Interdisciplinary Journal of Environmental and Science Education
2023, 19(1), e2303
e-ISSN: 2633-6537
https://www.ijese.com/

MODESTUM

Research Article

OPEN ACCESS

Exploring epistemic agency in students' problem-solving activities

Mahir Akgun [1*], Priya Sharma [2]

[1] College of Information Sciences and Technology, Pennsylvania State University, University Park, PA, USA
[2] College of Education, Pennsylvania State University, University Park, PA, USA
***Corresponding Author:** makgun@psu.edu

Citation: Akgun, M., & Sharma, P. (2023). Exploring epistemic agency in students' problem-solving activities. *Interdisciplinary Journal of Environmental and Science Education, 19*(1), e2303. https://doi.org/10.29333/ijese/12970

ARTICLE INFO

Received: 27 Dec. 2022

Accepted: 11 Feb. 2023

ABSTRACT

This case study presents an exploration of epistemic agency in a middle school context. The main focus of this study was to identify and characterize the actions indicative of epistemic agency that emerged in student interactions. The study was conducted with sixth graders. Data were collected from multiple sources including records of student participation in the classroom and in the virtual space, student-created artifacts, and non-participant observations. A qualitative data analysis was conducted to identify actions indicative of epistemic agency. The findings showed that eleven actions emerged in students' activities: generating new ideas, revising ideas, negotiating new ideas, sharing ideas, sharing data/information, drawing on other group's ideas, drawing on other groups' data/findings, collecting additional information, engaging in shared construction of data collection instruments, examining research data–seeking support for ideas, and creating a joint plan of actions. Future research identified by this study suggests further investigations of the interactional processes that may reveal key actions that trigger subsequent actions.

Keywords: epistemic agency, epistemic actions, science education

INTRODUCTION

A key goal of science education is developing students' epistemic agency (Lai & Campbell, 2017; Stroupe, 2014) to support them in becoming doers of science and engaging in authentic scientific practices (Miller et al., 2018). Achieving this goal involves bringing disciplinary practices into the classroom and engaging students in sense-making around science. However, the progressive nature of scientific discovery and practice can act as a model for education broadly. Scardamalia and Bereiter (2006) introduced knowledge building pedagogy as one such model for educational programs; knowledge building is characterized by iterative idea improvement as students work together on advancing ideas as part of educational programs. Epistemic agency, which refers to activities in which learners are directly involved in generating and advancing ideas through collective contributions, is a key principle of knowledge building (Scardamalia, 2002). Scardamalia's (2002) study emphasizes collaborative work as a discrete characteristic of epistemic agency. Evidence suggests that engaging students in collaborative group work at elementary and secondary levels has multiple social and cognitive benefits for students (Baines et al., 2007) including assumption of greater epistemic agency by students (e.g., Belland et al., 2019). Although epistemic agency historically has been explored in post-secondary education and professional contexts (Damşa et al., 2010; Tan et al., 2022), there is growing recognition that younger children are often positioned as receivers of knowledge rather than as contributors (Varelas et al., 2015) and opportunities are being missed to build on their intellectual curiosity and enthusiasm to contribute to classroom knowledge building practices (Carlone et al., 2021). An increasing body of work explores students' epistemic agency at the secondary school level, with a goal of fostering students' ability to engage authentically in sensemaking discourse and knowledge construction (Gonzalez-Howard & McNeill, 2020).

In a classroom that promotes epistemic agency, discourse does not act as critical filter to accept or refute knowledge claims, but rather it encourages students to pursue critical inquiry to improve ideas and redirect work based on failures and advances. Students' involvement in determining the direction of the class creates uncertainty in how learning unfolds in the classroom. Therefore, engaging students to enact epistemic agency requires disrupting traditional and authoritative discourse practices (Mortimer & Scott, 2003) and coexists with the tension of meeting target learning goals (Zivic et al., 2018). Many schools are held responsible for student success based on conventional measures of learning; thus, it is not easy for schools to depart from a "learning goals first" approach and move closer toward an "epistemic agency first" approach, especially if learning measurements are used to determine whether students achieve learning goals and advance to the next grade and to provide public ratings and funding for schools. This does not mean that there is no place

for students to act with epistemic agency in schools; but rather, we think that because of the importance of both bringing epistemic agency into schooling and recognizing the reality of large-scale standardized assessments, it is necessary to create a place for epistemic agency in a space dominated by a focus on learning outcomes.

While there is a growing body of work focusing on what needs to be done to shift epistemic agency from teachers to students, there is insufficient attention on how epistemic agency can be identified in practice. Stroupe (2014) examined classroom science practice communities in which students were provided with opportunities to act as epistemic agents and reported five discursive moves illustrating students' epistemic agency: making claims, integrating science ideas with other ideas, questioning, introducing new science ideas to public plane, and assigning value to ideas. These identified discursive moves demonstrate students' ability to go beyond being passive information recipients and engage in science-as-practice. Damşa et al. (2010) conducted an exploratory case study to identify indicators of a specific form of epistemic agency in learning practice. They reported epistemic and regulative actions evident in the collaborative object-oriented learning activities of two groups of university students. Our work builds from these perspectives on epistemic agency to explore group-level actions indicative of epistemic agency that are evident in middle school students' collaborative problem-solving activities. In this study we examined four groups of students who acted jointly to generate a singular idea and work continuously with it to provide a more inclusive explanation for a problem. A case study approach was adopted to address the following research question: *What group-level actions indicative of epistemic agency are evident in middle school students' collaborative problem-solving activities?*

THEORETICAL FRAMING

Epistemic Agency

While agency focuses on broad cultural, interpersonal, and contextual factors with which the learner engages to achieve certain goals (van Lier, 2008), epistemic agency is more clearly focused on knowledge advancement and is a sustained process of creating and improving shared ideas via collective contribution. Epistemic agency is conceptualized as an emergent characteristic of a group negotiated through interaction (Ko & Krist, 2019), rather than as a trait of an individual. In classrooms, it refers to students taking responsibility for their knowledge advancement (Chan & van Aalst, 2015). The state of knowledge in a classroom community is an aggregate of ideas of value to the community (Scardamalia & Bereiter, 2006). Students are encouraged to work collectively, and their collective work is channeled towards improving ideas (Scardamalia & Bereiter, 2010). Once generated, ideas are entered into the community space for sustained work, and thereby secure an autonomous existence in the idea landscape. Students in the community can explore the idea landscape where ideas are considered real things, find the ideas of other community members that look promising (Scardamalia & Bereiter, 2016), and collectively build their solutions based on those ideas (Hewitt & Scardamalia, 1998). They can pursue and refine promising ideas by redirecting work based on advances and failures (Scardamalia & Bereiter, 2016). Therefore, epistemic agency denotes the joint efforts of creating and collaboratively advancing shared knowledge objects and is defined as "a capacity that enables groups to deliberately carry out collaborative, knowledge-driven activities with the aim of creating shared knowledge objects" (Damşa et al., 2010, p. 154). Damşa et al. (2010) identified two major dimensions of epistemic agency: the epistemic and the regulative dimensions. The epistemic dimension consists of knowledge-related activities (e.g., coordinating personal ideas with others and structuring collective ideas) that lead to the creation of knowledge objects. The regulative dimension involves process-related activities that steer the object-development process, including setting goals, long-range planning, and monitoring collaborative efforts.

Students who are positioned as epistemic agents in classrooms play a key role in setting forth ideas or goals (Scardamalia & Bereiter, 2003; Scardamalia et al., 1989), formulating questions (Scardamalia & Bereiter, 1991), deciding methods by which to answer questions (Ko & Krist, 2019), collecting information from multiple sources (Miller et al., 2018), and designing and finding solutions to problems (Scardamalia, 2000). Epistemic agency emerges when learners are engaged in joint planning (Bereiter & Scardamalia, 1992), sharing responsibility to produce ideas towards solutions of problems (Scardamalia & Bereiter, 2003), contributing to collective knowledge advancement, and adding values to shared goals (Scardamalia, 2000). However, such activities do not match with students' experiences in most classrooms which promote the completion of curricular activities rather than sensemaking. In such classrooms, students are provided with limited opportunities to construct knowledge through engagement in the practices of scientists, so they do not act with epistemic agency (Gonzalez-Howard & McNeill, 2020; Miller et al., 2018). Argumentation plays an important role in how knowledge is constructed in disciplinary practices, and it involves students dealing with knowledge construction and engaging in eliciting, attending, critiquing, and building on peer's ideas in science classrooms promoting sensemaking. Gonzalez-Howard and McNeill (2020) view 'critique during argumentation' as a manifestation of epistemic agency. They explored interactional patterns related to critique during argumentation discussions as a way that students' epistemic agency might manifest. Their findings showed that students were central actors in evaluating their peers' ideas and carrying out language moves, such as positioning ideas as unreasonable and listing points of disagreement.

Shifting epistemic agency from teachers to students requires shifting power in the classroom (Ko & Krist, 2019); thus, for students to act as epistemic agents, authority is taken from teachers and redistributed within the classroom by placing students' ideas at the center of classroom science community (Stroupe, 2014). This requires supporting students' involvement in directing and monitoring knowledge building processes (Damşa et al., 2010) and situating them as the classroom members who are responsible for making decisions about the arc of their inquiry (Ko & Krist, 2019). As reported by Stroupe (2014), if authority is redistributed to students, they can make discursive moves illustrating

epistemic agency, such as asserting science ideas, introducing new science ideas to the public plane, integrating science ideas with other ideas mentioned on the public plane, assigning value to science ideas, and distinguishing important ideas from other ideas. Damşa et al. (2010) investigated how epistemic agency was evident in students' practice. In their investigation, different types of actions indicative of epistemic agency were observed, such as identifying a lack of knowledge, examining given sources, sharing information, generating new ideas, negotiating new ideas, setting common goals, and creating a joint plan of action. Damşa et al.'s (2010) work was in the context of college student groups, but K-12 school contexts have been underexplored in the literature. Most recent studies investigated teachers' role in carving space for students to act as epistemic agents in the classroom, but the literature lacks research that examines what students can do when authority is redistributed to them.

Implementing Epistemic Agency in the Classroom

To involve students as partners in the work of generating, investigating, and revising ideas, the instructional design work needs to be responsive to students' ideas about next steps in their inquiry and help them go deeper with their investigation, which supports students in meaningful science practices. However, this can lead to some obstacles for teachers in the classroom. Teachers are accustomed to lesson plans that target pre-determined learning objectives but transferring the authority of directing the knowledge building process to students in the classroom requires teachers to adapt curriculum materials and resources to students' ideas, which may deviate classroom activities from targeted learning objectives. This can lead to uncertainty in how learning unfolds in the classroom, which in turn can create a tension between achieving learning objectives and cultivating student agency in today's accountability climate of standards and assessments (Alzen et al., 2020). Developing and implementing a model that navigates this tension is a challenging, but important task. It is challenging because it requires collective work among teachers, curriculum designers, and school administrators to allocate resources that students need to act with epistemic agency. It is important because without navigating the tension, it would be very difficult to explore how students enact epistemic agency in the classroom, such as epistemic actions they perform as they engage in scientific practices. To contribute to the literature, in this study, we implemented a model that supports epistemic agency for students and explored patterns of actions that are indicative of epistemic agency in a middle school context. We focus on students' joint efforts of generating and collaboratively advancing ideas as a central component of epistemic agency.

METHOD

We conducted a qualitative case study in a middle school based on an analysis of video and audio records, and knowledge objects (i.e., ideas students generated) collected in the classroom. Actions that indicate epistemic agency were examined in detail while participants worked on a problem in their own classrooms. This type of examination is appropriate for case study research because of the boundedness of the research site and participants (Creswell, 2007).

In the present study, we assumed the applicability of the indicators of epistemic agency identified by Damşa et al. (2010) into the case of interest in this study and formulated the research question based on the expectation that these indicators could be directly observed when students are invited to act with epistemic agency. Framing the question in terms of what can be directly observed represents an instrumentalist approach to research questions (Maxwell, 2013). From this perspective, this study can be classified as an instrumental case study.

Research Site

The study was conducted in a Turkish private school where didactic approaches to teaching and learning were dominant. The school follows the Turkish national curriculum. Students from high-SES households usually enroll in the school, but to be admitted at the secondary level, students must complete a standardized entrance exam that dominates most curricular activities in the school. Parents are extremely sensitive about their child's success in the exam, which puts extra pressure on the teachers to prepare students for the exam. Most of the learning activities implemented in the school are designed to support retrieval and spaced practice and to encourage students to restudy the contents included in the exam. This approach leaves less room for inquiry-based learning activities that encourage students to assume more agency for their own learning. Therefore, students who participated in the current study were not familiar with problem-solving activities at the time of the study.

Design and Procedure of the Study

The study was part of a broader design study that aimed to transform the school into an organization where students are supported to assume a higher-level of agency in their learning. Shifting the focus completely from lower-level student agency to higher-level student agency was difficult due to the contextual constraints faced by teachers, including administrative curriculum mandates and a high-stakes testing system. In addition to contextual constraints, several school faculty voiced their concerns with the idea of putting student agency first in educational practice. For example, some of the math teachers emphasized the importance of following step-by-step procedures in math classes because of their belief that the process of learning begins with gaining competence in the procedure and developing procedural mathematics understanding.

In addition, teachers within the setting had little experience with collaborative inquiry and inquiry-based teaching. School administration considered these constraints, concerns, and differing beliefs and decided to take initial steps to carve out a place for students to assume a higher-level of agency in the school instead of transforming the entire school. Science classes were selected for pilot projects with the following design decision:

> Students are supported to assume a higher-level of agency in science classes, but procedural approaches are followed without transferring a higher-level of

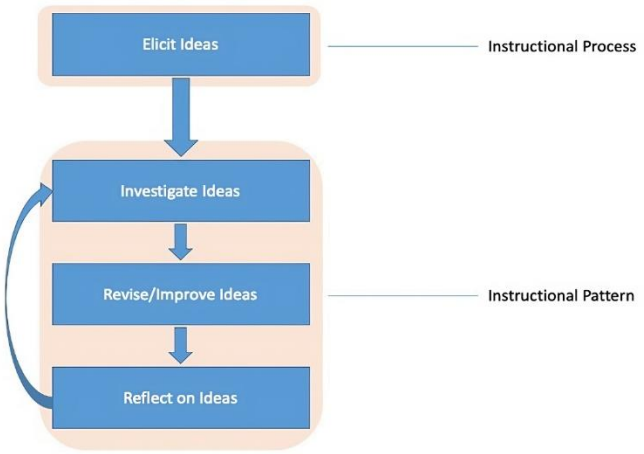

Figure 1. Instructional process/pattern followed in this study (Source: Authors' own elaboration)

> agency to students in other classes such as math and language arts.

This decision guided the design of the entire study. In addition, since students were new to the inquiry process and repeated aspects of inquiry (e.g., designing experiments, interpreting findings, making predictions, and forming arguments), they needed a repertoire of approaches to inquiry so as to enact the practices of science with agency. As emphasized by Linn et al. (2004), revisiting inquiry processes in science class helps students capture the reusable pattern of inquiry activities; then students can become autonomous learners. In line with this position, we embedded the *elicit ideas* process along with a repeated pattern of *investigate ideas*, *revise/improve ideas*, *reflect* to support students in their journey to become autonomous learners, and act with epistemic agency (**Figure 1**).

1. The *elicit ideas* process involves eliciting a wide range of ideas that students bring to science class (Linn & Eylon, 2011). It promotes diverse ideas by encouraging students to (i) articulate the ideas they hold about a scientific phenomenon, and (ii) select a more promising idea and work toward improving it at the outset.
2. The *investigate ideas* process involves conducting independent investigations (e.g., doing experiments and administering surveys), observing demonstrations, and using authoritative sources in a constructive way to gather evidence that can be used to detect problems and inconsistencies of ideas and refine them. Students who work in groups are encouraged to collectively gather data, analyze results, and share them with other groups. Groups can draw on other groups' findings to detect problems and inconsistencies of the ideas they work with.
3. The *revise/improve ideas* process involves interpreting results, removing inconsistencies in ideas, and providing more inclusive explanations to problems. If students notice that their original ideas do not look promising based on new information, they are encouraged to either revise their own idea or distinguish among alternative ideas proposed by other groups and start building on a more promising one. Students are encouraged to redirect their work based on advances and failures.
4. The *reflect* process involves engaging students in reflecting on progress and ideas.

To conduct the study, a design committee (DC) was formed with seven members comprising one researcher--PI of the current study--, three science teachers, one math teacher, one language arts teacher, and one visual art teacher. As the first task, the DC created the following problem:

> A student who was suffering from influenza started to take the antibiotics his mother gave him. But in the end, he did not recover from his illness. What could be the reason?

The second task that the DC completed was to find out a way to enable students to go through the processes of eliciting, investigating, improving/revising, and reflecting on ideas. It was decided to employ the following probing questions as scaffolds in web-based inquiry science environment (WISE, an online platform that offers cognitive hints, embedded assessments, online discussions, and tools for drawing, annotation, concept mapping, diagramming, graphing, and data collection):

1. Elicit ideas--What is your own idea about the problem? What is your group's idea?
2. Investigate ideas--How will you collect data? What data collection method would be the best to gather the data you need? What is the new information you obtained?
3. Improve/revise ideas--Does the new information lead to improvement or revision of your group's idea?
4. Reflect--What are the strengths and weaknesses of your group's idea?

As articulated by Berland et al. (2016), "one step toward supporting student engagement in scientific practices is to help them know what to do" (p. 1083), such as the acts of justifying, evaluating, revising, and rebutting claims. However, to act with epistemic agency, students should go beyond the rote performance of such scientific actions or practice, understand the purpose of such practices, and decide when and how to employ such strategies. As pointed out by Ko and Krist (2019), enacting epistemic agency as students engage in scientific practices adds another layer to the work of teaching, requiring teachers to make moment-to-moment decisions about how to respond to student ideas about next steps. In line with this stance, the DC decided not to fully develop the project for the present study in WISE. Instead, only the first three activities were completely designed before the study was conducted, and all subsequent activities emerged in response to students' ideas. With this decision, the DC aimed to (i) establish initial routines that help students capture the repeated pattern of *investigate ideas, revise/improve ideas, reflect* in the first three activities, and (ii) create a space for students to act with epistemic agency in subsequent activities. To start the project, the problem created by the committee was presented to the students, and then the following activities were completed.

1. After groups were formed, they were asked to generate their initial ideas to explain why the medicine taken by

the student did not help him recover from influenza (activity 1-elicit ideas).

2. After groups proposed their initial ideas, a physician was invited to the classroom so that she could present information about antibiotics and their usage. Following the physician's presentation, groups were asked to decide whether their initial ideas were challenged or supported by the data they collected during the presentation (activity 2-investigate ideas).
3. If their ideas were challenged, they revised the ideas; if supported, groups constructed a more inclusive explanation regarding the problem. Then, groups entered their revised or improved ideas to WISE (activity 3-improve/revise ideas)
4. Following the groups' submissions, students wrote their first reflective journal entry including their individual thoughts and reflections regarding what they had learned from group activities and published them on their personal blogs (activity 4-reflect).

Until this point, students' agency in the classroom activity was limited. Beginning from the fourth activity, a higher level of agency was turned over to students in the science classes. At the beginning of the second idea-generation cycle, groups were encouraged to make their own decisions about how to investigate their ideas. Once groups entered their methods of investigation as a final decision to WISE, the DC reviewed all proposed testing methods and discussed specific WISE tools that could be used to ease the data collection process and activities that could be created in WISE to support groups in the process. For example, three groups decided to construct a questionnaire to survey people in their near circle. To help these groups construct a questionnaire and enter survey data to WISE, the DC provided logistic support in creating tasks for each group using table and questionnaire tools in WISE. Then, groups performed the tasks created for them to construct questionnaires and collect survey data in WISE.

Once groups drafted their own questions to be used in the questionnaires, the science teacher noticed that most of the questions were neither grammatically sound nor well-expressed. With the request from the science teacher, the DC reviewed the curriculum objectives of the Language Arts course that could be linked to the question writing process and then decided to forward the groups to the language arts (LA) class to get support in writing grammatically sound and well-expressed items in collecting reliable data from participants. Students' agency was limited in the LA class because of the very structured procedure that was followed. Once the groups finished revising the questions, they entered the questions into WISE. The groups then assumed a higher-level of agency when they were back in the science class and took executive control of the data collection process. When they had managed to collect data and entered them into WISE, the DC met to decide which subject area could be linked to the interpretation of quantitative survey data and decided to direct the groups to the math class. Students were directed to the math class because they did not know how to convert raw data to percentages and visualize percentages with charts when they collected data. The math teacher showed students how to convert raw data to percentages and visualize with appropriate graphical representations (e.g., pie chart, bar chart, and line chart). Here again, in the math class, students followed a predefined procedure while working on data; therefore, student agency was limited in the class, but then higher levels of agency were re-assumed in the science class while interpreting the findings, exploring findings of other groups, and deciding whether to revise or improve ideas in light of findings. The science teacher was not involved in this decision-making process; instead, the groups were positioned as evaluators as well as constructors of ideas, which provided students with a supportive environment for developing and acting with epistemic agency. Ideas were treated as improvable in this project, so the groups were not searching for a final state but for the best explanation they could build for the problem. The repeating pattern *investigate ideas, revise/improve ideas, reflect* was used to guide the groups in creating new ideas, evaluating them, and revising or improving existing ones as their shared knowledge objects. The pattern was repeated until the end of the semester during which the study was conducted. Groups spent between 40 and 320 minutes on project activities in a week.

All activity sessions in the classrooms were videotaped. Because of the physical placement of a single video camera and its inability to capture detailed discussions that took place within groups, an audio recorder was placed at each group's desk. Group discussions were audio-recorded during each activity session. In addition to videotaped observations, student participation in a virtual learning platform was monitored. WISE provided us with an opportunity to view student work online in real-time. With the help of the WISE Classroom Monitor tool, we were able to quickly assess the progress of each group. Data collected for each case included: audio and video records of student participation in the classroom, records of student activities in the virtual space, and student-created knowledge objects (i.e., ideas entered to WISE).

Participants

Our access to the site and participants was negotiated at multiple levels via the administration and teachers. In selecting participants, teachers decided to take ownership of student grouping to minimize disruption to their general classroom procedures and the design committee accepted the practical suggestions of the teachers. While we understand that such grouping has limitations, the contextual nature of the decisions was important for us to highlight and adopt within the study. For the purpose of the investigation, five groups of four students were formed. In the present study, all data were reviewed to detect which group discussions were complete and could be analyzed. We focused our analytical efforts on an in-depth examination of four groups, which offered the richest data and most complete data. The group whose data were excluded was missing data from some group sessions.

Data Analysis

In this study, epistemic agency was construed as students taking collective responsibility with team members for the purpose of generating and advancing ideas toward solving problems. Conceptually, groups engaging in generating and

Table 1. Coding example

Segments of written data	Step 1	Step 2	Step 3
S1: I think main reason is overuse of antibiotics & assuming us specialists. These two cause big problems. Bacteria mutate due to overuse of them (1). But why? The doctor who came to our school gave us the answer. Some substances have an impact on some others & breaks their structure. The more antibiotics the more mutated bacteria. They are produced only for known bacteria but mutation of them cause new bacteria, which cannot be cured with these ones. For new bacteria new antibiotics are needed (2). S2: Let's see what we have done so far. First of all we shared our opinions (3). Then a doctor visited us. He told about types of immunization & how they are formed. Then we made a survey to send to pharmacists (4). And a pharmacist gave us the number of its use in our city. We were all astonished 1,881,600 boxes (5). Despite being a province this much, consider the rest of the country. S1: Right. What is our final decision? S3: I think people overuse antibiotics. Then this breaks bacteria's' structure & mutate them. For new bacteria there is no antibiotics. Then we say why they do not work (1).	(1) Idea generation (2) Receiving answer* (3) Sharing ideas (4) Constructing data collection instrument (5) Collecting information	(a) Idea generation** (b) Sharing ideas (c) Engaging in shared construction of data collection instruments (d) Collecting information** Among the codes generated and used in Step 1, the codes 'receiving answer' and 'collecting information' were used to represent the same action. The code 'receiving answer' was removed from the analysis in Step 2 as the code 'collecting information' better captures the action. In another segment, the code 'engaging in shared construction of data collection instruments' was used to refer to the action aiming at developing a data collection tool. We preferred that code over the code 'constructing data collection instrument' (appeared in this segment) as it emphasizes a group level engagement, which better captures the action.	(a) Generating new ideas*** (b) Sharing ideas*** (c) Engaging in shared construction of data collection instruments**** (d) Collecting additional information*** Damşa et al.'s (2010) used the following codes in their framework: (1) generating new ideas, (2) sharing ideas, & (3) collecting additional information. To align our codes with Damşa et al.'s (2010) framework, we replaced the code 'idea generation' with 'generating new ideas' & the code 'collecting information' with 'collecting additional information'.
S4: I noticed a problem while examining other [groups'] ideas (6). We stated that pharmacists are not aware of improper use of antibiotics. However, actually they are aware of improper use of antibiotics, we did not explain the problem correctly (7). S5: You are right, this is not related to pharmacists, but to people buying and using antibiotics excessively (8). S6: Right, pharmacists gave us information about antibiotic usage in our city & we noted it. We evaluated the information they provided (8). S5: Okay, then, we agree on correcting our statement (9).	(6) Identifying problem with the help of other groups* (7) Stating problem* (8) Confirming problem* (9) Correcting problem based on another group's ideas*	(e) Drawing on other groups' ideas' Both the code 'correcting problem based on another group's ideas' (appeared in this segment) and the code 'building on another group's idea' (appeared in another segment) represent actions aimed at drawing on another group's ideas. In order not to have redundant codes, these two codes were removed from the analysis, and the code 'drawing on other groups' ideas' that better captures the actions was retained.	e) Drawing on other groups' ideas'****

Note. S: Student; *Code not selected for the second step; **Code replaced by the one offered by Damşa et al. (2010); ***Code offered by Damşa et al. (2010); & ****Code created in this study, but not used by Damşa et al. (2010)

advancing ideas were considered epistemic agents in the current study. A case was defined as the activities and actions of one group of students during the project period; therefore, each group was considered a unit of observation in this research.

The analysis focused on observable actions (Engeström, 1987) performed by study groups to generate and advance ideas. The line-by-line reading was used as the analytical process of separating the transcribed data into constituent qualitative elements, but we also concentrated on portions of the data that were qualitatively meaningful units for signifying the actions we aimed to identify in the study. A meaningful unit may be a line, a sentence, a paragraph or any other entity, so we did not use a single entity as a unit of analysis in this study. Before beginning analyses, the complete audio recordings of group discussions were transcribed verbatim. Multiple readings of the transcripts were carried out to categorize the data into discrete episodes including group-level actions with respect to generating and advancing ideas.

The data were analyzed in an iterative manner in three steps. First, segments of the data related to idea generation and advancement were detected. To see actions in each segment of the data, line-by-line coding (Glaser, 1978) was conducted to name each line with a code (see **Table 1** for examples of line-by-line coding).

The codes were used to identify actions that emerged in groups' collaborative problem-solving activities. Step 1 was carried out by two researchers independently to identify actions and generate codes representing actions. Actions

Table 2. Actions indicative of epistemic agency

Action
Generating new ideas**
Revising ideas **
Negotiating new ideas **
Sharing ideas (with other groups)**
Sharing data/information (with other groups)**
Drawing on other groups' ideas*
Drawing on other groups' data/findings*
Collecting additional information**
Engaging in shared construction of data collection instruments*
Examining research data–seeking support for ideas or being open to alternative explanations*
Creating a joint plan of actions **

Note. *Actions emerged in this study, but not reported by Damşa et al. (2010) & **Actions emerged in both this study & Damşa et al. (2010)

detected by both researchers in the first step were marked for discussion in the second round of coding.

On the other hand, an action elicited by only one researcher was reviewed by the other researcher; if both researchers agreed that students took the action toward generating and advancing ideas, then it was selected for discussion in the second round of coding. If there was no agreement between the researchers about an action, that action was removed from the analysis along with the associated codes.

The second and third steps (i.e., rounds of coding) were carried out together by both researchers. The second step was to select the most telling codes gained through line-by-line coding. We, as researchers, revisited all new codes to see whether different codes were used to represent the same action. In such cases, we either created a new code that better captured the action or selected the most telling code among those already created. For example, 'receiving answer' and 'collecting information' were used as codes in the first step. Since the action represented by the code 'collecting information' was considered to cover the action captured by the code 'receiving answer' in the data segment presented in **Table 1**, the code "collecting information" is selected as the most telling code, and the code 'receiving answer' was removed from the analysis. The third step was to name the actions identified in the first two steps by applying Damşa et al.'s (2010) framework. To do so, we compared actions with the codes that emerged in Damşa et al.'s (2010) study and when our codes overlapped with a code created by Damşa et al. (2010) to capture the same action, we substituted the code used by Damşa et al. (2010) in the third step and removed our code from the analysis (**Table 1**).

Video recordings were reviewed in a timely manner to see how activities unfolded in the classroom and to better interpret emerging actions in groups' activities. In addition to videotaped observations, student participation in WISE was monitored in real time.

RESULTS

This section presents overall findings of the qualitative data analyzed as well as detailed analyses of seven excerpts taken from the data collected from groups. The analysis identified 11 actions. **Table 2** shows the actions that emerged in groups' collaborative problem-solving activities. To better illustrate how these actions emerged in the study, segments from each group's journey through the problem-solving process are presented in the following section. To better present results, we strategically selected one or two groups for each idea-generation cycle based on the richness of the discussions that took place within groups.

Activities of Groups and Actions Emerging in Groups' Activities

Groups began working on the problem by eliciting ideas towards solutions and went through four cycles of *investigating idea, revising/improving idea, reflecting on idea*. In this section, groups are presented separately with an introduction that pinpoints the most characteristic actions taken by groups. The activities performed by groups are briefly explained, and then actions emerging in groups' activities are discussed and interpreted.

Group A

Group A began the project after the problem was introduced. Each group member proposed at least one idea relevant to the source of the problem, and then as a group they went through each idea and decided on the most promising one. Group A proposed the following idea: ingredients of antibiotics might have changed over time.

To provide perspectives based on scientific facts, a physician was invited to the class to speak about what drugs are effective in treating what types of diseases. During the presentation, all groups took notes that focused on some diseases, their symptoms, whether they are caused by bacteria or viruses, and what diseases are cured by antibiotics. Based on their notes, group members decided to revise their idea and proposed that antibiotics might have been used for diseases caused by viruses, which led to the belief that antibiotics did not work.

After revising the initial idea, group members discussed how to test their revised idea and decided to use a questionnaire to survey people in their near circle. Upon completion of the questionnaire, Group A administered it to collect data from people in their near circle. Group members turned raw data into graphs in the math class to better present the data. Electronic copies of the graphs were shared with other groups in WISE so that other groups could access them easily. Similarly, Group A was able to access other groups' data in WISE. The group examined the graphs representing their

own data along with those shared by other groups. The following excerpt shows the data examination process.

Episode 1-Group A, first idea-generation cycle

> 1.1. Student A: Let's begin investigating graphs showing the distribution of responses.
>
> 1.2. Student B: Okay, let me start with the third question. Is there anyone in your near circle who uses antibiotics unnecessarily? 10 people said no to this question, and 12 people said yes. This shows people do not know how antibiotics should be used.
>
> 1.3. Student A: Yes, or they might use them without consulting a doctor.
>
> 1.4. Student C: I am reading the seventh question [created and shared by another group]. This was asked to a pharmacist. Do you give antibiotics to the patients who come to you without consulting a doctor? Five people said yes to this, and four people said sometimes.
>
> 1.5. Student D: The ninth question is "does overuse of antibiotics affect human health negatively?" 22 people said yes to this question, and none of the participants said no.
>
> 1.6. Student A: I do not see a question number here but let me read the question. Have you witnessed individuals who use antibiotics without prescriptions? eight people said yes, and two people said no.

In this excerpt, group A members took turns to examine research data as they sat around a computer and re-examined the graphs they had created as well as those submitted by other groups in WISE. The group interpreted the data and concluded that people used antibiotics without consulting doctors and that pharmacists contributed to the problem of improper use by selling antibiotics without asking for prescriptions. The group's own data showed some clues about the self-medication patterns of people in their near circle. They then successfully linked this pattern to pharmacists' practices of dispensing antibiotics without prescription which was revealed by another group (line 1.4). The tie established between self-medication by people and antibiotic dispensation by pharmacies appeared to help group members to understand the source of the problem, and in turn, revise their ideas about the problem.

Seeking data that can be used in class activities, examining data, driving students' attention to important aspects of the data to support a position, and encouraging students to evaluate ideas in light of new findings and revise them, if necessary, are actions that are traditionally assumed by teachers. Examining group A's activities revealed that the group assumed some of the teacher's roles, such as deciding how to collect or retrieve data, examining data, presenting research findings with other class members and deciding to revise ideas based on new evidence. Performing such actions as a group helped students work on their ideas to explain the source of the problem. The presence of this type of student discourse is considered a shift in the power structures present in the classroom and an opportunity for students to retain agency and authority in co-constructing knowledge. In learning environments where this type of discourse prevails, students act with epistemic agency (Gonzalez-Howard & McNeill, 2020). Redistributing the power to students creates epistemic space in their classrooms, which allows for dialog around ideas among students and the development of shared knowledge objects (Stroupe et al., 2018), advanced ideas in this case. Students in group A engaged in dialog around their ideas about the problem. They were able to generate multiple ideas in the first place, decide to dismiss their previous ideas and go with a new one. For example, student B had initially proposed that the problem could be related to the manufacturing process of antibiotics, but she revised her idea after she and other group members analyzed the research data and identified widespread improper use of antibiotics (see episode 2). Since there is no connection between her initial and last ideas, the change here is called idea revision.

Episode 2–Group A, first idea-generation cycle

> 2.1. Student B: When I first heard the problem, I thought that the problem could be related to the issues that came out while manufacturing antibiotics. But later I learned that nothing has changed with antibiotics so far, and saw that people use them improperly or unnecessarily. What did you think when you first heard the problem [the question was directed to student D].
>
> 2.2. Student D: I thought that antibiotics could be carelessly manufactured. In the light of new information, I think antibiotics are used improperly.

The shared understanding of the problem helped the group revise ideas to better explain the problem. We interpret this action as a characteristic of epistemic agency.

Group B

Like other groups, members of group B took notes during the physician's presentation; and based on their notes and ideas shared by other groups, they proposed that antibiotics no longer work because of careless misuse of antibiotics. To test this idea, the group decided to administer a questionnaire to survey pharmacists in their town. The following excerpt presents the group's conversation that took place during questionnaire development.

Episode 3–Group B, second idea-generation cycle

> 3.1. Student H: … I propose this question: Are there any people who come to you to get antibiotics without a prescription?
>
> 3.2. Student G: How is this related to misuse of antibiotics?
>
> 3.3. Student H: If people can get antibiotics without a prescription, they might be using them for wrong diseases [student appears to refer to diseases caused by viruses].

3.4. Student F: Okay, maybe we should revise this question a bit.

3.5. Student H: How?

3.6. Student F: What about this? Is there anyone who, you know, attempts to get antibiotics without consulting doctors?

3.7. Student G: Wait. We are preparing questions to be asked to pharmacists, not to people in our near circle. Other groups do that, but we have decided to reach out to pharmacists.

3.8. Student F: You are right.

3.9. Student E: Okay, this might sound better. Are there people who would like to get antibiotics without consulting doctors?

3.10. Student G: The same thing. Attempting to get antibiotics without a prescription means that they [patients] do that without consulting doctors.

3.11. Student H: Then, can we keep my original question?

3.12. Student G: I think so.

3.13. Student F: Let's move to the next question then.

3.14. Student G: Do not forget, we will ask questions to pharmacists.

This excerpt indicates that students in group B collaboratively worked on the question proposed by student H (line 3.1) by either critiquing its appropriateness for the purpose of their research (line 3.2) or offering revisions (lines 3.6 and 3.9). It is obvious in the excerpt that student G directed the group's work by questioning how it would help them reveal misuse of antibiotics (line 3.2) and by reminding other group members of who is targeted with the questionnaire (lines 3.7 and 3.14). The student helped the group critically analyze the question by regulating or controlling the interaction among the group; therefore, we interpret the moves made by the student (lines 3.2, 3.7, and 3.14) are of regulative nature. Group members collectively constructed the questionnaire by either proposing questions or critiquing those proposed by others in the group. Critique is conceptualized as "instances of individuals challenging or evaluating some aspects of another person's argument" (Gonzalez-Howard & McNeill, 2020, p. 958), and it is considered an indication of whether students are positioned and acting with epistemic agency (Gonzalez-Howard & McNeill, 2020). Students in group B were able to challenge and then approve their peer's ideas or suggestions when constructing the questionnaire. Therefore, the group's agency is characterized by its members' involvement in the joint construction of the questionnaire as a data collection instrument.

Once group members administered the questionnaire to collect data from pharmacists, they shared their results with other groups in WISE. As illustrated in the following excerpt, the group examined responses to each question to determine whether these responses could be used to support their idea.

Episode 4–Group B, second idea-generation cycle

4.1. Student G: What was the next question?

4.2. Student E: Have you given antibiotics to people with flu?

4.3. Student G: How many pharmacists did respond to this question and say 'yes'?

4.4. Student F: Four of them said yes.

4.5. Student E: It looks this [the total number of yes in responses to the question] partially support our idea.

4.6. Student H: Yes, some pharmacists have contributed to the misuse of antibiotics.

4.7. Student E: Doctors might have prescribed antibiotic without careful examination of patients' condition.

4.8. Student G: Okay, but we cannot make sure of this until we talk to medical doctors about this possibility.

4.9. Student E: Is there any other question that we can use to support our idea?

4.10. Student F: It looks like there is one.

4.11. Student E: Which one?

4.12. Student F: Have you been asked for antibiotics by people who do not have prescriptions?

4.13. Student G: It looks like all pharmacists said yes.

4.14. Student E: Yes, this result supports our idea.

The group did not attempt to look for any alternative explanations while examining the data, but instead, group members only sought supporting evidence for their idea (line 4.5, and lines from 4.9 to 4.14). The group designed their investigation to collect supporting evidence for the current idea, which appears to have caused the group to just focus on supporting evidence. We observed the same pattern in other groups' investigation of the problem in the second idea-generation cycle. The type of data (e.g., survey data including yes/no responses to questions) and source of data (e.g., group B reached out to pharmacists; all other groups reached out to people in near circle) are very similar across all groups; and this led to lack of information diversity, which in turn appears to have resulted in lack of idea diversity across all groups. This was evident in the following idea entered to WISE by the group.

> At the end of this activity we learned that all groups' ideas are nearly the same. Therefore, even after examining other groups' ideas, we did not change our idea because the conclusion all groups reached is improper use of antibiotics.

The lack of information diversity had an impact on the complexity of the group's idea, but their decision to focus on supporting evidence when examining the data helped them advance their idea by producing a more sophisticated explanation that was consistent with scientific knowledge (Zhang et al., 2009). Thus, agency is evident in the group's capacity in seeking supporting evidence for their idea in data.

Group C

Group C's initial idea about the problem was related to hygiene conditions of the places where antibiotics are manufactured. After the physician's presentation, group members revised their idea and put forward the misuse of antibiotics as a cause of the problem. They supported this idea with the data collected from people in their near circle. They decided to extend their investigation to include pharmacists in the third idea-generation cycle. The following excerpt shows the group's research design process.

Episode 5–Group C, third idea-generation cycle

> 5.1. Student L: Now, we should decide how to test the accuracy of our current idea.
>
> 5.2. Student K: Okay, are we going to administer a questionnaire again?
>
> 5.3. Student I: We can select another method. What would be a good way to test our idea? Any thought?
>
> 5.4. Student J: We can reach out to pharmacists.
>
> 5.5. Student L: Or people in our near circle.
>
> 5.6. Student J: We already collected data from them, but reaching out to pharmacists looks better to me. Which method would be better?
>
> 5.7. Student K: We can go to pharmacies and pretend to be sick, faking flue. Then, we can ask for antibiotics.
>
> 5.8. Student I: Who will go to pharmacies and pretend to be sick?
>
> 5.9. Student K: I can go.
>
> 5.10. Student I: But, how?
>
> 5.11. Student K: One of us can go to a pharmacy and tell them something like this. "I have flu. I do not feel well. Can you give me antibiotic?" If they give me [antibiotic], we will support [our idea]; if not, we will challenge [our idea].
>
> 5.12. Student I: Okay, that sounds good.
>
> 5.13. Student K: How many people do you think we should reach out?
>
> 5.14. Student L: I believe at least three.

The excerpt above illustrates that students in Group C engaged in joint planning of the research design. They determined the method to be used in collecting data (lines from 5.1 to 5.8), from whom data are to be collected (lines from 5.3 to 5.5), and how many pharmacists would be contacted (lines 5.13 and 5.14). They collected data and shared their results with other groups in WISE. The group created a joint plan of action; and agency is evident in the group's capacity in projecting activities necessary for testing ideas. Designing research, a science practice, is considered an opportunity for epistemic agency to manifest. Engaging in science practices, such as producing data and examining it to generate evidence for an explanation of a phenomenon, positions students with epistemic agency (Miller et al., 2018). The group appeared to act with epistemic agency as they worked on ideas through engagement in the practices of scientists.

Group D

In the third idea cycle group D conducted an independent investigation to support the idea that people tend not to take antibiotics as prescribed by doctors. Students in the group collected data from pharmacists, and turned raw data into graphs to better represent the data. They examined graphs along with those shared by other groups and, as evident in the following idea entered to WISE by the group, the group did seem to be affected by the statistics shared by Group B that indicates a high-level of antibiotic consumption.

> When we reviewed the results of another group's work, we learned that 1,881,600 boxes of antibiotics were sold in our city. This number is too high and supports the idea of people's misuse of antibiotics.

As illustrated in the following excerpt, students critiqued the usefulness of their findings and realized that the findings could not be used to challenge or support their idea (lines 6.2, 6.3, and 6.4).

Episode 6–Group D, third idea-generation cycle

> 6.1. Student P: … We should speed up and finish our work. Are we now confident that our results support our idea?
>
> 6.2. Student M: Actually, we don't have any evidence to support that people are not taking a full course of antibiotics as prescribed by doctors.
>
> 6.3. Student P: You are right. But our results don't say much about it [not taking a full course of antibiotics as prescribed].
>
> 6.4. Student M: It looks like pharmacists were not the right people to check it out.
>
> 6.5. Student O: Actually, we have some results that support our idea, especially misuse of antibiotics.
>
> 6.6. Student M: Which of them?
>
> 6.7. Student O: For example, the results showing excessive use of antibiotics.
>
> 6.8. Student P: Yes, I remember antibiotic [consumption] statistics shared by another group.

6.9. Student M: Too high, isn't it?

6.10. Student P: Yes, it is too much.

6.11. Student N: Do we know our country's rank in other European countries?

6.12. Student P: As far as I remember, we had higher consumption rates, I guess third highest [consumption rate]

6.13. Student N: Too bad.

6.14. Student P: Can we use it to support our idea?

6.15. Student M: I think we are allowed to use other groups' data.

Students, then, shifted their attention to the antibiotics consumption statistics shared by another group (lines 6.5, 6.6, 6.7, and 6.8), and decided to use it to support their idea. However, the high consumption rate of antibiotics may not be an indication of misuse or overuse of antibiotics; instead, it may be related to other factors, such as high infection rates in a community. Although, the evidence the group used was not sufficient to support the idea of people's misuse of antibiotics, the teacher did not step into the discussion and purposefully avoided "right evidence talk", such as telling students what can be considered evidence to support an idea. This decision was made in line with the guidance provided by the DC that informs teachers about their roles during idea-generation cycles.

Making decisions or driving conclusions in response to critique is central to how students act with epistemic agency (Gonzalez-Howard & McNeill, 2020). To promote epistemic agency, students have a voice in the questions they pursue, the evidence they collect, and the analysis they perform without someone else attempting to fix their misconceptions or problems (Stroupe et al., 2018). Therefore, students' engagement in critique, their capacity to decide what is to be used as evidence, and their shared effort in drawing on other groups' findings appear to fall within epistemic boundaries where students are positioned as epistemic agents.

The teacher was concerned that if students were not guided by teachers, they may continue to select wrong evidence to support ideas, and this, in turn, could lead to less sophisticated scientific claims. She brought this concern to the DC's attention for discussion. The DC updated its guidance to inform teachers how to deal with such situations. The DC advised the teacher to (i) continue to invite students to generate and advance their ideas without interrupting the process during the idea-generation cycle, and (ii) address the problems observed in students' science practices between idea-generation cycles. In line with this guidance, before the fourth idea-generation cycle began, the teacher explained to the group what is counted as good evidence in supporting and advancing ideas.

Group D used findings from the third idea-generation cycle to support the idea of misuse of antibiotics; however, the group could not explain the mechanism as to how misuse of antibiotics causes the problem. In consultation with the DC, the teacher decided to shift the direction of the class by keeping the group's idea of misuse of antibiotics at the center. The teacher started the fourth idea generation cycle with the following opening statement: "Please propose any other explanation regarding why the problem has happened. Please keep in mind that we are looking for a more elaborated explanation, and so your proposal should be related to overuse of antibiotics [a form of misuse of antibiotics]". The teacher in this idea-generation cycle played a directive role to support epistemic agency at the beginning and then invited students to propose alternative explanations. However, as indicated in the following excerpt, focusing discussion on a more elaborated explanation did not appear to be effective in supporting the group's agency.

Episode 7–Group D, fourth idea-generation cycle

7.1. Student N: What could be another explanation for the problem, other than improper use of antibiotics?

7.2. Student O: Could it be giving antibiotics without a prescription?

7.3. Student M: We already talked about that. It is improper use of antibiotics.

7.4. Student O: No, we now know that people uses [antibiotics] improperly. Besides that, pharmacists appear to have given [antibiotics] without prescription.

7.5. Student M: You are right, in the first place people ask for them [antibiotics] without consulting doctors. Also, a law was enacted last year requiring pharmacists not to give antibiotics without a prescription.

7.6. Student P: I have something to say. The reason could be taking inappropriate dose of antibiotic.

7.7. Student O: Doctors do not give wrong dose [of antibiotics].

7.8. Student P: I am now just inventing. Let's say a child got sick and an antibiotic was prescribed. But she did not use it as instructed.

7.9. Student O: This is another example to improper use [of antibiotics].

7.10. Student P: They might forget taking drugs.

7.11. Student O: Still improper use of antibiotics.

7.12. Student P: Or they might not like their taste.

7.13. Student O: Taking antibiotics without consulting doctors is also improper use [of antibiotics].

7.14. Student M: I am not sure what else there is other than improper use [of antibiotics].

In previous idea-generation cycles, data collection was part of the idea investigation process, but in this cycle, students used a different strategy to come up with an alternative or more elaborated explanation about how misuse of antibiotics

Table 3. Actions emerged in groups' activities

Action	Group A	Group B	Group C	Group D
Generating new ideas	+	+	+	+
Revising ideas	+	+	+	+
Negotiating new ideas	+	+	+	
Sharing ideas (with other groups)	+	+	+	+
Sharing data/findings (with other groups)	+	+	+	+
Drawing on other groups' ideas	+	+		
Drawing on other groups' data/findings	+	+		+
Collecting additional information	+	+	+	+
Engaging in shared construction of data collection instruments	+	+	+	+
Examining research data–seeking support for ideas or being open to alternative explanations	+	+	+	+
Creating a joint plan of actions (to test ideas)	+	+	+	+

are related to the problem. Instead of collecting data to generate new ideas or advance existing ones, they proposed some ideas and had a brief discussion on each idea. Some of the ideas proposed in the excerpt above (lines 7.2 and 7.6) were put forward in previous idea-generation cycles; and only one of them was generated in this cycle (line 7.8). Using antibiotics not as instructed was a new idea; however, like others, it was considered a form of misuse of antibiotics (lines 7.3, 7.9, 7.11, and 7.13). Therefore, it was apparent that idea diversity did not emerge in Group D's discussion in this cycle. Agency is evident in the group's capacity to generate new ideas, but this capacity did not give rise to the emergence of negotiating a fit between ideas in this idea-generation cycle because of the lack of idea diversity. Grouping all ideas under the same category appeared to prevent students from identifying the most promising idea among others. Students in group D were unable to bring an alternative explanation to the problem (line 7.14); thus, it was apparent that they needed external support to get alternative perspectives.

Overall Performance of Other Groups in Problem-Solving Activities

All actions presented in **Table 2** emerged in problem-solving activities of group A and group B, whereas some of the actions did not emerge in other groups' activities (**Table 3**). Negotiating a fit between ideas and drawing on other groups' ideas are the actions that were not taken by group D. Drawing on other groups' ideas and drawing on other groups' data/findings, were the actions not evident in group C's activities.

All groups began working on the problem by generating their initial ideas, and later they revised their initial ideas in the second idea-generation cycle. After revising the initial idea in the second idea-generation cycle, group D appeared to support the revised idea throughout the project without considering alternative or more inclusive explanations for the problem they worked on. The group also did not attempt to examine and draw on other groups' ideas. Group D used other groups' research findings in the event that findings had potential to support the group's idea. On the other hand, other groups revised their initial ideas and worked on ways to improve them. They examined ideas shared by other groups. Group A and group B drew on other groups' ideas to test or improve their ideas, whereas group C did not take others' ideas into account while seeking a deeper explanation for the problem.

DISCUSSION

The purpose of this study was to explore epistemic agency that emerged in the context of collaborative problem-solving activities of middle school students. Collaborative actions taken toward generating and advancing ideas were the focus of the current study in identifying dimensions of epistemic agency in a middle school context. Eleven actions of epistemic nature were identified in this study.

Epistemic Actions

Groups began working on the problem by proposing ideas that could explain the source of the problem. All groups continued to work on ideas until the end of the semester when the project was implemented. As stated by Scardamalia and Bereiter (2006), ideas are considered as real things that can interact with one another to generate new or more complex ideas. Setting forth an idea, interacting with ideas of other group members, and deciding which idea was more promising was one way in which the groups generated ideas. Once groups proposed their own ideas, they examined ideas arising from other groups and negotiated a fit between those ideas to decide whether their own groups' ideas subsumed, contradicted, or related to other groups' ideas. This decision-making process resulted in promisingness judgments (i.e., evaluating the promisingness of ideas) that has an important role in supporting student agency (Chen et al., 2015).

Three groups demonstrated advancement in the quality of explanations over time. Giving groups an opportunity to continuously work on ideas with the motivation of making them more inclusive and subjecting them to testing in a systematic way resulted in idea improvement. However, an unforeseen challenge arose during the implementation of *investigate idea, revise/improve idea, reflect on idea* pattern. In two consequent idea-generation cycles, group B attempted to generate supporting evidence for the same idea without seeking a more comprehensive explanation. We expected that with the implementation of the instructional pattern students could justify their new ideas first and then work on them to generate more inclusive explanations. However, group B just reached findings in the third idea-generation cycle that confirmed the idea already supported in the second cycle. This appears to have caused the group to retain the same idea without adding sufficient details to its content in the third cycle. Students in group B engaged in testing, evaluating, challenging, or supporting new ideas to justify them, which are

the range of activities that promote *justification mode* of *thinking* that characterizes activities concerned with questioning, accepting, or rejecting knowledge claims (Scardamalia & Bereiter, 2016). The group's discourse appeared to act as a critical filter to justify ideas by showing whether or not they are actually true. One potential reason as to why the group could not go beyond evaluating ideas and search for better explanations for the problem could be how science learning normally takes place in that particular context. In science classes, teachers propose ideas, and activities are designed to guide students to conduct investigations to evaluate the ideas, which subsequently have students access "correct" canonical information. This is what students were used to at the time of the study, which appears to have had an impact on their thinking in this study. Although the group made their own decisions about how to work with their ideas, the tendency to seek supporting evidence for ideas but not look for a more comprehensive explanation limited their ability to advance ideas, and so their capacity to act with epistemic agency.

Sharing ideas with other groups, negotiating a fit between ideas, and drawing on ideas shared by other groups were the actions of epistemic nature that supported idea generation. These epistemic actions are convergent with activities denoted by Bielaczyc et al. (2013), Damşa et al. (2010), and Scardamalia and Bereiter (2006). For example, Bielaczyc et al. (2013) identified similar activities performed by students to examine collection of ideas and exchange ideas with others, which refers to the actions performed by the groups in the current study to share ideas with other groups and examine ideas arising from other groups. Additionally, Stroupe (2014) observed some actions that emerged in a learning environment where students acted as epistemic agents and placed their science ideas as central to the classroom science practice community. Among those actions, integrating science ideas with other ideas and introducing new science ideas on the public plane are actions similar to the following actions that emerged in the current study: negotiating fit between ideas and sharing ideas with other groups.

Sharing ideas with other groups is an important action that results in idea diversity. As Scardamalia (2002) stated, idea diversity plays a prominent role in the development of knowledge advancement. Having access to a diversity of ideas provides all groups with an opportunity to understand the connection of their own ideas to the ones posed by other groups, which allows ideas to evolve into new forms (Scardamalia & Bereiter, 2010). The current study showed that when groups had an opportunity to make their own decisions on how to draw on other ideas, they could capitalize on other ideas in multiple ways. For example, some groups used another group's idea to support or revise their own idea, while other groups ignored additional ideas if it involved a deeper explanation. In general, it appears that being able to access other groups' ideas may help groups to advance their ideas. In addition, we find it important to note that all groups appeared to be open and willing to draw on other groups' findings to support their own ideas. It seems that groups did not value other groups' interpretations of research findings all the time, but that once they examined actual data shared by other groups and made their own interpretations, they evaluated whether findings could be used to support their own ideas. These findings suggest the integration of instructional tools in the context that can assist students to share not only their ideas but also their research findings with others.

In the current study, groups did not follow predetermined scripts of searching and gathering information, but instead, they decided what type of information they needed and how to access that information. They began the data collection process by constructing data collection instruments. After groups constructed a data collection instrument, they gathered and examined data to gain insights into their existing ideas. Engaging in shared construction of data collection instruments, collecting additional information (or data), and examining research data were the actions performed by groups to support or challenge existing ideas. These types of actions were also indicated in Damşa et al.'s (2010) study. Throughout the project, groups used two main data collection methods, namely administering questionnaires and conducting interviews. Groups were aware of these two data collection methods because they had been used in classes to gather data from scientists or experts in order to reproduce canonical information that teachers thought was important. For example, Group D used questionnaires and interviews to collect data from physicians and pharmacists, which is a common strategy employed by teachers in this context to invite views of other authorities, such as visiting scientists, to the classroom. It appears that students' repertoire of data collection methods was limited to the methods privileged by their teachers, which had an impact on students' capacity to enact science practices with agency. It is possible to argue that because students lack particular knowledge, they should be taught science practices before they are encouraged to enact the practices with agency. It is also argued that putting off engaging students with agency until later in schooling may seem reasonable and less challenging for teachers and designers, but that students may not want to exercise agency when it is redistributed to them later in schooling after they have appropriate foundational knowledge (Miller et al., 2018). Groups in our study were able to transfer and employ methods privileged by teachers in other classes, which suggests that a "putting off until later" approach may not be necessary because students can adopt methods or any other forms of knowledge into their practice even though they acquire them in the classroom where teachers retain agency. The question is how students can be taught the knowledge and skills they need while staying within the epistemic boundary where students engage in disciplinary practices with agency. Zhang et al. (2007) suggests the use of authoritative sources (e.g., textbooks, experts and teachers) in a constructive way for continual meaning making. It is difficult to function in a society without benefiting from the large amount of information on authority (Scardamalia & Bereiter, 2006), and so authoritative sources are necessary for effective science meaning making (Yeo & Tan, 2010). As noted by Yeo and Tan (2010), there is a place for teacher's authoritative voice in constructivist classrooms, but it should be used in directing students' attention to important knowledge that was overlooked instead of transmitting the knowledge found in textbooks and reference materials. Once students are made aware of alternative authoritative sources, the decision about

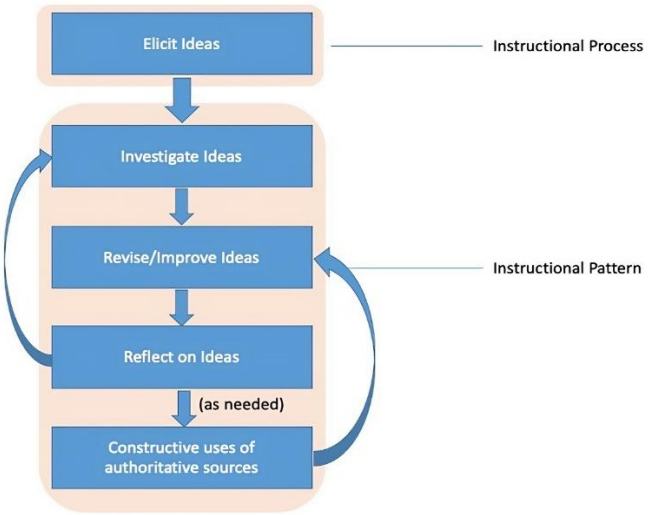

Figure 2. Revised instructional process/pattern (Source: Authors' own elaboration)

how these sources are connected to the problem context are left to students. In line with this stance, we revised the instructional pattern implemented in this study by adding "constructive use of authoritative sources" as an instructional process (**Figure 2**). We suggest the implementation of the revised instructional pattern to support continual idea improvement.

Collaboration was at the center of all activities mentioned above, which fostered epistemic agency in the groups' problem-solving activities. Epistemic agency is fostered by enhancing interaction or dialogue between peers (Scardamalia & Bereiter, 2003). In the current study, members of each group collaboratively worked to generate ideas and collect additional information to support those ideas. In addition to the collaborative work that took place within groups, the creation of shared understanding was also supported with interactions between groups. Groups shared information with other groups, examined information shared by other groups and decided what information could be used to support or challenge their existing ideas. Once they revised or improved their ideas, they shared their most current ideas with other groups and examined ideas arising from other groups to see if there were any other ideas that they could draw on. These types of epistemic actions are convergent with the activities indicated by Zhao and Chan (2014) such as providing other groups with useful information for project work and examining information from different perspectives to advance collective understanding. As explained by Arvaja (2010), collaboration includes both productive interaction among individuals and willingness to act as a resource for one another. In the current study, groups interacted with each other, and they acted as a resource for one another by sharing data/findings and ideas, which established a basis for the collaborative creation of knowledge.

Implications

In a system dominated by a focus on achieving learning outcomes, carving out a space for epistemic agency is a complex and challenging task that is impacted by contextual factors. In the context of our study, teachers in math classes believed that for students to achieve learning goals, teaching should focus on communicating knowledge in a structured way, giving students clear problems or examples and explaining correct solutions. On the other hand, science teachers were more open to the idea of facilitating student inquiry in the classroom. Because of teachers' differing beliefs about student learning, the school administration, in consultation with the researchers, decided to utilize science classes as a space where agency is transferred to students and to position other classes as a space where teachers retain agency, and students are taught knowledge they need to pursue the project. This strategy helped the school navigate the differing beliefs teachers hold about student learning while providing students with opportunities to act with epistemic agency. The design committee (DC) had an important role in the success of this strategy. It monitored the process taking place in science classes and made moment-to-moment decisions about how to respond to students' ideas about where to go next and what kind of support they would need to pursue the project. Our implementation suggests that the process of understanding teachers' belief about student learning, forming a design group representing differing beliefs, and tasking it with monitoring the implementation process creates opportunities for teachers to discuss how agency can be redistributed to students.

In our study, teachers were under the pressure of meeting curricular requirements and preparing students for high-stake exams, and so they were concerned about the time they had to spend on our implementation. Tasking the DC with dealing with all logistics students need to pursue the project helped science teachers save time. In addition, the school administration was able to repurpose time for this project that was normally used for the afterschool extended learning program. This is a temporary solution that can work for a small number of projects occurring simultaneously in schools with no staffing shortage. A better solution would be needed in our study context as the number of projects implemented to enact epistemic agency increases, especially when facing the reality of operating in an educational system dominated by high-stakes assessment.

One implication of this research is that it is possible to integrate inquiry-based activities designed to transfer epistemic agency from teachers to students within very different cultural and educational contexts with appropriate planning and using a combination of diverse tools. Our research also indicates that students in this specific context benefited from this integration; despite being new to inquiry-based learning and the tools and guidance, students were able to propose ideas to solve the problem, generate new ideas, create a joint plan action to test ideas, collect and examine data, share their findings with others, and draw on others' findings and ideas while constructing better explanations towards the problem. One general implication for teachers who work in a context similar to our own is to give more extensive consideration to the actions that emerged in the study while designing learning activities. A key focus in the study was on actions indicative of epistemic agency in a middle school context. While students perform these actions in a learning environment, the focus is primarily on the end result produced by those actions (i.e., idea advancement) rather than

the action itself. Because of outcome or end-product oriented assessment systems in schools, it is not surprising that epistemic actions that helped with development of final products are given little consideration. With this in mind, it might be helpful for teachers in a similar context to think more extensively about ways that encourage students to perform such actions so that they can act as epistemic agents. For example, the actions that emerged in the study, such as sharing ideas, can be placed at the center of the process of selecting learning technologies. Emerging technologies whose affordances support the emergence of those actions can be integrated into learning activities in a similar context. For instance, K-12 social learning platforms can be used for supporting collaboration within and between groups, blogging platforms can be used for making ideas available to others, and RSS feeds can be used for easily viewing other groups' ideas.

In addition to sharing ideas, groups acted as a resource for one another by sharing data/findings, which was supported by the learning technology used in the study. Our study showed that groups drew on other groups' findings to support or challenge their ideas, which we found very crucial to enhance epistemic agency in the classroom. A second implication for teachers in a similar context is to create a classroom culture that encourages students to value other students' work, elevate their ideas/research findings to the public plane, and draw on other groups' findings. Teachers can use tools such as those offered by WISE to share all groups' findings with everyone in the classroom and create activity steps that guide students to go through all findings/ideas presented in the public plane, assign values to findings/ideas, and select more promising ideas for their project. This type of guidance may limit groups' agency in the first place; but, teachers can fade out some activity steps over time, and gradually transfer agency to groups.

Teachers who are willing to experiment can take advantage of the multiple existing platforms (such as WISE and Knowledge Forum) to support their design efforts. We recommend teachers partner with technology coaches or other supports to explore these options as they offer multiple design and implementation combinations. As well, teachers can make sure to design learning activities to make space for the emergence of these activities. For example, adding time at the end of every phase of an activity for groups and individuals to pause, consider feedback and revise their course of action or thinking as needed may be more conducive to shared epistemic agency. The current study showed that having this space was useful to reflect groups' decisions to the design of classroom activities and to create an environment in which groups can act as epistemic agents.

This study suggests a general implication for further research. First, productive participation in joint meaning-making discourse is seen as a prerequisite for shared understanding to occur among people. According to Damșa (2014), in addition to joint actions contributing to shared goals, the emergence of actions directed towards the construction and progress of knowledge objects is also crucial for productive interaction to occur. In this study the focus was on joint actions performed by the groups. The actions indicative of epistemic agency that emerged in the groups' problem-solving activities were explored. However, actions important for idea improvement or advancement were not specifically investigated in the study. Identifying key actions that trigger subsequent actions and lead to idea improvement helps us understand what types of interactions exist between actions. Being able to establish such links between actions would provide a better understanding of the groups' dynamics and their effect on individual gains or performances in idea improvement. According to Stahl (2015), a group's understanding may be different from any individual member's understanding when not interacting within the group. Unfortunately, our analysis results do not allow for understanding of interaction patterns among group members. Therefore, (i) interaction patterns among group members, and (ii) key actions that trigger subsequent actions should be further investigated. Second, the analysis of group B's discourse revealed that the group's discourse acted as a critical filter to justify ideas whether they are true or not. However, acting with epistemic agency requires students to not only evaluate ideas but also work with them in design mode of thinking that characterizes activities concerned with exploring the idea landscape, crisscrossing it in multiple directions, identifying promising ideas, and continuously searching for a better way of doing things and for better explanations. In addition to opening up space for students to direct their idea generation process, teachers may have to adopt a broad range of activities to be carried out in design mode. There is an important line between teachers' involvement in guiding students to continuously improve the quality of their ideas or explanations and ensuring that students have decision making power about the direction and conclusions of their sensemaking. Navigating this line can create a teaching tension. Potential ways to navigate the line without creating the tension should be investigated by future studies.

Our study contributes to the literature by enhancing understanding of patterns of epistemic actions that can be performed by a group of students in a formal middle school setting. This study also enhances the theoretical construct of epistemic agency by adding the following actions of epistemic nature evident in a group of middle schoolers' collaborative problem-solving activities: drawing on other groups' ideas, drawing on other groups' data/findings, and examining research data–seeking support for ideas or being open to alternative explanations.

Nevertheless, the interpretation of the findings in this study is subject to some limitations. First, because of its qualitative nature, a small number of students participated in the study that did not seek to generalize findings. Second, the study was conducted in a real classroom; thus, many confounding factors (e.g., prior academic achievements, genders, and group composition) could not be controlled. Third, our analysis heavily relied on transcribed data from audio recordings as we had limited video recordings.

Author contributions: All authors have sufficiently contributed to the study and agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Ethical statement: Authors stated that the study was approved by the IRB at Penn State University on May 18, 2015.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Alzen, J. L., Edwards, K., Penuel, W. R., Reiser, B. J., Passmore, C., Griesemer, C., Zivic, A., & Murzynski, C. (2020). Exploring the connections between epistemic agency and a commitment to the collective enterprise of sensemaking in the science classroom. In M. Gresalfi, & I. S. Horn (Eds.), *The interdisciplinarity of the learning sciences* (pp. 1879-1886). International Society of the Learning Sciences.

Arvaja, M. (2010). Building understanding of the philosophy of science through immediate and mediated resources. In L. Dirckinck-Holmfeld, V. Hodgson, C. Jones, M. de Laat, D. McConnell, & T. Ryberg (Eds.), *Proceedings of the 7th International Conference on Networked Learning 2010* (pp. 27-34). University of Lancaster.

Baines, E., Blatchford, P., & Chowne, A. (2007). Improving the effectiveness of collaborative group work in primary schools: Effects on science attainment. *British Educational Research Journal, 33*(5), 663-680. https://doi.org/10.1080/01411920701582231

Belland, B. R., Gu, J., Kim, N. J., Jaden Turner, D., & Mark Weiss, D. (2019). Exploring epistemological approaches and beliefs of middle school students in problem-based learning. *The Journal of Educational Research, 112*(6), 643-655. https://doi.org/10.1080/00220671.2019.1650701

Bereiter, C., & Scardamalia, M. (1992). Two models of classroom learning using a communal database. In S. Dijkstra, H. P. M. Krammer, & J. J. G. van Merrienboer (Eds.), *Instructional models in computer-based learning environments* (pp. 229-241). Springer. https://doi.org/10.1007/978-3-662-02840-7_14

Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching, 53*(7), 1082-1112. https://doi.org/10.1002/tea.21257

Bielaczyc, K., Kapur, M., & Collins, A. (2013). Cultivating a community of learners in K-12 classrooms. In C. E. Hmelo-Silver, A. M. O'Donnell, C. Chan, & C. A. Chinn (Eds.), *International handbook of collaborative learning* (pp. 233-249). Routledge. https://doi.org/10.4324/9780203837290.ch13

Carlone, H. B., Mercier, A. K., & Metzger, S. R. (2021). The production of epistemic culture and agency during a first-grade engineering design unit in an urban emergent school. *Journal of Pre-College Engineering Education Research, 11*(1), 10. https://doi.org/10.7771/2157-9288.1295

Chan, C., & van Aalst, J. (2015) Knowledge-building communities. In R. Gunstone (Ed.), *Encyclopedia of science education* (pp. 553-557). Springer. https://doi.org/10.1007/978-94-007-2150-0_54

Chen, B., Scardamalia, M., & Bereiter, C. (2015). Advancing knowledge-building discourse through judgments of promising ideas. *International Journal of Computer-Supported Collaborative Learning, 10*(4), 345-366. https://doi.org/10.1007/s11412-015-9225-z

Creswell, J. W. (2007). *Qualitative inquiry and research design: Choosing among five approaches*. SAGE.

Damşa, C. I. (2014). The multi-layered nature of small-group learning: Productive interactions in object-oriented collaboration. *International Journal of Computer-Supported Collaborative Learning, 9*(3), 247-281. https://doi.org/10.1007/s11412-014-9193-8

Damşa, C. I., Kirschner, P. A., Andriessen, J. E., Erkens, G., & Sins, P. H. (2010). Shared epistemic agency: An empirical study of an emergent construct. *The Journal of the Learning Sciences, 19*(2), 143-186. https://doi.org/10.1080/10508401003708381

Engeström, Y. (1987). *Learning by expending: An activity–theoretical approach to developmental research*. Orienta-Konsultit.

Glaser, B. (1978). *Theoretical sensitivity*. Sociology Press.

Gonzalez-Howard, M., & McNeill, K. L. (2020). Acting with epistemic agency: Characterizing student critique during argumentation discussions. *Science Education, 104*(6), 953-982. https://doi.org/10.1002/sce.21592

Hewitt, J., & Scardamalia, M. (1998). Design principles for the support of distributed processes. *Educational Psychology Review, 10*(1), 75-95. https://doi.org/10.1023/a:1022810231840

Ko, M. L. M., & Krist, C. (2019). Opening up curricula to redistribute epistemic agency: A framework for supporting science teaching. *Science Education, 103*(4), 979-1010. https://doi.org/10.1002/sce.21511

Lai, K. W., & Campbell, M. (2018). Developing secondary students' epistemic agency in a knowledge-building community. *Technology, Pedagogy and Education, 27*(1), 69-83. https://doi.org/10.1080/1475939x.2017.1369150

Linn, M. C., & Eylon, B.-S. (2011). *Science learning and instruction: Taking advantage of technology to promote knowledge integration*. Routledge. https://doi.org/10.4324/9780203806524

Linn, M. C., Davis, E. A., & Eylon, B. (2004). The scaffolded knowledge integration framework for instruction. In M. C. Linn, E. A. Davis, & P. Bell (Eds.), *Internet environments for science education* (pp. 47-72). Lawrence Erlbaum Associates. https://doi.org/10.4324/9781410610393-10

Maxwell, J. A. (2013). *Qualitative research design: An interactive approach*. SAGE.

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *Journal of Research in Science Teaching, 55*(7), 1053-1075. https://doi.org/10.1002/tea.21459

Mortimer, E. F., & Scott, P. H. (2003). *Meaning making in secondary science classrooms*. Open University Press.

Scardamalia, M. (2000). Social and technological innovations for a knowledge society. *Proceedings of the ICCE/ICCAI, 1*, 22-27.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.), *Liberal education in a knowledge society* (pp. 67-98). Open Court.

Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *The Journal of the Learning Sciences, 1*(1), 37-68. https://doi.org/10.1207/s15327809jls0101_3

Scardamalia, M., & Bereiter, C. (2003). Knowledge building. In *Encyclopedia of education* (pp. 1370-1373). Macmillan Reference.

Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. In K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 97-118). Cambridge University Press. https://doi.org/10.1017/cbo9780511816833.008

Scardamalia, M., & Bereiter, C. (2010). A brief history of knowledge building. *Canadian Journal of Learning and Technology, 37*(1), 1-16. https://doi.org/10.21432/t2859m

Scardamalia, M., & Bereiter, C. (2016). Creating, criss-crossing, and rising above idea landscapes. In R. H. Huang, Kinshuk, & J. K. Price (Eds.), *ICT in education in global context: Comparative reports of K-12 schools innovation* (pp. 3-17). Springer-Verlag. https://doi.org/10.1007/978-3-662-47956-8_1

Scardamalia, M., Bereiter, C., Mclean, R. S., Swallow, J., & Woodruff, E. (1989). Computer-supported intentional learning environments. *Journal of Educational Computing Research, 5*(1), 51-68. https://doi.org/10.2190/cyxd-6xg4-ufn5-yfb0

Stahl, G. (2015). Conceptualizing the intersubjective group. *International Journal of Computer-Supported Collaborative Learning, 10*(3), 209-217. https://doi.org/10.1007/s11412-015-9220-4

Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education, 98*(3), 487-516. https://doi.org/10.1002/sce.21112

Stroupe, D., Caballero, M. D., & White, P. (2018). Fostering students' epistemic agency through the co-configuration of moth research. *Science Education, 102*(6), 1176-1200. https://doi.org/10.1002/sce.21469

Tan, S. C., Wang, X., & Li, L. (2022). The development trajectory of shared epistemic agency in online collaborative learning: A study combing network analysis and sequential analysis. *Journal of Educational Computing Research, 59*(8), 1655-1681. https://doi.org/10.1177/0735633121100156 2

van Lier, L. (2008). Agency in the classroom. In J. P. Lantolf, & M. E. Poehner (Eds.), *Sociocultural theory and the teaching of second languages* (pp. 163-186). Equinox.

Varelas, M., Tucker-Raymond, E., & Richards, K. (2015). A structure-agency perspective on young children's engagement in school science: Carlos's performance and narrative. *Journal of Research in Science Teaching, 52*(4), 516-529. https://doi.org/10.1002/tea.21211

Yeo, J., & Tan, S. C. (2010). Constructive use of authoritative sources in science meaning-making. *International Journal of Science Education, 32*(13), 1739-1754. https://doi.org/10.1080/09500690903199564

Zhang, J., Scardamalia, M., Lamon, M., Messina, R., & Reeve, R. (2007). Socio-cognitive dynamics of knowledge building in the work of 9- and 10-year-olds. *Educational Technology, Research and Development, 55*(2), 117-145. https://doi.org/10.1007/s11423-006-9019-0

Zhang, J., Scardamalia, M., Reeve, R., & Messina, R. (2009). Designs for collective cognitive responsibility in knowledge-building communities. *The Journal of the Learning Sciences, 18*(1), 7-44. https://doi.org/10.1080/10508400802581676

Zhao, K., & Chan, C. K. (2014). Fostering collective and individual learning through knowledge building. *International Journal of Computer-Supported Collaborative Learning, 9*(1), 63-95. https://doi.org/10.1007/s11412-013-9188-x

Zivic, A., Smith, J. F., Reiser, B., Edwards, K., Novak, M., & McGill, T. (2018). Negotiating epistemic agency and target learning goals: Supporting coherence from the students' perspective. In *ICLS Proceedings* (pp. 25-32).