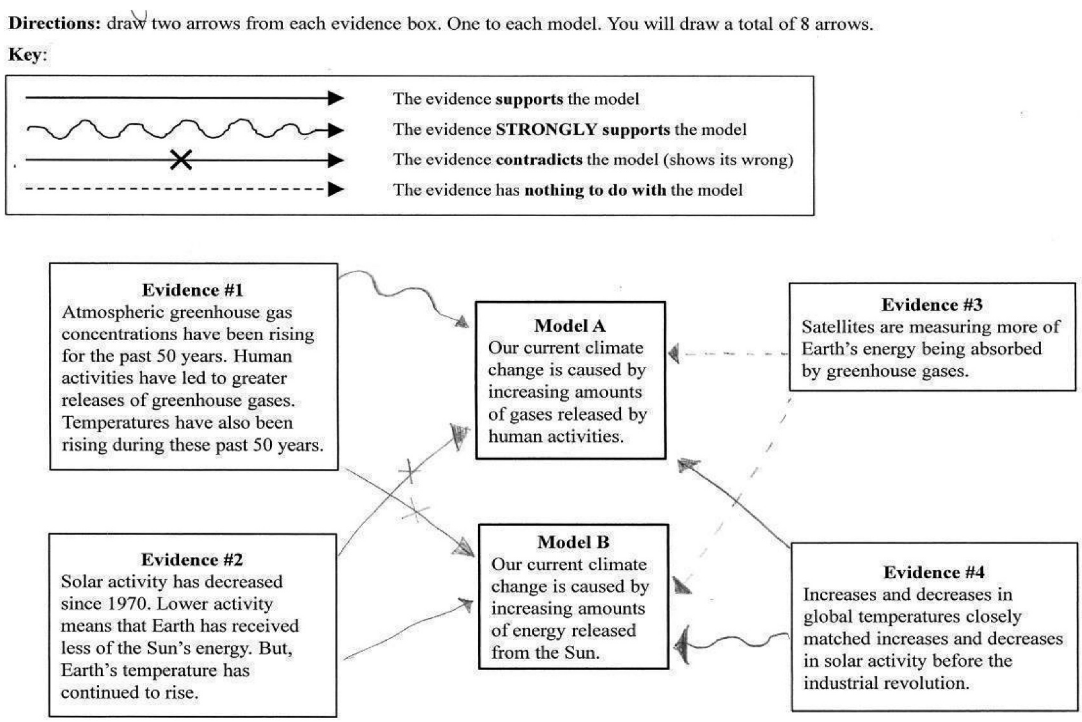

Figure 1. Student example of a fracking preconstructed model-evidence link (pcMEL) diagram.

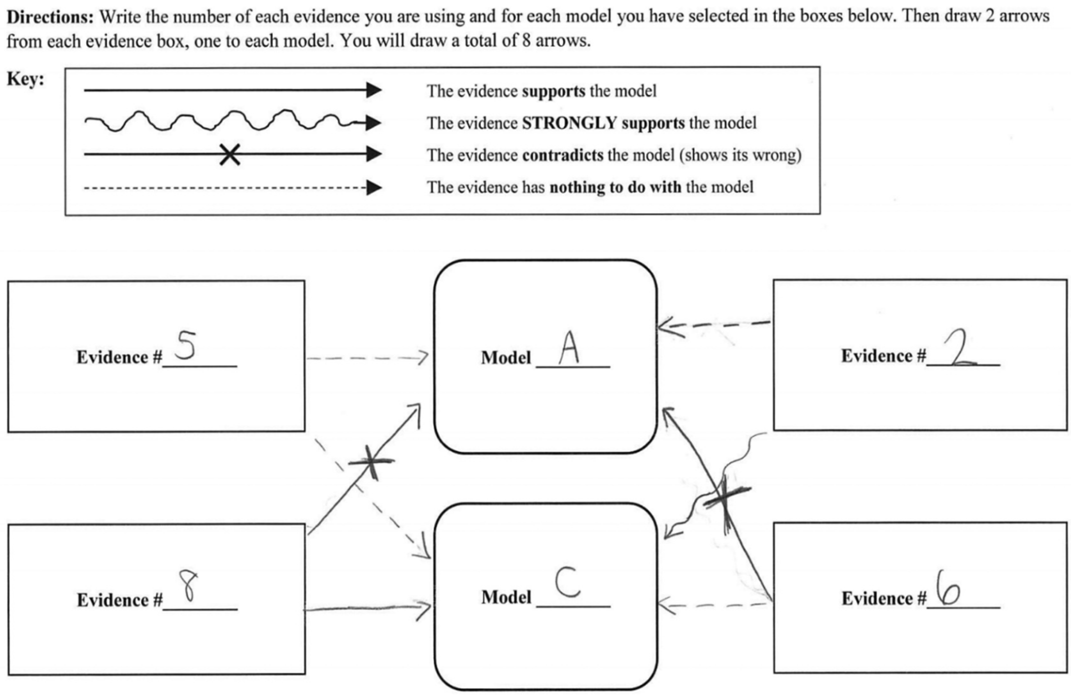

Figure 2. Student example of a fossils build-a-model-evidence link (baMEL) diagram.

Methods

Participants and context

We collected data from middle school students (n = 15) who used the two instructional scaffolds in their grade 6 earth science class. This class met in a traditional, face-to-face classroom setting prior to the COVID-19 pandemic, and we selected this classroom starting from a pool of 36 teachers who had volunteered to participate in a previous summer's workshop to learn about the MEL activities. Of these voluntary professional development participants, we selected five teachers across a diverse range of factors (e.g., location, district willingness to participate in a research study) for classroom-based research, and of these five teachers, we randomly selected one teacher's classroom when she used the pcMEL (topic of fracking and earthquakes) and the baMEL (topic of fossils as indicators of past climates) in her science instruction.

The classroom teacher self-identified as being White and female, with 6 to 10 years of teaching experience. The grade 6 participants (i.e., those students who gave consent to be a part of the study, with their parents giving consent) predominantly identified as Hispanic (of any origin) (n = 6; 40%), with the remainder identifying themselves as White (n = 4; 27%), Asian (n = 3, 20%), and Black (n = 2, 13%). Slightly more of the participants identified as male (n = 8, 53%), and six students (40%) identified as eligible for reduced-price or free lunch (a demographic indicator that is often, but controversially, used as an indicator of lower socio-economic status; Harwell & LeBeau, 2010). The classroom was in the Middle Atlantic United States in a suburban community flanked on one side with a high-density population area of appreciable poverty and on the other side with a low-density population area of appreciable wealth (U.S. Census, 2021).

Data sources and collection

We used audio recordings of five student groups, three students in each group, during two 50-minute lessons. The first lesson featured the fracking pcMEL and the second featured the fossils baMEL, with each lesson taught about 5 weeks apart and including a winter holiday break in that time span. The teacher incorporated these lessons within instructional units aligned to the school's existing earth science curriculum. We constructed line-by-line transcripts of each lessons' group discussion phase, which occurred simultaneously during the last 30 minutes of each lesson, and these transcripts were a primary data source for analyses. Our transcripted lines reflected "discourse units," which were whole or partial sentences dialogically uttered from each participating student. We used these utterances as the units of analysis and classified these discourse units as macro-level codes bounded within the specific conceptual focus of the activity structure (the pcMEL and baMEL lesson, which we characterized as both a communicative situation [Hennessy et al., 2020] and interactional episode [Brown & Spang, 2008]). We also obtained student work samples and video recordings of the lesson, but these were not data sources in the present study.

Prior to breaking into group discussions, the teacher presented students with competing scientific explanatory models and several lines of scientific evidence. The fracking pcMEL specifically presents four lines of scientific evidence and two models (scientific alternative and other alternative) investigating the phenomenon of increased earthquake activity in the Midwestern United States (Figure 1) (Hopkins et al., 2016). When completing the pcMEL, participants read and referred to four, one-page handouts (containing some text, graphs, and diagrams to further explain each line of scientific evidence) and completed the diagram on a separate sheet of paper in small groups. In the pcMEL diagram sheet (Figure 1), the explanatory models are in the center of the page in two separate boxes with no labeling indicating which one is scientific and alternative explanation. The teacher provided instructions on how to complete the diagram: drawing one of four different types of arrows from each line of evidence to both models based on how well the participants thought the evidence supported an explanatory model, with a squiggly arrow indicating that the participant believed a line of evidence strongly supported an explanatory model, a straight arrow indicating that a line of evidence supported a model, a dotted line arrow indicating that a line of evidence had nothing to do with the model, and an arrow with an "X" in the middle indicating that a line of evidence contradicted the model. Overall, the participants drew eight arrows on their diagrams.

For the fossils baMEL (Figure 2), participants constructed their own MEL diagrams. First participants read eight, one-page handouts for each of the lines of scientific evidence related to the phenomenological possibility that buried fossils are linked to past paleoclimatic and surface changes. Students were also introduced to three alternative models (one based on the scientific consensus and two that were alternative but nonscientific explanations). Participants worked together to select four lines of evidence from the eight available and two alternative models from the three available. This baMEL construction took one class period, with participants constructing their baMELs on a separate sheet of paper. In the next day's class period (the class meeting including in the present study), participants completed the diagrams they had constructed in the same way that they had for the pcMEL described above.

For both scaffold types, groups collectively discuss and write justifications for two of the evidence-to-model arrows that they drew on their diagrams on sheet that we refer to as the "explanation task." This second phase of the activity constituted the majority of ~30 minutes of group work that we recorded for the present study. Focusing the analysis on the explanation task phase allowed us to compare similar discourse episodes between the two scaffold types. Overall, each MEL activity took ~90 minutes (just under two class periods) to complete the diagram construction and explanation task phases. Although there are more steps involved in the baMEL, participants progressed more quickly with the diagram phase because of their prior experience with the pcMEL.

Study design

Our goal was to investigate and compare the nature of classroom discourse when students used the pcMEL and baMEL in small groups. We began by using discourse analysis to qualitatively code small group discussions. Next, we did frequency counts of the qualitative codes. Thus, we used data transformation to quantify the qualitative data (Teddlie & Tashakkori, 2009). Then, we used SNA to analyze the transformed data quantitatively. This allowed us to visually depict the small group discussions and investigate whether there were quantitative differences in the use of qualitative codes when students used the pcMEL and baMEL. Lastly, we integrated the discourse analysis and SNA to better understand the interactional sequences that demonstrate aspects of agency in learners.

Qualitative data analysis

We used a qualitative content analysis to analyze participants' discourse. We specifically applied the themes of disciplinary and learning agency to code group transcriptions using a directed content analysis, which marshaled existing theories and prior research to identify "key concepts or variables as initial coding categories" (Hsieh & Shannon, 2005, p. 1281): disciplinary and learning agency.

Disciplinary agency coding

To ensure the accuracy and reliability of coding, we conducted four "rounds" of analysis and revision involving all coauthors serving various roles during some or all the rounds. In the first round, we coded disciplinary agency using the 13 epistemic operations identified by Christodoulou and Osborne (2014, Table 2, p. 1286) and assigned coding pairs to each group discussion randomly. Coders worked individually at first, reading each line of the transcripts and assigning these 13 codes to lines as they saw fit. Each pair then met to discuss and come to a consensus on the appropriate labeling of applicable situations and made notes about the utility of the coding scheme and process. Upon reporting a consensus, one coauthor, who we called the revisioner, reviewed all final consensus codes and made notes of trends and inconsistencies that may have impacted coding. The research team then met to provide feedback and reflection on the revisioner's notes about the codes and coding process, which prompted a discussion of recommendations for potential modifications and revisions to the categories that we were using to code disciplinary agency. This discussion specifically revealed overlaps between some epistemic operations. Prior to the second round of coding, we consulted the literature to more systematically identify closely related operations and combined a few categories of some operations.

We then conducted a second round of coding using our revised coding scheme with the same coder pairs and the same process. After pairs finalized and reached consensus once more, the entire research team met to discuss the coding. Again, consulting the literature, we decided to synthesize a couple of categories and began a third round of coding. In this round, we randomly assigned authors to serve as checkers of other pairs' codes (i.e., other assignments they had not previously analyzed). This time each transcript line was coded by one coauthor and asked if they agreed with the consensus made by prior coders, verifying whether it made sense to them and/or seemed consistent with what has been done before. This stage was critical in establishing and ensuring that all team members were defining and coding terms in a consistent manner. In the final round, the revisioner, along with the lead author, combed through the transcripts as one final quality check for consistency and accuracy. After conducting a preliminary categorical analysis of code frequency and consulting the literature one final time, we combined a couple of similar codes to get our final coded categories. Table 1 lists, describes, and provides examples of the final disciplinary agency codes that we used in the present study.

Table 1. Disciplinary agency discourse codes.

Code	Description	Participant Discourse Example
Describing, identifying, defining, explaining, and/or recalling evidence	Lombardi et al. (2016) said that explanations are "accounts of how phenomena unfold that may lead to a feeling of understanding" (p. 36). Explanations generally have greater complexity because they may involve some combination of descriptions (e.g., listing characteristics), identifications (indicating component characteristics from a set), and/or definitions (e.g., bounding the scope and meaning). Explanations may also involve narratives that may describe cause and effect relations over time to derive broader meaning (Dahlstrom, 2014; Trabasso & Magliano, 1996; Trabasso & Wiley, 2005). In science, evidence may be recalled supporting a particular claim.	"These trees lived hundreds of millions of years ago. This is saying that millions of years ago Norway was once a tropical place filled with whatever that thing is called. Whatever that is called."
Categorizing, comparing, and/or classifying	Categorizing is a common scientific process, occurring with group formation via distinct characteristics (Chi, 2005). Then things, events, objects, and/or other phenomena are distributed into groups, where they may be compared or classified based on orders, families, etc. based on shared and common characteristic and plausibly connected attributes (e.g., taxonomies, hierarchies; Kind & Osborne, 2017). Such categorizations, comparisons, and classifications may be made more concrete via metaphors and analogies.	"So like 5 earthquakes in the same place"
Questioning	Within the scientific discipline, questioning involves asking, What exists? Why it happens? and How do we know? (Kind & Osborne, 2017). Scientific questions can arise out of curiosity, by theory-based and model-based predictions, and/or the consequences of problem solutions (National Research Council, 2012).	"So um . . . so trilobites? they lived in the salt water right? Creatures that live more than 250 million years ago lived in salt water. But they're found in Ohio which is more than 500 miles from where they most commonly lived right?"
Reasoning, predicting, and/or justifying	In science, reasoning involves many processes, including validating some cause-and-effect relation (Perkins & Groetzer, 2005). Similarly, scientific predictions are statements about what might happen and emerge from theoretical cause and effect explanations (National Research Council, 2012). Predicting can involve logical, statistical, and/or mathematical thinking about how a certain cause may result in a certain effect (Kind & Osborne, 2017). Epistemic knowledge (knowledge about what constitutes validated scientific knowledge and the process for constructing validated scientific knowledge) is used to justify scientific claims. To do this requires critical-analytical thinking via logical reasoning (e.g., deductive, inductive, and abstract reasoning) and that is evidence-based. Justifying involves expressions of rightness, which in science often applies to both evidence and explanations and may involve warrants (e.g., reasoning) that connect evidence to explanations (Kind & Osborne, 2017).	"Yea! But this hints that the water level was lower, how is that misleading? This is evidence that the water level might have been lower 19,000 year ago. But how does . . . how is that misleading?

(*Continued*)

Table 1. (Continued).

Code	Description	Participant Discourse Example
Contradicting, critiquing, evaluating, and/or judging	Contradicting occurs when taking an opposite statement on a position. Bachelard (1968) states, "Two people must first contradict each other if they really wish to understand each other" (p. 114). Lombardi et al. (2016) stated that contradictory evidence (i.e., evidence that contradicts a particular claim) is important for changing epistemic judgments about a particular explanation, especially in light of the alternative explanation. Epistemic judgments result from evaluations (e.g., plausibility judgments result from how well a line of evidence supports a particular explanation; Lombardi et al., 2016). From online dictionary definitions, judgments reflect opinions, decisions, and conclusions about something or someone, especially after thinking carefully. For judging, we need to see evidence of making the judgment (credibility, reliability, plausibility). Evaluation involves the general process of consideration and may involve questioning about the scientific process (e.g., have we thought about this? did we do this?).	"This is misleading because the coral reefs are found down below but sunlight can't reach that far. Even though they are there."

Table 2. Learning agency discourse codes.

Code	Description	Participant Discourse Example
Demonstrating competence in the learning task	Competence demonstrates effectiveness in group actions we undertake and leads to engagement via building of ownership of the learning material and confidence to complete a learning task (Collie & Martin, 2020). Such self- and group-efficacy beliefs serve as the foundation for agency (Bandura, 2001).	"It contradicted that idea—the graph clearly shows when there's an increase in fracking, the number of earthquakes also largely increased, right? From the normal? From the average 1.6 per year to 20 then 35, 64, back down to 35 but up to 109 and in recent years it's been up to 584. So you gotta find information that it was caused by [fracking], right?"
Showing relatedness of the topic/content to culture and experience	Learning agents help to form meaningful relationships with between the group members by including personal and shared experiences and/or cultural expressions of shared values and norms (Kumar et al., 2018; Ryan & Deci, 2017). Agentic engagement is fostered through relatedness to both topic and culture (Patall et al., 2019).	"Yeah, you remember we watched the video, the Alaska one?"
Setting group goals to accomplish the learning task	Goals are an important motivational factor for learning and incorporating students' goals into the instructional task may increase their achievement (Reeve et al., 2020). Setting goals represents intentionality, a core feature of agency (Bandura, 2001).	"Ok so we'll have to start, so we should each start with um . . . . reading the models"
Monitoring group's understanding and achievement of learning goals	Beyond goal setting, agents of learning express self- and peer-reactiveness to shape courses of action and regulate execution of the learning task (Bandura, 2001). Autonomy-supportive instruction can support self- and collaborative monitoring (Vansteenkiste et al., 2018)	"No we want . . . right now she said. Right now we have to like pick what we want to use. So let's maybe use one that uh . . . . against uh . . . like using fossils and then one that is for it."
Validating group's understanding of the topic/content and achievement of learning goals	Validating peer's achievement of goals increases ability to lead and persist learning activities (Barnett, 2011). Agents validate understanding by facilitating self- and group-reflection of the learning process and judging thinking against outcomes and effects of group actions (Code, 2020).	"So we have something that strongly supports Model C right? Now we want something that contradicts it."
Taking leadership/lead role in the learning task	Leadership involves seeking group members' feedback and perspectives, providing opportunities for group members' participation, and explaining the reasoning behind task completion (Collie & Martin, 2020). "Conceiving of leadership as a practice allows anyone to participate in leadership as he or she engages in agentic activity" (Raelin, 2016, p. 141)	"If you can find any of that information then you can share it. Otherwise it probably has nothing to do with it, it's just stating information on how earthquakes are normally caused."
Assuming autonomy in the learning task that is different from the group or teacher	Feelings of autonomy can support creativity (Patall et al., 2010), and learning agents change directions to promote collaboration, creativity, and innovation in accomplishing the task (Yamazumi, 2014). Moving in a creative and/or innovative direction can promote a transformation toward greater understanding (Pugh, 2011)	"So does this say the opposite of when people make mistakes? Like if it gave an example . . . wait that gives me an idea. Is there an example where? Uhhh . . . not 7 or 8 . . . evidence 2 maybe. Wait."

Learning agency coding

We also conducted a four-round process to ensure the accuracy and reliability of our learning agency coding, with all authors participating in the coding. This process was conducted simultaneously to the disciplinary agency coding and followed the same basic steps, with specific differences highlighted here. Prior to conducting the first round, we consulted the literature on autonomy supportive classroom environments for increasing students' learning agency. For example, we used Reeve and Shin's (2020) teaching suggestions for students' agentic engagement and specifically developed our initial set of codes with the idea that students who are learning agents would work collaboratively to set goals for accomplishing the classroom task (i.e., in the present study, evaluating evidence to model links) and monitor their progress toward task completion and validating the group's process. In this way, learning agency bears some similarity to self-regulated and co-regulated learning, but in this case their learning agency would be manifested via students' intent and actions, as expressed via their discourse. We therefore created three codes for goal setting, monitoring, and validating. Further, learning agents should also express their competence and relatedness while engaging in their classroom tasks (Collie et al., 2018), resulting in two additional codes.

At the end of the first round of coding, we identified that some student participants were exerting leadership in ways other than through goal setting, monitoring, validating, competence, and relatedness. Such expressions of leadership were more general, such as supporting other group members and encouraging all to participate (Collie & Martin, 2020). Additionally, some student participants sometimes went in a different direction than their groupmates or their teacher. In these situations, participants expressed independent thought that was more autonomy seeking and contributed constructively to the group discourse via creativity and innovation (Patall et al., 2010; Yamazumi, 2014). Therefore, we created two additional codes about leadership/lead roles and going in an independent direction. We then conducted a second round of coding using our revised coding scheme with the same coding pairs and the same consensus-driven process and verified/revised these codes in the third round via randomized checkers. In the final round, the revisioner and the lead author made one final pass to ensure consistency and accuracy. Table 2 provides a final list, description, and examples of our learning agency codes.

Quantitative data analysis

We used SNA as a quantitative approach to infer interactional and discourse dynamics during participants' group work. In SNA, individual relationships between pairs of actors are called dyads (Valente, 2010). Dyad relationships connect to form paths that allow actors to indirectly influence one another within networks. These relationships eventually form the network structure (in our case, a three-person group), where actors hold structural positions within the network (group) and which might ultimately influence the opportunities or constraints (in this case, related to learning) that the other actors would encounter (Borgatti & Ofem, 2010; Moolenaar, 2012; Valente, 2010).

Unlike traditional SNAs, which may rely on survey methods and interviews to ask participants who they are connecting with, we overlaid network ties between actors using audio recordings of classroom discourse to code and map talk segments (Ryu & Lombardi, 2015). By diagramming each coded discourse unit, we were able to map out how discussions manifested in disciplinary and learning agency, how these agency types were distributed across participants (actors), and how individual members might have shifted in their influence across the two scaffolds. In constructing the SNAs, we were able to determine parameters (e.g., centrality, which specified ways in which group members might control the flow of information; Valente, 2010) and visualize patterns within these discourse units to examine whether and how disciplinary and learning agency might have shifted between scaffolds (Wagner & González-Howard, 2018).

The SNA allowed us to compare group member turns in the pcMEL and baMEL conditions. Thus, mixing at the level of data analysis through data transformation (quantify) allowed us to more precisely evaluate directionality and number of turns during group discussions, which addressed the mixing purpose of complementarity. To our knowledge, this is the first study that has used combined discourse and SNAs to examine how different forms of instructional scaffolds (more and less autonomy-supportive) might support both disciplinary and learning agency.

Table 3. Disciplinary and learning agency discourse unit counts and percent of total (in parentheses).

Code	pcMEL	baMEL
Disciplinary agency		
Describing, identifying, defining, explaining, and/or recalling evidence	27 (13%)	13 (11%)
Categorizing, comparing, and/or classifying	5 (2.5%)	0 (0.0%)
Questioning	35 (17%)	8 (7.0%)
Reasoning, predicting, and/or justifying	75 (36%)	63 (55%)
Contradicting, critiquing, evaluating, and/or judging	65 (31%)	31 (27%)
Total	207 (100%)	115 (100%)
Learning agency		
Demonstrating competence in the learning task	18 (10%)	3 (1.5%)
Showing relatedness of the topic/content to culture and experience	4 (2.2%)	0 (0.0%)
Setting group goals to accomplish the learning task	6 (3.4%)	19 (9.5%)
Monitoring group's understanding and achievement of learning goals	58 (32%)	48 (24%)
Validating group's understanding of the topic/content and achievement of learning goals	21 (12%)	24 (12%)
Taking leadership/ lead role in the learning task	63 (35%)	104 (52%)
Assuming autonomy in the learning task that is different from the group or teacher	9 (5.0%)	2 (1.0%)
Total	179 (100%)	200 (100%)

Results

Qualitative findings

Table 3 shows counts of coded discourse units (n = 701) for the different types of disciplinary and learning agency expressions made by participants. These 701 coded interactions accounted for 27% of all interactional turns of dialogue, including every day and hybrid talk (Brown & Spang, 2008). We coded that participants' disciplinary agency was expressed most often via reasoning, predicting, and/or justifying during both the pcMEL and baMEL activities. Almost as frequent was the disciplinary agency code that showed participants' expressions of contradicting, critiquing, evaluating, and/or judging. These counts seem to closely reflect the designed nature of the scaffolds (i.e., to promote students' evaluations between the lines of scientific evidence and alternative explanations). The least frequent expression of disciplinary agency was categorizing, comparing, and/or classifying. In fact, we did not code any discourse unit in this category for the baMEL scaffold. This also may reflect the designed nature of the scaffold, where, for the pcMEL, lines of scientific evidence are presorted and placed on the diagram, and for the baMEL, students had already selected the lines of evidence and explanatory models in the previous day's class meeting.

We coded that student participants' learning agency was expressed most often for taking leadership/lead role in the learning task for both the pcMEL and baMEL. The second most frequent learning agency code for both scaffolds showed that participants expressed monitoring their group's understanding and achievement of learning goals. These counts seem to suggest that learning agency was manifested by some participants' taking leadership via monitoring so that the group would successfully complete their evaluations using the scaffolds. The least frequent category of learning agency expression for both scaffolds was showing relatedness of the topic/content to culture and experience, which could reflect that participants were primarily focused on the information presented within each scaffold as they conducted group work.

Quantitative findings

After establishing the category codes via the qualitative analysis but prior to running the quantitative SNAs, we calculated frequency counts and constructed contingency tables of disciplinary and learning agency discourse units for each group member. We summed each group to get a total classroom effect (i.e., an omnibus group, with the group members identified as Alpha [the participant in the group who had the most turns when doing the pcMEL], Beta [the participant with the second most turns], and

Table 4. Discourse units (turns) by group member.

	Scaffold	
Group Member	pcMEL	baMEL
Disciplinary agency		
Alpha	128	24
Beta	47	58
Gamma	32	22
Learning agency		
Alpha	108	55
Beta	48	109
Gamma	23	36

Gamma [the participant with third most turns]). Summing individual groups into an omnibus group may have mitigated idiosyncrasies that are often inherent in classroom-based studies. Table 4 shows these contingency tables for the Alpha-Beta-Gamma omnibus group.

To better understand these differences, we conducted SNAs using the Gephi analysis tool (Bastion et al., 2009). We calculated each group member's centrality for disciplinary and learning agency, with centrality specifying the ways in which group members might control the flow of information during the classroom task (Valente, 2010). Centrality is an index of group members' connection and influence in the network (Carolan, 2014) and includes both turns (the total number of times a group member's statement was coded for disciplinary or learning agency) and directionality (who spoke to whom; Wagner & González-Howard, 2018). We summed turns and directionality from each group to get an omnibus group effect, with Alpha (the participant in the group who had the most turns when doing the pcMEL), Beta (the participant with the second most turns doing the pcMEL), and Gamma (the participant with third most turns doing the pcMEL) group members. In Figure 3 (disciplinary agency) and Figure 4 (learning agency), the arrows indicate directionality and number turns (expressed quantitatively as relative arrow weight). Group members are shown as circles, with the Gephi-calculated centrality parameter indicated by the side number and proportional size of the circle. Figure 3 shows that disciplinary agency was centered on group member Alpha with the pcMEL, and this changed to more equal distribution among all members with the baMEL. This may be indicative of

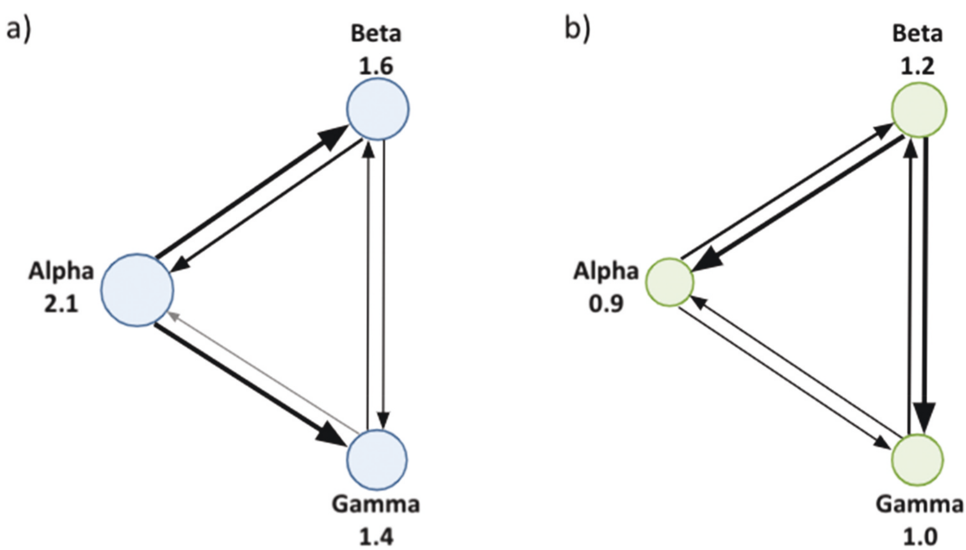

Figure 3. Social network analysis of disciplinary agency for the (a) fracking pre-constructed MEL and (b) the fossils build-a-MEL. Arrows indicate directionality and number turns (expressed quantitatively as relative arrow weight). Group members are shown as circles, with centrality parameter indicated by the side number and proportional size of the circle.

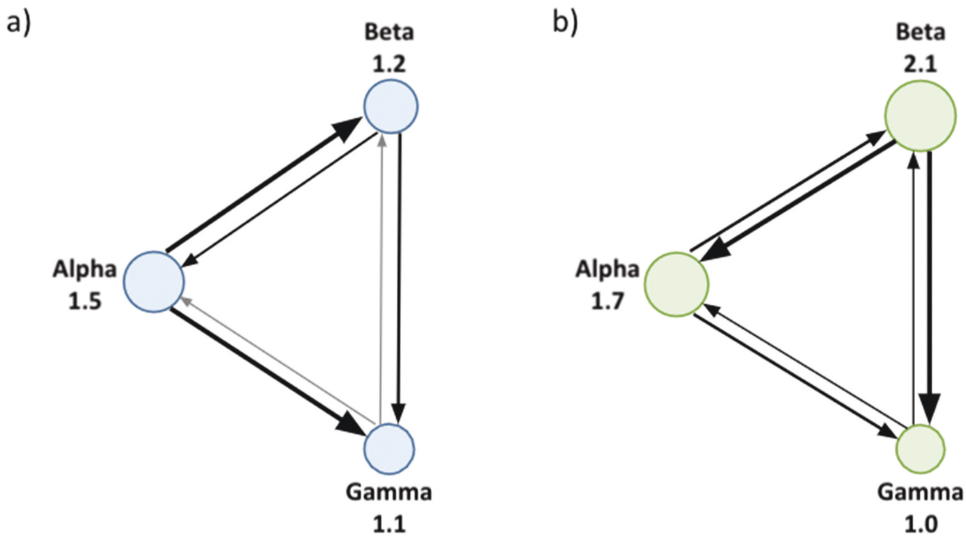

Figure 4. Social network analysis of learning agency for the (a) fracking pre-constructed MEL and (b) the fossils build-a-MEL. Arrows indicate directionality and number turns (expressed quantitatively as relative arrow weight). Group members are shown as circles, with centrality parameter indicated by the side number and proportional size of the circle.

more collective disciplinary agency during the baMEL activity. Figure 4 shows that learning agency was likewise centered on group member Alpha with the pcMEL but switched to group member Beta with the baMEL. This may be indicative of a transfer of agency from one group member (Alpha) to another (Beta) between the pcMEL and baMEL, respectively.

Integration of qualitative and quantitative findings

We next expanded the analysis by integrating the discourse analysis and SNA. We specifically considered patterns of social interaction and attempted to explain the patterns we found in terms of agency. We interpreted how the qualitative data in the form of small group discussions explained differences in the nature of discussions when using the pcMEL and the baMEL as visualized in the SNA.

Relations between disciplinary and learning agency

We considered correspondences of some of the codes in our qualitative analysis. First, we noticed that participants from one representative group generally engaged in back-and-forth conversations, often analyzing the reliability and validity of evidence. For example, discourse around the validity of evidence tended to demonstrate disciplinary agency via epistemic operations of describing, identifying, defining, explaining, and/or recalling evidence followed by questioning, then responses related to reasoning, predicting, and/or justifying, and concluded by evaluating. For example, in one group a participant said, "Here it [a line of evidence] talks about earthquakes and stress. This is the color of it [participant pointing to a stress line on a figure]. But they talk about it with fracking." Another group member then asked, "Yeah, but like stress, doesn't stress?" Then the original participant said, "This [line of evidence] could be for this [explanatory model]. This would not support this [line of evidence] because this is talking about fracking." Finally, the second group member evaluated the link connection by stating, "So it [a line of evidence] has nothing to do with it [an alternative explanatory model]."

Learning agency often emerged in the middle or the end of the conversations focusing on validity. For example, and from the representative group conversation above, the first member began to exert learning agency via taking leadership/lead role in the learning task. This leadership then supported the second student's learning agency to monitor the group's understanding and achievement of learning goals. At the end of this exchange, an agreement was reached as one textual evidence seemed to have sufficient probity to establish validity of a particular evidence to model connection. This suggested that disciplinary agency contributed to learning agency within the group, with leadership established and learning monitored once sufficient agency was manifested in participants' disciplinary moves (i.e., scientific discourse via epistemic operations) within the context of the scaffolded task.

There was an exception to this common sequence (i.e., where disciplinary agency preceded learning agency). At the start of the group work, learning agency was often expressed. For example, at the beginning of the discussion, one student participant said "Ok guys we have to work! Ok I think we should use Model A and C." Such examples happened at the start of each episode for almost all the groups, regardless of the scaffold.

Individual and collective agency

Our qualitative analysis suggested agency changes between the pcMEL and baMEL. For example, in almost all groups, one participant had a much greater frequency of discourse units expressing his or her disciplinary and learning agency during the pcMEL, which could be interpreted as a more leadership and managerial stance (i.e., using epistemic operations to help the other group members successfully complete the pcMEL). However, this individual often shifted toward a secondary role during the baMEL, allowing another participant to assume the role of leader and manager. It was also interesting that many groups had more evenly distributed expressions of disciplinary agency during the baMEL, suggesting more collective agency in use of epistemic operations, with shift in learning agency between group members and suggesting a transfer of the leader and managerial role. This may have indicated that one group member modeled use of epistemic operations during the pcMEL, with the rest of the group then using this as a role model, which may have increased and shifted disciplinary agency during the baMEL. By modeling in the pcMEL, this one participant may have been able to relax in the expressions of learning agency during the baMEL, allowing another group member to assume the leader and managerial role. This also supports the notion above that there may be a relation between disciplinary and learning agency in scaffolded science tasks.

Discussion

The aim of this study was to examine differences in group members' expressions of epistemic and learning agency when engaging instructional scaffolding designed to facilitate scientific evaluations about connections between lines of evidence and alternative explanatory models of geological phenomena. We specifically investigated differences in two types of MEL scaffolds: the fracking pcMEL, which is less autonomy-supportive, and the fossils baMEL, which is more autonomy supportive. The present study was part of a 6-year project, which includes both qualitative and quantitative data collection. In previous studies that used quantitative data analysis methods only, there was some evidence that the baMEL resulted in more scientific evaluations and deeper science understanding than the pcMEL, although both scaffolds demonstrate robust performance (medium to large effect sizes after only about 90 minutes of instruction during each scaffold; Bailey et al., 2022; Dobaria et al., 2022; Klavon et al., 2022; Medrano et al., 2020). In the present study, we used a sequential mixed methods design to examine at greater depth the nature of these earlier quantitative results in terms of participating students' disciplinary and learning agency (McCrudden et al., 2019).

In our study design, we first coded transcripts from large amounts of audio data collected during participants' group work and analyzed these data qualitatively using a content analysis focusing on theoretical frameworks supporting both types of agency. We then used these codes to quantitatively construct SNAs to infer changes in discourse and agency patterns among the group members. When integrating the qualitative and quantitative methods, we thought about how the different analyses were connecting together McCrudden et al., (2019). For example, the quantitative SNA connected to the results of the qualitative coding via frequency counts and centrality calculations. Similarly, we built on what we were seeing in the content analysis (distribution of agency among the group participants) to the omnibus participant assignments using the Alpha, Beta, and Gamma designations. In interpreting how the results integrated, both the qualitative and quantitative analyses suggest that there was meaningful change from more individual disciplinary agency in the pcMEL to more collective disciplinary agency in the baMEL. Changes in learning agency seemed to be different, with a shift from Alpha to Beta group members when going from the pcMEL to the baMEL. Even though the style of change may have been different, the results also suggested that when disciplinary agency preceded learning agency, group members exhibited discourse episodes deeply analyzing the validity of connections between lines of scientific evidence and explanations. Thus, it could be that increased comfort with disciplinary agency may allow students to share leadership aspects of learning agency. We speculate that these changes in agency structure may be a reason for earlier quantitative results suggesting an advantage of the baMEL (i.e., more scientific evaluations and judgments and deeper knowledge) over the pcMEL (Bailey et al., 2022; Dobaria et al., 2022; Klavon et al., 2022; Medrano et al., 2020).

Governor et al. (2021) had somewhat complementary findings when analyzing a preservice teacher group using the climate change pcMEL and extreme weather baMEL. In their qualitative study, Governor et al. used systemic functional linguistics, a very fine-grained and robust approach to analyze group discourse among undergraduate, preservice teachers using the MEL diagrams. These researchers found that preservice teachers' engagement in negotiation during scientific argumentation promoted productive assertions about relations between evidence and models, and negotiation toward consensus decisions. Further, such consensus decisions indicated greater depth of knowledge about climate phenomena.

Limitations and future directions

We designed the present study to be rich in context, both in setting (in situ classroom learning) and topic (complex and potentially controversial geological phenomena). There are certainly advantages to seeking such richness in educational and psychological research, but there are also associated limitations.

The present study was limited by the context of the science topics. Each scaffold featured a different geology topic, with the pcMEL covering the relations between hydraulic fracturing and earthquakes and the baMEL covering the validity of using fossil evidence to infer past surface and climate processes. As a science topic, fossils are commonly found in many places and may be covered in primary grades instruction (NGSS Lead States, 2013). Contrastingly, fracking and earthquake connections are a more regional phenomenon (e.g., the Midwestern United States), with human impacts and seismicity not generally covered until secondary grades instruction (NGSS Lead States, 2013). Our intent in the present study was to compare disciplinary and learning agency between two types of instructional scaffolds, but we acknowledge that topic difference and the influence of this difference, such as background knowledge, may have influenced the different expressions of agency and networks of discourse (McCarthy & McNamara, 2021). It was also not possible to blind the coders to condition (pcMEL vs. baMEL) because of the topic-specific nature of the discourse. Although we were vigilant during our rigorous coding and checking process, we do acknowledge that there may have been some implicit nudging toward hypothesized effects.

The participants experienced these scaffolds in a sequence, using the pcMEL first and the baMEL second. This order of the treatment may have influenced the results; however, there was a 5-week delay with a holiday break between the pcMEL and baMEL, which might have mitigated this ordering effect. Regardless, it is likely that practicing with the pcMEL influenced performance on the baMEL. The results of the present study aligned with previous quantitative comparisons, with appropriate statistical controls accounting for activity ordering. We acknowledge this as a potentially serious limitation, and we are duly cautious about results from these previous studies as well as the present study and suggest that additional research examining a broader range of science topics (see, for example, Bae & Debusk-Lane, 2019; Bae et al., 2021) may be warranted to better understand the link between students' agentic engagement and the science learning. For example, future studies could incorporate a quasi-experimental design, counter-balancing by condition and time to more gauge differences between the two scaffold forms. Future studies could also investigate the occurrence frequency of different categories of disciplinary and learning agency using a comparison of each code across the pcMEL and baMEL.

Conclusions

Research suggests that increased student engagement and agency may help promote science learning (Bae et al., 2021; Grabau & Ma, 2017; Lee et al., 2016). However, deepening students' disciplinary and learning agency may require the appropriate instructional scaffolds to facilitate more scientific evaluations about the connections between lines of evidence and alternative explanations about a phenomenon. The present study, which was an in-depth mixed methods investigation comparing the effectiveness of two such scaffolds, the pcMEL and baMEL, provided some initial and tentative evidence of discourse reflecting middle school students' agency to complete such a scientific task. Although we approach our conclusions with caution, the more autonomy-supportive task (baMEL) resulted in greater collective disciplinary agency (i.e., agency to construct knowledge scientifically) and learning agency (i.e., agency to facilitate individual and peer learning) than the less autonomy-supportive task (pcMEL). Current methods of teaching science are often teacher-centered, with little room for students to think critically about the validity of evidence and the plausibility of alternative claims, and could limit students' agency to engage in the scientific enterprise (Lombardi et al., 2021). However, based on the results of the present study, we suggest that the MEL scaffolds may be one of many effective autonomy-supportive tools that facilitate students' socioscientific learning (see also, for example, Bohn-Gettler & McCrudden, 2021; Darner, 2019; Dauer et al., 2021; Nussbaum, 2021). Engaging students in more autonomy-supportive learning may help them to productively and actively participate in a more civically minded and inclusive society, where all play a more beneficial role in democratic and scientific decision-making.

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