Exploring Pedagogical Strategies for Promoting Student Epistemic Agency through the Transfer of Cognitive Authority in an Online Science Class

Jooeun Shim, Noora F. Noushad, Susan A. Yoon
jshim@upenn.edu, noora@upenn.edu, yoonsa@upenn.edu
University of Pennsylvania

Abstract: Promoting epistemic agency in science classrooms benefits student learning. One critical variable in the development of epistemic agency is the activation of intrinsic motivation that can happen when cognitive authority is shared between teachers and students. With the recent pivot to online teaching, opportunities to engage in such learning environments have been challenging using online platforms. We investigate one teacher's implementation of a science unit that was delivered online. While the unit was specifically constructed to build epistemic agency with students in in-person classes, using various instructional design choices, this teacher was able to cede cognitive authority over to his students by engaging them in activities that improved intrinsic motivation. We describe those choices, such as, using unmonitored scaffolds to enable student autonomy, and leveraging familiarity with their local context through peer-led collaborations. We then discuss implications for this research in support of better learning and engagement in online environments.

Keywords: Epistemic agency, online synchronous instruction, self-determination theory, online science class, computer-supported collaborative learning, COVID-19

Introduction

Promoting student agency has been identified as an important precursor to activating intrinsic motivation and fostering students' deeper engagement with learning (Miller et al., 2018). In science classrooms, fostering student agency enables students to actively participate in decision-making roles during the production and use of scientific knowledge inside and outside classrooms (Ballard et al., 2017; Miller et al., 2018). When students engage with epistemic agency, they display ownership of the knowledge-building process and share the cognitive authority with teachers with respect to directing science inquiry (Hardy et al., 2020; Miller et al., 2018; Stroupe et al., 2018). Furthermore, when epistemic agency is supported, it propels a shift from students mimicking "correct" canonical science information to adopting strategies that empower them to develop their own ideas (Hardy et al., 2020; Miller et al., 2018; Stroupe et al., 2018). This helps fulfill the larger need of engaging students in disciplinary practices as advocated by the Next Generation Science Standards (NGSS) (NRC, 2012).

In terms of mechanisms that can promote epistemic agency, some researchers have highlighted the importance of attending to the elements of intrinsic motivation, such as those components in Deci & Ryan's (2004) Self-Determination Theory (SDT), i.e., students need to be provided autonomy in their choices; they need to experience competence in their mastery of knowledge; and they need to feel a sense of relatedness through interactions with others. Furthermore, studies have found that students engage with epistemic agency when they contribute to the knowledge-building process through practices such as argumentation and experimentation, as opposed to simply replicating the practices modeled by the teacher (Haverly et al., 2020; Zimmerman et al., 2018). However, the success of these models is largely dependent on the teacher's instruction and the space the teacher provides for students to negotiate ownership of ideas by relinquishing some of the teacher's cognitive authority (Haverly et al., 2020; Stroupe et al., 2018). Enabling epistemic agency and transferring of cognitive authority has been especially difficult due to the recent pivot to online environments, caused by the COVID pandemic, that has resulted in increased teacher-centered instruction through lectures and individual work and a decrease in collaborative student activities (Means & Neisler, 2021). Furthermore, global reports have revealed that since the pivot, teachers have experienced challenges in a number of ways including capturing and maintaining student attention and creating engaging learning tasks (Chiu, 2021; UNESCO, 2020).

One way to address these challenges is through the construction of knowledge-building communities, such as Knowledge Forum, that provide teachers with computer-supported collaborative platforms with built in cognitive scaffolds that simultaneously reduce a teacher's cognitive authority while supporting students to build epistemic agency (Miller et al., 2018; Scardamalia, 2002). However, the adoption of such knowledge-building platforms in schools has been limited due to their inherent reliance on specialized technologies and professional development (PD) to understand how to implement the tools and pedagogies (Scardamalia & Bereiter, 2021). Given that teachers had no time and little PD to make the pivot to online instruction, they needed to make do with what was available to them, which was most commonly Zoom or Google Classrooms (Means & Neisler, 2021). Our paper explores how epistemic agency in online instruction can be supported without specialized tools and pedagogies. Using the lenses of three degrees of distribution of epistemic authorities (Haverly, 2020) and SDT, we examine how one teacher implemented a problem-based learning unit both in-person before the pandemic and then online during the pandemic using Zoom and Google Classroom, illustrating how epistemic agency and cognitive authority was enabled in the different modalities. We ask the following research questions: 1) How did the teacher adapt in-person units to retain instructional strategies that promoted student's epistemic agency in an online class? 2) What factors led students to engage actively with the opportunities created for epistemic agency by the teacher?

Conceptual Framework

Teaching for epistemic agency

Recent science education studies have found that any learning environment that can support the development of epistemic agency should be contextualized in ways that value students' ideas as resources in producing useful knowledge in the curriculum (Stroupe et al., 2018; Schwartz et al., 2018). This kind of teaching requires pedagogical strategies that leverage students' ideas for a knowledge production process within classrooms and activate student's intrinsic motivation (Brown, 2017; Miller et al., 2018). One of the important teaching characteristics that relates to epistemic agency is the emphasis on a student's cognitive authority over what counts as knowledge within an activity (Erikson & Lindberg, 2016; Haverly et al., 2020). This kind of teaching requires teachers to notice students' "status and positioning" in groups as well as their "individual student histories" inside and outside of class (van Es et al., 2017, p. 266). Teachers must be disposed to notice such nuances within the classroom (Hand, 2012). For example, Miller et al. (2018) detail four opportunities to unpack epistemic agency within the NGSS and argue for these to be specified in the design of the lesson to provide opportunities: 1) to solicit and build on student knowledge as a resource for learning; 2) for students to build knowledge; 3) for students to build a knowledge product that is useful to them; and 4) to change structures that constrain and support action. Likewise, Stroupe et al. (2018) recommend an instructional model, where the cognitive authority is constantly negotiated between students and teachers. Teachers give cognitive authority to students by enabling them to frame arguments and allowing them to evaluate the efficiency of methods employed by the teacher.

Depending on the degree of shared cognitive authority, instructional strategies can be conceptualized across three degrees of distribution of epistemic authorities; (a) co-constructed practices where the teacher and students share epistemic authority, (b) teacher-constructed practices where the teacher retains epistemic authority, or (c) student-constructed practices where epistemic authority shifts entirely to students (Haverly, 2020; Scardamalia, 2002). Teachers use different instructional strategies depending on the degree of epistemic authority they choose to distribute or retain in classrooms (Haverly et al., 2020). For instance, teachers who intentionally share (i.e., co-construct) epistemic authority with students will create more opportunities for students to share their understanding and leverage these responses to direct thinking (González-Howard & McNeill, 2020; Haverly et al., 2020). They will also distribute the teaching authority by referring student questions to their peers instead of being the primary person who validates understanding inside classrooms. Conversely, teachers who retain epistemic authority (i.e., use teacher construct practices) might reign control over the thinking being developed in class by using teacher-centered scaffolds such as modelling, asking close-ended questions or leading students to an answer that the teacher has decided is the right one (Schoerning et al. 2015; Erikson & Lindberg, 2016). In classrooms that employ student-constructed pedagogical practices, where the epistemic authority completely shifts to students, is limited within existing literature in formal science classrooms (Haverly et al., 2020; Stroupe, 2014).

The pedagogical recommendations for co-constructed and student constructed strategies are difficult to implement in online settings due to a lack of control over instructional materials, challenges in monitoring student engagement, little flexible pacing support as students perform, and few opportunities to provide emotional support because of a lack of in-person interaction (Carter et al., 2020). Consequently, these limitations make it difficult to activate students' intrinsic motivation and to have them develop epistemic agency (Deci & Ryan, 2020). In this study, we use the three degrees of epistemic authority to identify the instructional moves adopted by Eric (the focal teacher in our study) to create opportunities for students to participate in his online class. We then use the three aspects of SDT, detailed below, to identify how students became intrinsically motivated to respond positively to the opportunities created by Eric.

Self-determination theory

Self-Determination Theory is a theory of motivation which asserts that people constantly integrate internal and external information to persist in completing activities based on three psychological factors: Autonomy, Relatedness, and Competence. (Deci & Ryan, 2004). *Autonomy* is defined as a need to feel in control of one's own behaviors and goals. *Competence* is defined as the need to gain mastery over knowledge and skills. When students feel that they have the skills needed for success, they are more likely to take action that will help them achieve their goals. *Relatedness* is defined as a desire to feel connected to others. This is about a personal need to experience a sense of belonging and attachment to other peers. According to the theory, these three needs can be satisfied when one identifies personal goals, feels empowered in their own learning, and receives appropriate guidance and competence-relevant feedback (Chiu, 2021; Van Petegem et al., 2011). Also, research has shown that meeting these needs can positively influence an individual's engagement and critical thinking (Taylor et al., 2014).

To develop these needs in the classroom, as expected, teachers play a pivotal role. In classrooms where teachers are able to create opportunities for students to direct their own learning, students demonstrate increased motivation to learn and take action (Ahn et al., 2021; Roth et al., 2007). Furthermore, the mechanisms that support this improved motivation are related to different aspects of student learning and engagement. Perceived relatedness has been shown to be a primary predictor of student engagement; perceived competence has been shown to be the most important predictor of cognitive engagement; and finally, perceived autonomy has been shown to be a significant factor in student engagement (Chiu, 2021). However, according to Lam et al. (2009), most K-12 students have fewer autonomy needs and more relatedness needs when learning online because the space is less supervised and often lacks human interaction. Although studies have shown that the teachers' role and pedagogies are critical to enhance student motivation, there has been limited studies that focus on how instructional practices foster intrinsic motivation to undertake complex tasks, such as for problem-based learning (Jeong et al., 2019).

Methodology

Context

This study is part of a larger project aimed at constructing curriculum that integrates bioinformatics concepts into the high school biology classroom through a problem-based learning unit that was designed to be implemented as an in-person curriculum in 2019 that spanned approximately 20 hours of instruction. The curriculum consisted of three parts: In the first part (6 hours), students explored the issue of high asthma rates in their local community due to low air quality in urban cities. In the second part (8 hours), students are provided with sensors and phones to measure air quality in different locations of their community and asked to analyze the data using Google Sheets. In the third part (6 hours), based on an analysis of collected data, students are asked to design interventions to address the air quality issue in their neighborhood. Due to the pandemic in 2020, teachers had to revise the in-person curriculum designed for student mobility and collaboration in a physical space to be delivered online.

Teacher and student participants

We study one teacher named Eric who was nominated as an expert teacher by the director of science in the school district. When he joined the teacher PD workshop in July 2019, he had 15 years of teaching experience and was a biology teacher in a public magnet school in the northeastern U.S. During his second year with the project, he partnered with our research team as a design collaborator to revise the PD and bioinformatics curriculum. He participated in the PD in July 2020 as a teacher facilitator whose role was to support the next cohort of teachers. Eric taught 9th-grade biology in both year 1 and 2. Eric implemented the first iteration in-person where we observed ways in which he was successful in activating students' epistemic agency by employing teacher co-constructed strategies (Noushad et al., 2021). In the second iteration, Eric pivoted the classes online due to the pandemic. In this paper, we focus mainly on the second-year iteration. This class consisted of 20 students (11 female, 9 male), who self-reported to be 30% White, 20% African American, 15% Asian or Pacific Islander, 30% others or multiple ethnicities, and 5% Latinx. The classes were hosted on Zoom. The implementation ran across approximately 22.7 hours and students logged in from various locations in and around the States.

Data sources and analysis

We collected and analyzed three data sources: online class recordings, classroom observation notes, and student focus group interviews. Eric's synchronous online class was observed 11 times, each observation lasting 60 minutes on average (ranging between 39 - 106 minutes, including double periods). Observations included a description of the classroom context and reports of the instruction and activities taking place, including the types of instruction and the teachers' strategies to support students' epistemic agency. Finally, we interviewed four students in his class where we probed their experiences with the curriculum and the online synchronous sessions. Students were interviewed four times throughout the unit to capture their understanding of the content and learning experiences as they emerged over time. The interviews lasted 20 minutes on average (ranging between 14 - 43 minutes).

To analyze the data, the online classroom recordings from the second year and the in-person implementation from the first year were organized to group instances that were reflective of Miller et al.'s (2018) epistemic opportunities which were built into the in-person curriculum. These recordings were examined to observe the changes made by Eric. Additionally, classroom observation notes were reviewed to understand the rationale behind the changes he made. This transcribed data was then deductively coded to identify instances of teacher constructed strategies, co-constructed strategies, and student constructed strategies (Haverly, 2020). They were then qualitatively coded separately by the first two authors. Any discrepancies that occurred were negotiated until consensus on the codes were reached. For example, the excerpts below from Eric's in-person implementation and online implementation were coded differently. During an investigation planning activity, in the in-person class Eric says "So if you look up at the classroom, spreadsheet your group ideas here, research questions, data collection time, locations, and link to put to the map. I need this before I let you get out tomorrow." This was coded as a co-constructed strategy because he provided students with choices in selecting the context of data collection and identifying investigation questions, but he retained the ultimate authority when students asked him for permission to pursue the investigation. However, in the online class, Eric introduced the same activity by stating that "Today is an asynchronous day. You guys should work on one of three things. If you want to use this time to work on the planning in a breakout room with your group, feel free." This instance was coded as a student-constructed strategy because Eric let students plan their route to collect data and make a decision on how to conduct the investigation without his supervision. Further explanations with illustrative instances are included in the findings.

To understand students' intrinsic motivation, we examined student focus group interviews and extracted the data that related to the rationale behind their engagement in the class. The segments of data were further deductively coded using the three factors of SDT. For example, the following quote, "I enjoyed the independent aspect of it and I also really enjoyed being able to just go out. And it was really nice during this year too because it gave me the opportunity to go out and walk around my neighborhood with my friends and stuff. So, I thought that was really nice, especially when we haven't really been able to do that at all." was coded as autonomy because the student refers to a feeling of ownership and freedom to direct her own learning in the project. We triangulated the student focus group interviews data with the classroom observation codes to affirm the supporting epistemic agency and instances of students reporting on the cognitive authority being shared in online classrooms. Through repeatedly reading the codes and iterative discussions, we continually refined the codes.

Findings

The findings are organized to first illustrate how the teacher adapted the in-person units to the online environment through an epistemic agency and cognitive authority lens. The second half of the findings examine how students responded to these adaptations specifically through an SDT lens.

Curating opportunities for shared cognitive authority

In the first year, during in-person instruction, Eric was able to support the development of his students' epistemic agency through myriad structures (both embedded in the design of the curriculum and modified using his own professional judgement) that transferred his cognitive authority to them. This included allowing students to select the context of data collection (where they wanted to collect air-quality variables); setting their own investigation questions (asking questions pertaining to their neighborhood), directing students to use peers as resources when working with their data, and positioning his students as people whose opinions and interpretations were worthy of being challenged by their peers (asking students to collaborate on data analysis and come to consensus on their group's claims). Below we detail differences in the levels of cognitive authority afforded to students between the in-person and online classes and the revisions he made to the online implementation that allowed for similar student-constructed opportunities to occur (i.e., strategies that shifted the cognitive authority entirely to students).

Legitimizing student autonomy

In online instruction, Eric created multiple opportunities for students to take ownership of designing their science inquiry process without his explicit supervision. We observed that Eric curated more opportunities where students were given complete authority to determine the nature of tasks using group consensus in his absence, as compared to in-person classes. He allowed students the freedom to host group discussions in his absence, giving them the choice to consult with him or continue working independently in groups. For example, in the in-person implementation of the lesson where students planned their data investigation process, the whole class worked in smaller groups to design their data investigation proposals detailing the data they intended to collect and analyze around the school. Students were asked to submit their research questions and investigation plans so that Eric could review and approve the trip to the outdoor data collection. Here although the cognitive authority of deciding the nature of the final project was negotiated between Eric and students, the final approval of the project design was made by Eric. Hence, the in-person instructional strategy was reflective of a co-constructed teaching strategy allowing for sharing instead of student owned or student-constructed epistemic agency.

However, in the online class, Eric revised this unit to introduce studio sessions every week. These studio sessions were unmonitored asynchronous sessions where students were asked to plan their route to collect data around their neighborhood and decide how to conduct the investigation within a group. He invited students to join the class link and also provided them with the freedom to create their own Zoom or Google Hangout link to connect with each. While he was always on call for consulting purposes, students who didn't use this opportunity were not penalized, instead, this independent organization was encouraged. In the class observation notes, the researcher details this interaction as captured below,

> Eric opens the class, "You guys should work on one of three things. If you want to use this time to work on the planning in a breakout room with your group, feel free [...] You guys should work on planning your data collection trial run, collecting the data or the asynchronous assignment that I just posted this morning." [...] During the debrief Eric mentioned that one of his students shared the idea of virtual data collection in the previous class and decided to introduce this way to the entire class (5/6/2021).

In the above excerpt, Eric ceded his authority for students to organize their work without his detailed supervision. He also proposed adopting the idea of virtual data collection to the whole class, a suggestion that came from the student. This shows the shift from the in-person instruction's co-constructed pedagogy to a more student-constructed classroom in the online environment, allowing students to not only share the cognitive authority but to own it, allowing for a higher degree of epistemic agency to occur. This was echoed in student responses that followed. For example, one student said, "We got a lot of independent time in asynchronous periods to work on our own and with our friends. So, I think we got a substantial amount of freedom." Another student agreed, "I think we're given an ample amount of time. I think that being able to just kind of have some flexibility as to when we should do it so we can figure it out on our own schedules when collecting data would work. I think that was useful." In these responses, the group makes a reference to the substantial amount of freedom provided by the studio sessions, where they had the liberty to plan the final project's line of inquiry to align with their schedule and interests. Students also referenced the affordability of conducting an open-ended line of inquiry in a flexible manner, for example, a student said, "I did like that the project was very open-ended. So, we were able to just use what we knew and come up with a research question about something that applied to us."

Unmonitored collaborative scaffold

Eric was also successful in adapting the in-person lesson to allow for more opportunities for student's epistemic agency during the part of the curriculum that required student's physical mobility–specifically, the part where students were asked to collect data outside off of the school's grounds. In the in-person implementation, Eric had students work in groups of four where they were assigned specific roles (e.g., sensor manager, time manager, navigator, observation, note taker). He also distributed worksheet templates with detailed prompts to guide students' data collection process. In the online class, however, Eric adopted instructional strategies that allowed students more freedom to design their investigation plan. Because of the COVID pandemic, Eric was not able to monitor the selection of data collection sites due to the different locations that students were logging in from. Thus, Eric used an alternate strategy where he grouped students based on their geographical proximity to each other and allowed students the complete freedom to select and negotiate the sites, the routes, and the process of data collection. He communicated to the students that this investigation is under their control as he was less familiar with the sites near the student's homes. This made it easier for students to negotiate the data investigation process with their peers (as opposed to with Eric) due to their shared familiarity with their own neighborhoods. In the observation field note, the researcher captured the following student discussions,

> Bella starts the conversation, "The only thing I can think of is like going to different parks because some parks will be [located] near streets or on busier streets." Melody likes the idea. Bella adds, "we could maybe add playground stuff and like dog parks." Bella says, "I kind of

wish I could bring the device here cuz it will be interesting to see how the air quality is in the middle of nowhere compared to the city. I didn't bring the device so that's too bad." (5/14/2021).

In the research planning, this group of students selected four different parks and wrote a supporting rationale for their site selections. For example, they selected Garden [A] and wrote "we think this will be the busiest location since it's close to a busy section of South street. We have been there as children, sometimes on field trips." Another site they selected was Garden [B], and they documented "We think this location will be somewhere in the middle when it comes to the air quality readings, since the street can be somewhat busy, but it really depends. Some of us used to go there after school with my friends a lot."

The above excerpts demonstrate that students chose their data collection sites and planned the routes based on the proximity of the location to their homes as well as their familiarity of the locations from their childhood. Their research hypothesis was, "If a park is located on a busier street, then the air quality readings will be higher than a park on a less busy street. It is more likely that the locations located in busier areas will have higher readings." It is important to note that both their hypothesis and research plans were constructed and carried out independently, with little to no input from Eric. This group continued to initiate frequent meetings over Zoom unprompted by Eric. In this interaction, the cognitive authority was completely owned by students and hence indicates the presence of an entirely student-constructed learning environment and strong evidence of the student's epistemic agency.

Students' intrinsic motivation to develop epistemic agency

In this section, we discuss possible reasons why students responded positively to the epistemic opportunities created by Eric. We provide evidence of a) activation of autonomy; b) development of relatedness; and c) enhanced need for competence.

Activation of student's autonomy

Eric's instructional move to introduce student-run studio hours helped activate student autonomy, which consequently led them to stay on task and to direct their learning. Autonomy refers to the need to feel in control of one's own behaviors and goals. This sense of being able to take control over one's own learning plays a major part in helping students feel intrinsically motivated to engage actively with opportunities and to share cognitive authority in class (Haverly, 2020; Stroupe, 2018). On multiple occasions across student groups, we noticed that students referenced "freedom" in the design of studio hours provided. For example, one of the students referring to the studio time, mentioned the following, "We got a lot of independent time in asynchronous periods to work on our own and with our friends. So, I think we got a substantial amount of freedom. And of course, since we had to take the data outside of class and do that independently, then I think that gave us a lot of freedom too." Similarly, another student commented, "I felt like we were given enough freedom to direct our own learning in this class and I also think it was a good balance because we were given the subject question, and then we went off on our own and decided our locations and decided what direction we wanted to take in interpreting the data and what improvements we'd like to make." In these excerpts, we interpret Eric's studio hours design as a space where student autonomy was legitimized and activated.

Leveraging student's relatedness

Eric's decision to group students based on their geographic proximity and to cede cognitive authority in determining the data collection locations provided them with an opportunity to leverage their familiarity with their local contexts and with their peers. In other words, it allowed students to meet the personal need of relatedness. Relatedness refers to the desire to feel connected to others. This is about a personal need to experience a sense of belonging and attachment to other peers. For example, one group self-organized the data collection process to include a group member who couldn't physically join them due to the pandemic restrictions, saying in the student focus group, "Well, Sinthia is going to be at the beach, so she's going to FaceTime. Me and Rose live in South [City], Center [City] area, and Bella is going to come out here and we're going to go from a little park right near our house and then to the Italian market, and then to [river side]." Instead of choosing not to include the group member who was positioned geographically away from the rest, the group opted to Facetime the peer to ensure she was actively involved in the process of data collection. This was done independent of Eric's mentorship. This indicates that Eric's instructional move of enabling unmonitored collaborative time may have created a space for students to accommodate their need to experience a sense of belonging and attachment to their peers, which consequently influenced students' decisions to respond positively to the space of cognitive authority being shared by Eric.

Heightened sense of student's competence

Eric's instructional move of legitimizing student cognitive authority and allowing for unmonitored peer collaboration created a space where students felt a heightened sense of mastery. Students displayed confidence in using data collection and analysis tools (e.g., Google Sheet) with little guidance from Eric. They also demonstrated a sense of transfer, where they felt capable of applying the skills learned in class outside classroom settings. For example, one of the students commented, "I think just generally when I look at stuff, I think it makes it a little easier to understand certain things because I have better knowledge of that [data]." In addition, another student mentioned, "on a more general scale, everything we've been learning about Google Sheets is going to be really helpful [...] in other places, learning how to look at data and how to sort it and stuff is going to be helpful [...] If I'm reading a news article, sometimes there'll be a graph or a chart and so being able to understand that is definitely useful." In these excerpts, students discussed potential applications of data literacy in their daily lives. Students referred to being able to read graphs and better comprehend data representations in external sources, such as news articles. This shows that Eric's instructional move to adopt student co-constructed instructional strategies activated competence, resulting in students' enhanced intrinsic motivation to engage actively with the concepts underlying the curriculum unit.

Discussion

In this paper, we advance the notion that negotiating the knowledge building process of directing science inquiry can be adapted and, in some cases, even thrive in online learning spaces through adoption of instructional practices that support shared cognitive authority. This, in turn, can support the development of student epistemic agency in synchronous online classrooms. Eric's instructional moves of using unmonitored collaborative scaffolds, hosting student run studio time, grouping students based on geographical proximity allowed for opportunities where the instructor ceded complete cognitive authority to students, which in turn, were actively engaged with by the students. SDT provides a framework to understand how the instructional moves supported student engagement and learning (Ryan & Deci, 2020). Our data demonstrates that these instructional moves may have been successful as they met the three needs of activating students' intrinsic motivation to engage actively, i.e., autonomy, relatedness, and competence. While previous studies have shown that students often have fewer autonomy needs and more relatedness needs when learning online because learning spaces are less supervised and lack physical human interaction (Chiu, 2021), our study indicates that autonomy and relatedness needs must be equally emphasized, if online spaces are to be leveraged to support students' epistemic agency. Findings in this study also provide examples of instructional moves that can be adopted during synchronous online sessions (e.g., self-organized studio sessions) to activate students' epistemic agency. A limitation of this study is that we report on the perceived mastery or competency of students conceptual understanding. While our findings indicate a high perceived level of mastery, we are limited in our ability to determine the extent to which the perceived mastery of concepts reflects a concrete understanding of concepts. Another limitation is the case-study method sued in this study, the findings of this study would be specific to the data set analyzed within the setting observed and hence need to be cautiously generalized to other settings.

Reference

Ahn, I., Chiu, M. M., & Patrick, H. (2021). Connecting teacher and student motivation: Student-perceived teacher need-supportive practices and student need satisfaction. *Contemporary Educational Psychology*, *64*, 101950.

Ballard, H. L., Dixon, C. G., & Harris, E. M. (2017). Youth-focused citizen science- Examining the role of environmental science learning and agency for conservation. *Biological Conservation, 208*, 65–75

Brown, J. C. (2017). A metasynthesis of the complementarity of culturally responsive and inquiry-based science education in K-12 settings: Implications for advancing equitable science teaching and learning. *Journal of Research in Science Teaching*, *54*(9), 1143-1173.

Carter Jr, R. A., Rice, M., Yang, S., & Jackson, H. A. (2020). Self-regulated learning in online learning environments: strategies for remote learning. *Information and Learning Sciences, 121(5/6)*, 321-329.

Chiu, T. K. (2021). Applying the self-determination theory (SDT) to explain student engagement in online learning during the COVID-19 pandemic. *Journal of Research on Technology in Education*, 1-17.

Deci, E. L., & Ryan, R. M. (Eds.). (2004). *Handbook of self-determination research*. University Rochester Press.

Erikson, I., & Lindberg, V. (2016). Enriching 'learning activity' with 'epistemic practices'–enhancing students' epistemic agency and authority. *Nordic Journal of Studies in Educational Policy*, *2016*(1), 32432.

González-Howard, M., & McNeill, K. L. (2020). Acting with epistemic agency: Characterizing student critique during argumentation discussions. *Science Education*, *104*(6), 953-982.

Hardy, L., Dixon, C. & Hsi, S. (2020). From data collectors to data producers: Shifting students' relationship to data. *Journal of the Learning Sciences, 29*(1), 104-126.
Haverly, C., Calabrese Barton, A., Schwarz, C. V., & Braaten, M. (2020). "Making Space": How novice teachers create opportunities for equitable sense-making in elementary science. *Journal of Teacher Education*, *71*(1), 63-79.
Jeong, H., Hmelo-Silver, C. E., & Jo, K. (2019). Ten years of computer-supported collaborative learning: A meta-analysis of CSCL in STEM education during 2005–2014. *Educational research review, 28*, 100284.
Lam, S. F., Cheng, R. W. Y., & Ma, W. Y. (2009). Teacher and student intrinsic motivation in project-based learning. *Instructional Science, 37(*6), 565-578
McNeill, K. L., & Vaughn, M. H. (2012). Urban high school students' critical science agency: Conceptual understandings and environmental actions around climate change. *Research in science education, 42*(2), 373-399.
Means, B., & Neisler, J. (2020). *Suddenly online: a national survey of undergraduates during the COVID-19 pandemic*. Digital Promise.
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.
National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.
Noushad, N. F., Shim, J., Yoon, S. A., & Cottone, A. M. (2021). Are community relevant PBL supports enough to promote epistemic agency? Exploring variation in epistemic pedagogical practices in science classrooms. In *Proceedings of the 15th International Conference of the Learning Sciences-ICLS 2021. International Society of the Learning Sciences*.
Roth, G., Assor, A., Kanat-Maymon, Y., & Kaplan, H. (2007). Autonomous motivation for teaching: How self-determined teaching may lead to self-determined learning. *Journal of educational psychology*, *99*(4), 761.
Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. *Contemporary Educational Psychology*, *61*, 101860.
Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. *Liberal education in a knowledge society*, *97*, 67-98.
Scardamalia, M., & Bereiter, C. (2021). Knowledge building: Advancing the state of community knowledge. In *International Handbook of Computer-Supported Collaborative Learning* (pp. 261-279). Springer, Cham.
Schoerning, E., Hand, B., Shelley, M., & Therrien, W. (2015). Language, access, and power in the elementary science classroom. *Science Education, 99*(2), 238-259.
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.
Taylor, G., Jungert, T., Mageau, G. A., Schattke, K., Dedic, H., Rosenfield, S., & Koestner, R. (2014). A self-determination theory approach to predicting school achievement over time: The unique role of intrinsic motivation. *Contemporary Educational Psychology, 39*(4), 342-358.
United Nations Educational, Scientific and Cultural Organization. (2020). *COVID-19 impact on education data. COVID-19 education disruption and response.* Paris, France: The United Nations Educational, Scientific and Cultural Organization, UNESCO.
van Es, E. A., Hand, V., & Mercado, J. (2017). Making visible the relationship between teachers' noticing for equity and equitable teaching practice. In *Teacher noticing: Bridging and broadening perspectives, contexts, and frameworks* (pp. 251-270). Springer, Cham.
Van Petegem, S., Beyers, W., Vansteenkiste, M., & Soenens, B. (2011). Association between adolescent autonomy and psychosocial functioning: Examining decisional independence from a self-determination theory perspective. *Developmental Psychology, 48*(1), 76-88.
Zimmerman, H. T., & Weible, J. L. (2018). Epistemic agency in an environmental sciences watershed investigation fostered by digital photography. *International Journal of Science Education*, *40*(8), 894-918.

Acknowledgement

This work was funded by grants from the U.S. National Science Foundation DRK12 (#1812738)