Fostering Students' Epistemic Agency For Rigorous Science Instruction

Ozlem Akcil-Okan & Miray Tekkumru-Kisa

Abstract

Reform-based rigorous instruction which fosters all students' thinking and sensemaking is possible; however, it is not yet prevalent in science classrooms. This study explored promoting rigorous instruction by enhancing students' intellectual work through cognitively demanding tasks. We examined instruction during the five lessons in a science classroom. We found variations in students' intellectual work across the lessons. Our analysis revealed that the instructional practices associated with promoting students' engagement in rigorous thinking were consequential for promoting students' epistemic agency. Thus, we argue that maintaining and enhancing demand on students' intellectual engagement in cognitively demanding tasks requires the work of providing opportunities for students to learn science-as-practice by acting as epistemic agents. These findings can inform professional efforts regarding rigorous instruction.

Topic Descriptors

Cognitive Demand, Instructional Strategies, Epistemic Agency, Attending and Advancing student thinking

Purpose

Recent reform vision for science education comes with a set of new demands for supporting "three-dimensional learning", which calls for students' engagement in science and engineering practices, crosscutting concepts, and disciplinary core ideas as they try to make sense of phenomena or solve problems (e.g., Furtak & Penuel, 2019; NRC, 2012; Resnick et al., 2018). Rigorous science instruction aligned with this vision is possible; however, it is not yet prevalent in U.S. science classrooms (NASEM, 2015). More insight is needed about enacting rigorous science instruction as students engage in three-dimensional learning to promote the vision in science classrooms (e.g., Kang et al., 2016; Tekkumru-Kisa et al., 2021).

By building on prior research, we contend that designing lessons around cognitively demanding science tasks and implementing them in ways that foster students' high-level thinking and sensemaking can provide robust opportunities for three-dimensional learning. However, engaging students in high-level thinking and sensemaking throughout science lessons continues to remain as a challenge (e.g., Kang et al., 2016; Tekkumru-Kisa et al., 2020a; Thompson et al., 2016). To address this issue, this study aims to explore how to promote rigorous students' thinking and sensemaking throughout the trajectory of science lessons. Specifically, we aim to better understand instructional practices that can help to enhance students' engagement in high-level thinking and sensemaking.

Conceptual Framework

Science tasks are classroom-based activities that shape students' learning opportunities (Doyle, 1983; Hiebert & Wearne, 1993). Tasks provide contexts for the processes, practices, resources that students draw on and use during their intellectual engagement. However, all classroom tasks do not provide similar opportunities for learning (Tekkumru-Kisa et al., 2015; Henningsen & Stein, 1997; Stein & Lane, 1996). Based on the Task Analysis Framework (Tekkumru-Kisa et al., 2015), science tasks with low cognitive demand primarily provide opportunities for students to reproduce scientific knowledge or engage in well-defined procedures without making sense of science ideas or practices. However, science tasks with high cognitive demand call for meaningful integration of scientific content and practices as students engage in high-level thinking and sensemaking to figure out phenomena or solve problems.

Rigorous instruction involves students' high-level intellectual engagement as they work on cognitively demanding tasks (e.g., Tekkumru-Kisa et al., 2021; Windschitl et al., 2012). Although cognitively demanding tasks are considered as essential for rigorous instruction, they are not sufficient. Demand on students' thinking often declines when students start working on complex science tasks designed to position students as sense-makers (e.g., Harris et al., 2015; Kang et al., 2016). Task Phases Framework (Tekkumru-Kisa et al., 2020a) provides a lens to identify and describe changes in demand on student thinking in three phases across the trajectory of a science lesson: (1) potential intellectual work for students as defined by task design (2) framing of the intellectual work for students during task launch in a classroom, and (3) actual intellectual work students engaged in during the enactment of the task. Design features of a classroom task, how it is set-up by the teacher and enacted by the teacher and students can shape opportunities for thinking and learning (Henningsen & Stein, 1997; Tekkumru-Kisa et al., 2020a).

Prior research has revealed factors associated with the decline in demand on students' thinking during the implementation of cognitively demanding tasks (e.g., Henningsen & Stein 1997; Tekkumru-Kisa et al., 2018; 2020b;). However, there is limited research about instructional practices that help to enhance the demand of tasks on students' thinking during their enactment. This is the area that the findings of this study elucidate by uncovering the instructional practices of a science teacher that consistently enhanced the demand on her students' thinking during the implementation of lessons that she designed. Our analysis revealed that the instructional practices associated with promoting students' engagement in rigorous thinking were consequential for promoting students' epistemic agency. We argue that promoting rigorous thinking throughout the trajectory of science lessons requires the work of providing opportunities for students to learn science-as-practice by acting as epistemic agents who shape the knowledge building work in their classroom community (e.g., Engle & Conant, 2002; Ko & Krist, 2019; Sandoval et al., 2019; Stroupe, 2014).

Study Design and Context

This study was conducted as a part of a National Science Foundation-funded professional development (PD) program in which a group of science teachers learned to facilitate productive discussions with their students where students can learn science-as-practice. The PD included a summer workshop and four PD cycles throughout the 2018–2019 year. Each PD cycle consisted of three parts: (a) co-designing a new science lesson with another teacher or research team member, (b) teaching the co-designed lessons, (c) reflecting on the lessons. Among four science teachers who attended the PD program, in this study, we focused on Ms. Kate's instruction, which allowed us to examine science instruction during the enactment of tasks with different levels of cognitive demand. By building on our previous work (Tekkumru-Kisa et al., 2020b), we focused on Ms. Kate's implementation of all five lessons that she designed as part of the PD.

The following research questions guided this study:

1. How did the demand on students' thinking change across the trajectory of science lessons in Ms. Kate's classroom?

2. How was the demand on students' thinking enhanced throughout the trajectory of the lessons in Ms. Kate's classroom?

Data Sources and Analysis

Data sources were planning materials and video recordings of the five lessons in Ms. Kate's classroom (see Table 1 and Table 2). Data analysis consisted of three stages: examining changes in demand on students' thinking across all five lessons, exploring instructional practices associated with enhancement of demand on students' thinking, and students' epistemic agency (see Figure 1).

To address the first research question, we used Science Instruction Quality Rubrics (Tekkumru-Kisa et al., 2021) to assess and explore changes in rigor in students' thinking across three phases of a lesson: design, launch, and enactment. Our analysis revealed that rigor in students' thinking was consistently enhanced throughout all the lessons in Ms. Kate's classroom (See Table 3). Considering how rare it is in research to find cases of instruction in which demand of designed lessons on student thinking are enhanced, (e.g., Harris et al., 2015; Kang et al., 2016; Stein & Lane, 1996), we explored further how she facilitated rigorous instruction.

To address the second question, exploring how students' thinking was enhanced in Ms. Kate's classroom, we conducted detailed thematic analyses (Miles & Huberman,1994). We focused on the lessons in which demand on students' thinking was maintained at or enhanced to level-4 and 5 (i.e., the high scores on the rubrics) in Ms. Kate's classroom because instruction rated at these levels reflect features of rigorous instruction that provide opportunities for students to engage in learning science-as-practice as emphasized in instructional reforms.

First, we separated the lessons into small parts based on academic activity structure (e.g., small group, whole-class discussion, see Table 4). Next, within each of these activity structures, we described what Ms. Kate did to support rigor in students' thinking. Our theme identification was informed by the literature on ambitious science teaching (e.g., Windschitl et al., 2012), accountable talk (e.g., Resnick et al., 2010), responsive teaching (e.g., Levin et al., 2009), and productive disciplinary engagement (e.g., Engle & Conant, 2002). Looking across her moves and strategies within these activity structures across the lessons, we identified the common themes in her teaching that helped to enhance rigor in students' thinking.

What was common across these patterns in her teaching was her effort to redistribute epistemic agency and then promote students' epistemic agency throughout the lessons (Engle & Conant, 2002; Ko & Krist, 2019; Sandoval et al., 2019; Stroupe, 2014). Thus, our next level of analysis focused on exploring students' epistemic agency within the same activity structure that we focused on for analyzing Ms. Kate's instructional practices. This allowed us to juxtapose Ms. Kate's instructional moves for promoting rigor and students' actions that illustrate their epistemic agency. To explore students' epistemic agency, we used a coding scheme (see Table 5) informed by the literature (e.g., Ko & Krist, 2019; Miller et al., 2018; NGSS, 2013; Stroupe, 2014; Stroupe et al., 2018).

Findings

Addressing the first research question, our analysis revealed variations in potential, launch, and enactment phases of Ms. Kate's lessons regarding rigor in student thinking (see Table 3). For example, the potential cognitive demand of the task in her fourth lesson was rated as level-2, which means that the task required students' superficial engagement in integration of science content and practices. However, the cognitive demand of the task in her fifth lesson was rated as level-4 because it required students to use science content and practices to make sense of a phenomenon.

Our analysis also indicated the critical role of teachers' instructional practices in providing opportunities to enhance students' engagement in high-level thinking and sensemaking. Rigor in student thinking was consistently enhanced from what the design lesson afforded in Ms. Kate's classroom (see Table 3). Specifically, during all her lessons, except one, rigor in students' thinking during the enactment phase was rated as level-4 or 5. Throughout these lessons students were deeply thinking about the phenomenon or phenomenon-based problems and used their understanding of relevant science ideas and disciplinary practices to figure out the phenomenon or solve the problem.

Addressing the second research question, our analysis revealed four consistent patterns in Ms. Kate's instructional practices that appeared to play a role in fostering rigorous student thinking. First, throughout the lessons Ms. Kate held students intellectually accountable to each other, disciplinary norms, and resources. Ms. Kate linked students' ideas, made epistemic press about how students supported their claims, justified their arguments, incorporated new resources to inform development of their arguments through collective effort. Second, she regularly promoted productive puzzlement through problematization by asking questions, giving examples, and introducing new resources. Third, she redistributed cognitive authority by positioning students as capable of working on science ideas and practice to progress in their thinking through collective effort. She gave value to students' ideas and did not evaluate them as correct or wrong. Fourth, she framed students' intellectual work as responding to phenomenon-based questions by doing science. She also positioned students as community members who would decide how to work and develop arguments together.

The common theme across her teaching practices was her efforts to redistribute epistemic agency and then promote students' epistemic agency throughout the lessons (e.g., Engle & Conant, 2002; Ko & Krist, 2019; Stroupe, 2014). Consistently, our analysis of students' epistemic agency revealed that in Ms. Kate's classroom, as epistemic agents, students shared and built on their own resources and their peers' ideas as they discussed how to progress in their work and developed arguments. They also engaged in disciplinary practices while doing science as they developed evidence-based arguments. This allowed us to see students' discourse moves and work illustrating their epistemic agency when Ms. Kate was enacting specific practices that we identified as being related to enhancing demand on students' thinking.

Conclusions and Scholarly Significance

Our analysis revealed that Ms. Kate's instructional practices promoting demand on students' thinking were consequential for promoting students' epistemic agency. Thus, this study makes a bridge between students' learning science-as practice by acting as epistemic agents (e.g., Stroupe, 2014) and promoting rigorous instruction by maintaining and enhancing demand on students' thinking (e.g., Kang et al., 2016; Tekkumru-Kisa et al., 2020a). The common themes that we identified in Ms. Kate's instructional practices to enhance opportunities for students' thinking provide a more concrete depiction of means to foster all students' learning science-as-practice by acting as epistemic agents during rigorous instruction. Revealing these specific practices can help to promote rigorous instruction where all students can be positioned to act as epistemic agents. The study findings can contribute to a better understanding of how to enact reform-based, equitable science instruction and inform professional development efforts to support teachers' capacity for promoting all students' high-level thinking in science classrooms.

This material is based upon work supported by the National Science Foundation under DRL #1720587. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

Doyle, W. (1983). Academic work. Review of Educational Research, 53, 159.

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and instruction*, *20*(4), 399-483.

Furtak, E. M., & Penuel, W. R. (2019). Coming to terms: Addressing the persistence of "hands-on" and other reform terminology in the era of science as practice. *Science Education*, *103*(1), 167-186.

Harris, C. J., Penuel, W. R., D'Angelo, C. M., DeBarger, A. H., Gallagher, L. P., Kennedy, C. A., Cheng, H.B.,& Krajcik, J. S. (2015). Impact of project-based curriculum materials on student learning in science: Results of a randomized controlled trial. *Journal of Research in Science Teaching*, *52*(10), 1362-1385.

Henningsen, M., & Stein, M. K. (1997). Mathematical tasks and student cognition: Classroom-based factors that support and inhibit high-level mathematical thinking and reasoning. *Journal for Research in Mathematics Education*, *28*, 524–549.

Hiebert, J., & Wearne, D. (1993). Instructional tasks, classroom discourse, and students' learning in second-grade arithmetic. *American Educational Research Journal, 30,* 393–425.

Kang, H., Windschitl, M., Stroupe, D., & Thompson, J. (2016). Designing, launching, and implementing high quality learning opportunities for students that advance scientific thinking. *Journal of Research in Science Teaching, 53*(9), 1316-1340.

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.

Levin, D. M., Hammer, D., & Coffey, J. E. (2009). Novice teachers' attention to student thinking. *Journal of Teacher Education*, *60*(2), 142-154.

Miles, M.B. & Huberman, A.M. (1994). *Qualitative data analysis: an expanded sourcebook*. Sage Publications.

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*. Washington, DC: National Academies Press.

National Academies of Sciences, Engineering, and Medicine. (2015). *Science teachers' learning: Enhancing opportunities, creating supportive contexts*. Washington, DC: National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: National Academies Press.

Resnick, L. B., Asterhan, C. S. C., & Clarke, S. with Schantz, F. (2018). Next Generation Research in Dialogic Learning. In: G. E. Hall, D. M. Gollnick, & L. F. Quinn (Eds), *Handbook of Teaching and Learning*. Wiley.

Resnick, L. B., Michaels, S., & O'Connor, C. (2010). How (well structured) talk builds the mind.

Innovations in educational psychology: Perspectives on learning, teaching and human development, 163-194.

Sandoval, W. A., Enyedy, N., Redman, E. H., & Xiao, S. (2019). Organizing a culture of argumentation in elementary science. *International Journal of Science Education*, *41*(13), 1848-1869.

Stein, M. K., & Lane, S. (1996). Instructional tasks and the development of student capacity to think and reason: An analysis of the relationship between teaching and learning in a reform mathematics project. *Educational Research and Evaluation*, *2*, 50–80.

Stein, M. K., Remillard, J., & Smith, M. S. (2007). How curriculum influences student learning. *Second handbook of research on mathematics teaching and learning*, *1*(1), 319-370.

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.

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.

Tekkumru-Kisa, M., & Akcil-Okan, O. (2020a). Designing and implementing cognitively demanding science tasks for fostering productive disciplinary engagement. In Melissa Gresalfi, & Ilana Horn (Eds.), *The Interdisciplinarity of the Learning Sciences. 14th International Conference of the Learning Sciences (ICLS)* (pp. 2038-2045). International Society of the Learning Sciences, Inc.

Tekkumru-Kisa, M., Akcil Okan, O., & Kisa, Z. (2020b, April 17-21). *Exploring opportunities for students' sense-making and rigor at the instructional core.* Paper accepted to the American Educational Research Association Annual Meeting 2020, San Francisco, CA. (Conference Cancelled).

Tekkumru-Kisa, M., Stein, M. K., & Coker, R. (2018). Teachers' learning to facilitate high-level student thinking: Impact of a video-based professional development. *Journal of Research in Science Teaching*, *55*(4), 479-502.

Tekkumru-Kisa, M., Preston, C., Kisa, Z., Oz, E., & Morgan, J. (2021). Assessing instructional quality in science in the era of ambitious reforms: A pilot study. *Journal of Research in Science Teaching*, *58*(2), 170-194.

Thompson, J., Hagenah, S., Kang, H., Stroupe, D., Braaten, M., Colley, C., & Windschitl, M. (2016). Rigor and responsiveness in classroom activity. *Teachers College Record*.

Windschitl, M., Thompson, J., Braaten, M., & Stroupe, D. (2012). Proposing a core set of instructional practices and tools for teachers of science. *Science education, 96*(5), 878-903.