Research in Science Education (2021) 51:1107–1121
https://doi.org/10.1007/s11165-020-09924-y

Intellectual Work Required of Students in Science Classrooms: Students' Opportunities to Learn Science

Miray Tekkumru-Kisa[1] · **Zahid Kisa**[2] · **Hannah Hiester**[3]

Abstract

Students' opportunities to learn science are shaped by the intellectual work in which they engage in science classrooms. By considering the opportunity to learn as a more nuanced and complex concept than simply as exposure to the subject matter, we argue that the kind of tasks that teachers assign to students presents an important element to understand how students are positioned to learn in science classrooms. Teachers, undoubtedly, play a critical role in the selection of these instructional tasks. This study aims to investigate the cognitive demand of science tasks and teachers' reasoning for what makes these tasks cognitively demanding. Guided by a framework, which was designed to classify science tasks according to cognitive demand and the integration of science content and practices, we analyzed 224 science tasks shared by 125 teachers through a statewide survey. The analyses revealed many of the science tasks, which were identified by teachers as demanding high-level intellectual work from students and were classified into low-level categories of this framework. The qualitative analyses of teachers' responses to survey questions revealed the factors that influenced science teachers' decisions about the cognitive demand of instructional tasks.

Keywords Instructional tasks · Opportunity to learn · Teacher thinking · Cognitive demand

Introduction

Within the past few decades, much discussion and concern has focused on the limitations imposed by students' learning science as a fragmented set of ideas presented through "a mile

---

✉ Miray Tekkumru-Kisa
mtekkumrukisa@fsu.edu

[1] School of Teacher Education & Learning Systems Institute, Florida State University, 1114 W. Call Street, Tallahassee, FL 32306, USA

[2] Learning Systems Institute, Florida State University, Tallahassee, FL, USA

[3] Wakulla High School, Crawfordville, FL, USA

wide and an inch deep" curricula (Schmidt et al. 1997) without understanding the inherent logic of the scientific practices (European Commission 2015; NRC 2012). Students are asked to verify knowledge, follow procedures, or carry out activities with weak or no conceptual links to underlying scientific ideas (Roth and Garnier 2006). They rarely engage in the scientific practices (Banilower et al. 2018).

Addressing these concerns, the Framework for K–12 Science Education (NRC 2012) has led to new instructional reforms in the USA (e.g., Next Generation Science Standards, NGSS Lead States 2013) to improve teaching and learning science. The aim is to move science teaching away from a focus on many discrete facts covered at a superficial level to a focus on a smaller number of disciplinary core ideas that can be explored in-depth (Krajcik et al. 2014). Accomplishing this goal would require students to engage in scientific practices to explain phenomena and develop understanding through engaging in the practices of science. Undoubtedly, achieving this vision requires considerable changes in how science is taught and learned in many classrooms (NRC 2015).

Underlying these efforts is the recognition that students need to be provided with the *opportunities to learn* science by engaging in classroom experiences that blend three dimensions of science learning: disciplinary core ideas, scientific practices, and crosscutting concepts (i.e., three-dimensional learning) (NRC 2012). Opportunities to learn are influenced by the *tasks* assigned to students (Doyle 1983; Hiebert and Grouws 2007; Greeno and Gresalfi 2008; Stein et al. 1996). Consistently, in a report by the NRC (2015), it is stated that:

> The types of tasks that students are asked to engage in will look different in a classroom aligned to the NGSS. For example, simply memorizing a science vocabulary list—such as the names of parts of a cell or reading a textbook selection and answering questions at the end of the chapter that requires students to restate or repeat portions of the text—is not consistent with the vision for learning in the Framework and the NGSS. Instead, students could be asked to explain how the function of a particular part of the cell fulfills the organism's needs and use of evidence to support that explanation (p. 34).

As illustrated with this example, not all tasks provide similar opportunities for students to engage with scientific ideas and practices because different science tasks require different levels and kinds of student thinking (Tekkumru-Kisa et al. 2015). By considering the *opportunity to learn* as a more nuanced and complex concept than simply as exposure to the subject matter (Hiebert and Grouws 2007), we argue that the kinds of tasks that teachers assign to students provide a lens to understand *how* students are positioned to learn in science classrooms.

An instructional task is viewed as a joint event between the work of the teacher and students in the classroom; by developing and selecting tasks, teachers create opportunities for students to work in classrooms, and by completing this work, students develop an understanding of science (Marx and Walsh 1988). Therefore, teachers' selection of the tasks forms the foundation for the learning experiences that students encounter in science classrooms. According to the results of a nationally represented survey of science teachers in schools across the USA (see Banilower et al. 2018), teachers often use the units and lessons that they developed in comparison to commercially published textbooks, or lessons and resources that are available through other sources. These teacher-created lessons heavily influence instruction, especially in science classrooms. In more than 75% of secondary school science classrooms, teacher-created lessons form the basis of science instruction (Banilower et al. 2018). These findings provide strong evidence for the pivotal role of science teachers in the kinds of instructional tasks assigned to students in science classrooms. Therefore, it is essential to understand science teachers' decision-making addressing the selection of instructional tasks that they assign to students in science classrooms. We believe that how to identify cognitive demand of tasks on students' thinking should be a part of a teacher's problem space in the design arena during the lesson planning stage (see Remillard 1999) and a factor in teachers' decision-making process about what to teach and how to teach it.

In this study, by proposing instructional tasks as a critical factor in opportunities to learn that students are provided with in science classrooms, we examined the quality of the intellectual work in which students are required to engage in science classrooms. Our focus on science tasks is important because tasks provide a *context for students' thinking* in science classrooms (Doyle 1983). Thus, we examined the kind and level of thinking demanded by science tasks (i.e., cognitive demand of science tasks) assigned to students in science classrooms to understand the opportunities that they afford for students' learning. Moreover, considering the role of the teacher in the selection of these tasks, we explored teachers' reasoning about the tasks that they assigned to students in their classrooms. Given the scarcity of research in this area, we believe that understanding teachers' thinking about cognitive demand of instructional tasks is essential for supporting high-quality opportunities for students' science learning.

Theoretical Framework

Instructional Tasks: the Basis of Students' Opportunities to Learn

Opportunity to learn is one of the critical connections between teaching and learning. It is conceptualized and studied in different ways in the literature, such as exposure to the subject matter, time on task, or content coverage aligned with the standards (e.g., Carroll 1963; Floden 2002; Gamoran et al. 1997). In this study, we draw on the way the opportunity to learn is conceptualized in the situative perspective and its relation to instructional tasks. Greeno and Gresalfi (2008) define the opportunity to learn (OTL) as the affordances of a setting for changing participation and practice. They stated, "one of the most critical aspects of understanding OTL comes from the activity system in which students are participating. Classroom activities are generally organized as tasks, so OTL depends on the tasks that students have to work on" (p. 177). Therefore, instructional tasks constitute a key component of an activity system that can influence students' opportunities to learn in science classrooms. In interaction with the other components of the activity system, they shape students' opportunities to learn science.

Researchers have historically advocated for a close examination of tasks (e.g., Doyle 1983; Hiebert and Wearne 1993; Stein et al. 1996; Tekkumru-Kisa et al. 2015) because tasks are considered as "a primary link among teachers, curriculum, and student outcomes" (Blumenfeld 1992, p. 81). It is argued that what and how students learn is largely defined by the tasks that they are assigned (Doyle 1983; Hiebert and Wearne 1993). A science task (as part of a lesson or spanning multiple lessons) can be a project, a science activity, a lab, a set of problems or a question that students are given to focus their attention on particular scientific ideas and/or practices.

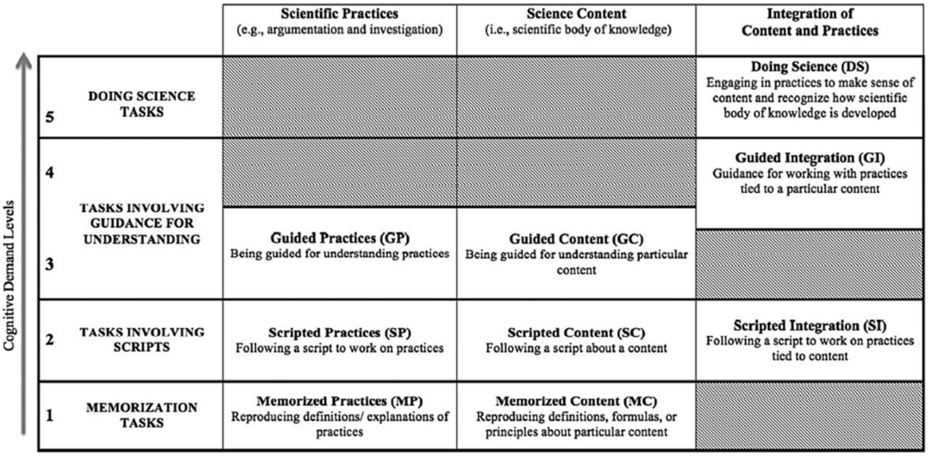
Cognitive Demand: a Key Construct to Understand Students' Opportunities to Learn

Cognitive demand is defined as the kind and level of thinking required of students in order to successfully engage with a task (Tekkumru-Kisa et al 2015; Doyle 1983; Stein et al. 1996).

The cognitive demand of tasks, and hence the kinds of agency students are afforded in classrooms, makes a difference in their opportunities to learn (Greeno and Gresalfi 2008). Cognitively demanding science tasks are often less structured, more complex, and longer than more routine and procedural tasks. Students often perceive these tasks as highly ambiguous (not having a predictable precise pathway to approaching them) or risky because it is generally not clear what to do in these tasks and how to do it, necessitating students' decision-making, having higher possibility of risk that answers will be incorrect (Doyle 1983, 1988; Stein et al. 1996; Tekkumru-Kisa et al 2015). These tasks can cause students to experience uncertainty that supports students' productive struggle and sensemaking. Prior research revealed the affordances of these tasks for students' learning (e.g., Förtsch et al. 2018; Stein and Lane 1996; Schneider et al. 2005), which is also coupled with the challenges in maintaining students' intellectual engagement during the implementation of these complex and inherently ambiguous tasks in classrooms (e.g., Jones and Eick 2007; Kang et al. 2016; Schneider et al. 2005; Tekkumru-Kisa et al. 2019).

To characterize the thinking demands of science tasks, Tekkumru-Kisa et al. (2015) developed the Task Analysis Guide in Science (TAGS) (Fig. 1). It is a two-dimensional framework for analyzing science tasks in terms: (1) cognitive demand and (2) the integration versus isolation of science content and practices.

As shown in Fig. 1, the rows indicate the levels of cognitive demand and the columns identify whether or not science content and scientific practices are integrated within a task, in other words, whether or not the task has the potential to expose students to *both* scientific practices and science content (i.e., discipline-specific core ideas and crosscutting concepts across disciplines). Cognitively demanding, integrated tasks require students to develop an understanding of disciplinary core ideas (e.g., gas law) and think about the crosscutting concepts (e.g., cause and effect) within the context of scientific practices (e.g., developing and using models) while explaining a phenomenon or solving problems. In other words, these tasks have the potential to engage students in three-dimensional learning. We will refer to the tasks that can be placed at level 4 (i.e., High-Guided Integration) and level 5 (i.e., Doing Science) (Fig. 1) as "3D science tasks." For example, a student may be assigned a task that involves modeling the spread of cancer in human body tissues, which would be different with



		Scientific Practices (e.g., argumentation and investigation)	**Science Content** (i.e., scientific body of knowledge)	**Integration of Content and Practices**
5	DOING SCIENCE TASKS	▨	▨	**Doing Science (DS)** Engaging in practices to make sense of content and recognize how scientific body of knowledge is developed
4	TASKS INVOLVING GUIDANCE FOR UNDERSTANDING	▨	▨	**Guided Integration (GI)** Guidance for working with practices tied to a particular content
3		**Guided Practices (GP)** Being guided for understanding practices	**Guided Content (GC)** Being guided for understanding particular content	▨
2	TASKS INVOLVING SCRIPTS	**Scripted Practices (SP)** Following a script to work on practices	**Scripted Content (SC)** Following a script about a content	**Scripted Integration (SI)** Following a script to work on practices tied to content
1	MEMORIZATION TASKS	**Memorized Practices (MP)** Reproducing definitions/ explanations of practices	**Memorized Content (MC)** Reproducing definitions, formulas, or principles about particular content	▨

Fig. 1 Task Analysis Guide in Science (TAGS) (Tekkumru-Kisa, Stein, et al. 2015)

respect to the kind and level of thinking required of students than a task that asks students to draw the phases of mitosis. The first task requires students to engage in disciplinary practices and use their ideas and experiences to develop explanations for cancer spread by drawing on disciplinary ideas and crosscutting concepts, while the second task requires students to regurgitate textbook definitions of science concepts such as mitosis. The NRC Framework emphasizes a shift from the use of tasks like the second one to the use of tasks like the first one, which are classified into high-Guided Integration or Doing Science categories of the Task Framework.

Why this Study?

One reason for conducting this study is to reveal opportunities for learning provided for students in science classrooms by specifically focusing on the cognitive demand of science tasks that they are assigned. It is commonly accepted that many of today's classroom-based science tasks do not provide students with the kinds of opportunities to learn demanded by the new generation of standards. However, research is limited in systematic analysis of the cognitive demand of science tasks assigned to students. Even less is known about the reasoning used by teachers in selecting these tasks. Thus, it is essential to incorporate in our exploration both the tasks assigned and identification of teachers' reasoning that ground their task selection. We were particularly interested in the characterization of what teachers attend to make decisions about the cognitive demand of science tasks that they assign to students in order to engage them in high levels of thinking and sensemaking.

While this study reveals teachers' thinking and the kinds of support that they may need to provide rich opportunities for students' learning, it brings attention to the science tasks in an activity system that shape students' opportunities for learning. There has been much discussion in recent years about productive discourse and teachers' noticing of students' ideas to facilitate sensemaking (e.g., Robertson et al. 2016). These studies often lack attention to the kinds of tasks that students work on, which is associated with the affordances of a setting for changing participation and practice.

It is important to underscore that selecting tasks is essential but not sufficient to engage students in high levels of thinking and reasoning in science classrooms. The effect of a task on students' learning is shaped by how it is enacted in the classroom by the teacher and students. Prior research consistently revealed that cognitive demand of tasks changes once they are placed into real classroom settings. Despite the potential of the tasks in engaging students in high levels of thinking, cognitive demand on student thinking may decline as students and the teacher work on these tasks (e.g., Tekkumru-Kisa et al. 2019). On the other hand, students do not engage in high-level reasoning in these classrooms in which low-level tasks are used (Jackson et al. 2013; Kang et al. 2016; Stein et al. 1996). Because of this, selecting cognitively demanding tasks is an essential to set the stage for engaging students in productive opportunities for learning science.

The following questions guided our investigation:

1. What is the cognitive demand of instructional tasks assigned by the science teachers?
2. How do science teachers identify the cognitive demand of a science task?

3. Is there a relationship between classroom characteristics and the use of cognitively demanding science tasks that has the potential to engage students in three-dimensional learning?

Methods

Data Collection

Our analyses are based on the data collected from science teachers from a state in the Southeastern region of the United States via the Qualtrics online survey tool. In the first part of the survey, teachers were asked to upload two science tasks, which they have assigned in the most average science class (based on student performance) that they taught: one required high cognitive demand (i.e., high-level task) and one required low cognitive demand (i.e., low-level task) on students' thinking. They were asked to answer a set of open-ended questions related to these tasks and also explain why they identified them as high level or low level. In the second part of the survey, teachers were asked to provide demographic information about their most average science class in which they used the tasks. The survey questions were reviewed by six teacher educators. The survey was disseminated to a list of STEM educators across the state. As an incentive, the survey participants were entered into a drawing upon their completion of the survey. We collected 224 science tasks shared through the survey by 125 science teachers who had used these tasks in their most average class. To support the interpretation of the findings, we provided descriptive information about the classroom contexts where the science tasks shared by the teachers were implemented (Tables 1, 2, and 3).

Data Analysis

To answer our first research question, we analyzed the science tasks based on their cognitive demand levels. Two raters categorized science tasks shared by the survey participants by using the TAGS. Before analyzing the tasks, two raters separately coded a different set of science tasks to ensure an acceptable agreement in their ratings. Then, the ratings of the survey tasks were completed. The same two raters separately coded a subset of tasks and then discussed their ratings. Inter-rater reliability between these two raters was calculated as 0.73 based on randomly selected 40% of the total 224 tasks.

To answer the second research question, we analyzed teachers' responses to an open-ended question in the survey, which asked teachers to provide up to three reasons for why they

Table 1 Frequencies of classes by grade level and content area

High school (grades 9–12)	*N* (%)	Middle school (Grades 6–8)	*N* (%)	Elementary (Grades K-5)	*N* (%)
Life Sciences/Biology	21(17%)	General/Integrated Science	27(22%)	Science	39(31%)
Chemistry	7 (6%)	Life Sciences	4 (3%)		
Physics	4 (3%)	Earth Sciences	2 (2%)		
Env. Science/Ecology	4 (3%)				
Earth/Space Science	2 (2%)				
Other	5 (4%)	Other	8 (6%)	Other	2 (2%)
Total	43(34%)	Total	41(33%)		41(33%)

Table 2 Frequencies of classes by class type

Class type	Frequency	Percent
General	83	66%
AP or Honors	33	26%
Other (including Resource)	8	6%
Total	125	100%

thought the high-level task that they shared was cognitively demanding for the students. We started the analysis by reading through the survey participants' written responses and generating codes. We generated a codebook, which provided a detailed description of the codes that characterizes the factors teachers use to make decisions about the cognitive demand of a task. We separately coded a subset of written responses by the participants and discussed our coding to refine the definitions of the codes. Once the codebook was finalized, two of us separately coded 25% of the randomly selected written responses by the survey participants. The inter-rater reliability was calculated as 75%, and the inconsistencies in ratings were then discussed to come to an agreement. The rest of the responses were then coded by using the codebook and the decision rules that we developed during the initial coding and the inter-rater reliability process. We then identified the patterns across the teachers in their reasoning for their characterization of the cognitive demand of tasks (Miles & Huberman 1994).

To answer the third research question, we focused on the 3D science tasks. These have the potential to make students to *figure out* how a phenomenon works or how to solve a problem; they are not framed as learning about science content such as the water cycle or balancing equations (Schwarz et al. 2017). We examined whether there was a relationship between teachers' use of 3D science tasks and the characteristics of classrooms in which these tasks were used. Specifically, we examined classroom characteristics concerning students' prior knowledge and classroom type (General, Honors, etc.).

Findings

Many of the science tasks that were identified by teachers as cognitively demanding were placed into low-level categories of the TAGS. Moreover, written responses of survey participants revealed the factors that shaped teachers' reasoning to decide on the cognitive demand of a science task, including students' prior knowledge, specific features of the task, and the types of intellectual engagement.

Tasks Identified by the Teachers as Demanding High-Level Thinking

Addressing the first research question, Table 4 provides the frequency of the instructional tasks identified by the teachers and the categorization of these tasks based on the TAGS. *High-level*

Table 3 Distribution of students in the classes based on prior achievement

Prior achievement	Number	Percent
A mix of levels	40	32%
Mostly average achievers	39	31%
Mostly high achievers	27	22%
Mostly low achievers	19	15%
Total	125	100%

Table 4 Classification of science tasks within the categories of the TAGS

Categories	Identified as High-Level by the Teacher *N%*	Identified as Low-Level by the Teacher *N%*
Doing science	6 (6%)	0 (0%)
Guided integration	26 (24%)	2 (2%)
High-guided integration	10	0
Low-guided integration	16	2
Guided practices	7 (6%)	0 (0%)
Guided content	12 (11%)	4 (4%)
High-level total	51 (47%)	6 (6%)
Scripted integration	15 (14%)	10 (9%)
Scripted practices	0 (0%)	2 (2%)
Scripted content	10 (9%)	5 (4%)
Memorized practices	0 (0%)	5 (4%)
Memorized content	29 (26%)	78 (70%)
No thinking required	5 (5%)	8 (5%)
Low-level total	59 (54%)	108 (94%)
	110 (100%)	114 (100%)

tasks shared by the survey participants were classified into different categories by the researchers.

One striking finding is that slightly more than half of science tasks (53.6%), which were identified by the teachers as demanding high-level student thinking, were classified into one of the low-level cognitive demand categories (level 1 or 2) of the TAGS. The highest proportion of high-level tasks (26.4%) was categorized as *Memorized Content* (*MC*), which is the lowest cognitive demand level. The tasks in the MC category demand students to reproduce information to which they were previously introduced. For example, one of the MC content tasks, which was identified as cognitively demanding by one of the survey participants, consisted of a set of free-response and multiple-choice questions about human organ systems. This science task includes questions such as “What is homeostasis?” “What organ system works with the kidneys to control the amount of urine produced?” These questions might be difficult for students to answer when they could not memorize the features of human organ systems to which they were introduced before. However, ultimately, this low-level task requires students to reproduce previously learned scientific body of knowledge.

Scripted Integration (*SI*) was another commonly observed low-level category. Among the tasks that teachers identified as high level, 13.6% were categorized as *SI.* While working on such tasks, students often engage in some scientific practices but at a superficial level. SI tasks often require students to follow a set of scripted steps that help them to arrive at a single correct solution without understanding what they did and why. As argued by Germann et al. (1996), in such cookbook activities, students “work like technicians” (p. 496). For example, in one of the SI tasks provided by the survey participants, students are asked to use red cabbage juice as a pH indicator to test common household liquids and test their pH levels. The task provides the pH chart and step-by-step instructions to complete the lab without being motivated by a larger question or problem. Students are required to mix the liquids with the cabbage juice and decide on the pH level based on the information provided on the pH chart. As evident in this task, SI tasks do not require students to make sense of disciplinary ideas or how these ideas develop.

Even though students are often required to work on a hands-on lab and engage in some scientific practices superficially, these tasks often fail to engage students in the kind of reasoning processes employed in real scientific inquiry.

Among the tasks identified by the teachers as demanding high-level student thinking, 46.4% was categorized into one of the high-level cognitive demand categories. Among these, 17.3% of the tasks were classified into either *Guided Content* (*GC*) or *Guided Practices* (*GP*), and 23.6% were classified into *Guided Integration* (*GI*) category. GC and GP tasks are level 3 tasks that can provide high-level thinking and reasoning opportunities for students. They often come in the form of "application" activities. GI tasks can also engage students in high-level thinking, but they also require students to meaningfully engage in the scientific practices.

While the 14.5% of high-level tasks were categorized as low-GI, 9.1% of them were categorized as high-GI. For example, one of the high-GI tasks was developing an explanatory model for the phases of the moon. Students are guided to collect data, use models to develop an explanation for this phenomenon. Low-GI tasks generally begin as a verification style lab but include a set of intellectually demanding questions, usually post-investigation and in data analysis. For example, in one of the low-GI tasks, students are required to collect data on the altitude, velocity, and flight time of a model rocket. The task included a table for students to record the data that they collected and a set of questions for them to explain the patterns in the data by using what they learned about Newton's first and second law and the relationship between different variables.

Finally, only 5.5% of the high-level tasks that were shared by the teachers were classified into *the Doing Science* (*DS*) category. Like high-GI tasks, DS tasks require students to use various scientific practices and deepen their understanding of a scientific idea as they explore a natural phenomenon. Therefore, the kind of thinking required in DS tasks is similar to what is required in a high-GI task. However, in GI tasks, students are supported to engage in high-level thinking through scaffolding embedded in the task.

Tasks Identified by the Teachers as Demanding Low-Level Thinking

Our analysis revealed that learning opportunities afforded by the science tasks that teachers identified as demanding low-level student thinking were predominantly (94.8%) classified into the low-level categories of the TAGS. The majority of the low-level tasks (72.8%) was categorized as MC, or MP. Fifteen percent of the tasks required students to engage in scripted procedures where students were required to follow a set of scripted steps without needing to understand what they are doing and why. Only 5% of the low-level tasks shared by the survey participants were classified into high-level categories. These findings suggest that teachers could better identify science tasks that require their students to reproduce previously known information by engaging in low levels of thinking.

Teachers' Reasoning About Task Demands

Our analysis addressing the first research question brings attention to the need for building a common language and understanding for identifying cognitively demanding tasks for providing rigorous opportunities for students' learning. Understanding teachers' reasoning about the cognitive demand of science tasks is an important step in this direction. Overall, our analysis of teachers' reasoning revealed variation in survey participants' thinking about what makes science tasks cognitively demanding. Table 5 provides a summary of what survey participants

Table 5 Factors that influence teachers' reasoning for what makes tasks cognitively demanding

Factors	n (%)	Example
Kind of intellectual engagement	95 (30%)	"Must synthesize new information learned to complete tasks." "Students have to apply what they have learned previously about gravity and the gravity constant."
Engaging in disciplinary practices	50 (15.8%)	"Their conclusion forced them to the data (evidence) and connects it with scientific reasoning to support their claims." "They must use observations, collect data and make conclusions just like real scientists."
Features of the task	50 (15.8%)	"Answer requires students to put into their own words." "Students were not given specific directions."
Prior knowledge and experiences of students	50 (15.8%)	"Students are low achieving." "Low level math background in my student population. Lack of common sense with simple formulas."
Engaging in design	25 (7.9%)	"They had to create a design to solve a problem." "It requires students to create something original."
Subject specific issues	14 (4.4%)	"There are so many types of inheritance, each with different phenotypic outcomes."
Other	33 (10.4%)	Grouping students; reading and other skills needed; students' affect
Total	317 (100%)	

considered to determine the cognitive demand of a task by focusing on the *reasons* that they provided for what makes high-level tasks that they selected cognitively demanding for students.

As shown in Table 5, 30% of the factors that influence survey participants' reasoning to decide on the cognitive demand of a science task were related to the kind of intellectual engagement. Some of the survey participants were already considering thinking processes that students would engage in as they work on the task, such as recalling or memorizing, synthesizing, and analyzing given information. The next commonly observed factors were attention to engagement in disciplinary practices, structural features of a task, and students' prior knowledge and experiences, each comprising 15.8% of teachers' reasons for what makes the tasks cognitively demanding. Analyzing and interpreting data was the primary practice that stood out in participants' comments. Asking students making observations, predictions, and inferences was also grouped under this factor. For structural features of a task, teachers attended to the types of questions included in the task, types of scaffolding embedded in the task to assist students' thinking, and the nature of the response that was expected of the students. Finally, 15.8% of the factors observed in survey participants' responses were related to students' prior knowledge, ability, and experiences. Some teachers stated that they have low-achieving students, and so the selected task is cognitively demanding considering this student population.

Use of 3D Tasks in Science Classrooms

Out of 110 tasks that teachers identified as high level, 16 of them (15%) were classified as 3D science tasks. Our analysis revealed that teachers' use of 3D science tasks was related to the prior achievement level of the classroom. A Fisher-Freeman-Halton exact test of independence indicated a marginally significant relationship between classrooms with regard to students' prior science achievement levels and using 3D science tasks ($p = 0.064$). Comparisons of column proportions showed that the proportion of 3D science tasks (50%) is significantly

Table 6 Relationship between achievement level and the use of 3D science tasks

		3D task		Total
		Yes	No	
Mostly high achievers	% within 3D tasks	50%*	18%*	23%
	Count	8	17	25
Mostly average achievers	% within 3D tasks	19%	31%	29%
	Count	3	29	32
A mixture of level	% within 3D tasks	19%	36%	34%
	Count	3	34	37
Mostly low achievers	% within 3D tasks	13%	15%	15%
	Count	2	14	16
	Total % within	100%	100%	100%
	Total count	16	94	110

A chi-square test indicated a significant difference between classrooms with regard to students' prior science achievement levels and using 3D science tasks χ^2 (3) = 8.01, $p = 0.044$. Since, three cells (37.5%) have expected count less than 5 (Yates, Moore & McCabe, 1999), we used a more conservative Fisher-Freeman-Halton exact test. It still showed a significant difference (at a marginally significant level at $p = 0.064$) between classrooms with regard to students' prior science achievement levels and using 3D science tasks

*Column proportions differ significantly from each other at the 0.05 level

higher than the proportion of tasks that are not 3D (18%) only for classrooms with mostly high-achieving students. In classrooms with mostly average achievers and with a mix of achievement levels, the proportion of 3D science tasks is lower than the proportion of non-3D science tasks, but these differences are not statistically significant. For classrooms with low achievers, the proportion of 3D and non-3D science tasks was comparable (Table 6).

We found no significant relationship between classroom type and teachers' use of 3D science tasks ($\chi^2(3) = 2.87$, $p = 0.412$). The proportion of using 3D science tasks was not different for general, honors/AP, and other classroom types (Table 7).

Conclusions and Discussion

We started this article by calling attention to the instructional tasks used in science classrooms as a window into the opportunities for learning provided for students in science classrooms.

Table 7 Relationship between classroom type and the use of 3D science tasks

Classroom type		3D tasks		Total
		Yes	No	
General	% within 3D tasks	56%	68%	23%
	Count	9	63	72
Honors/AP	% within 3D tasks	44%	26%	29%
	Count	7	24	31
Other	% within 3D tasks	0%	7%	34%
	Count	0	6	6
	Total % within	100%	100%	100%
	Total count	16	93	109

We argue that instructional tasks constitute a key component of an activity system, and their cognitive demand on students' thinking provides a lens to understand *how* students are required to learn in science classrooms. For us, cognitive demand is about the kind and level of thinking required of students in order to successfully engage with a science task, so, it is related to students' thinking and intellectual engagement in science. Even though there might be some overlaps (see Russo 2015), cognitive demand is different than cognitive load (Sweller 1994) and task difficulty (Cartier et al. 2013). While differentiating these concepts is beyond the goal of this paper, it is important to point out the difference for potential misinterpretations of the study findings.

One striking finding of the study was that many of the tasks that were identified by the survey participants as demanding high-level thinking from students were grouped into lower-level categories of the TAGS. With a limited sample size in this study, generalizations to the larger population of teachers are limited. However, these patterns invite more careful attention to the cognitive demand of instructional tasks used in science classrooms. This attention to the cognitive demand of tasks used in science classrooms is also consistent with the recent calls for facilitating NGSS vision for all students. To transform instruction so that it reflects the NGSS vision, many teachers will need to reconsider the tasks that they typically assign to their students (NRC 2015).

Our findings suggest that some science teachers may need support to develop a common language and to make more informed decisions about the tasks that they assign to their students in science classrooms to provide them with rigorous opportunities for science learning. It is worrisome that about half of the science tasks that we classified as low level were considered as cognitively demanding by the participants of this study. Moreover, analysis of the factors that made up participating teachers' decision-making for selecting cognitively demanding tasks revealed limited attention to critical factors such as how the science tasks would position students to engage in scientific practices. While our analysis of teachers' thinking was limited to their responses on a set of open-ended survey questions, interviews with teachers structured around the artifacts from their teaching could provide more insight into their thinking. Therefore, more research is needed to understand teachers' thinking about cognitive demand of science tasks and develop mechanisms to support their learning to select instructional tasks that are of high cognitive demand and aligned with the 3D vision for science learning. For example, prior research in mathematics education showed that learning to classify tasks based on their cognitive demand levels increased teachers' focus on student thinking and resulted in changes in teaching practices (Boston 2014). Our recent efforts have begun to yield changes in teachers' learning to differentiate between science tasks based on their cognitive demand levels as a result of their participation in carefully designed professional learning opportunities (e.g., Tekkumru-Kisa et al. 2017). Within the recent instructional reforms in the USA, while many curricular materials will be created aligned to the NGSS vision, many others will continue to be available to teachers that are not aligned to NGSS. Teachers will continue to play a critical role in designing or modifying lessons by carefully crafting the tasks that they assign to students in science classrooms. Therefore, the field will benefit from more research in this area to support science teachers' learning to differentiate and also more frequently use cognitively demanding tasks that provide rigorous opportunities for students to engage in three-dimensional learning.

While the study findings bring attention to the cognitive demand of tasks selected and assigned to students by science teachers, the study is limited to the *potential* cognitive demand of these tasks on students' thinking. As evident in research, selecting cognitively demanding science tasks is necessary but not sufficient to engage students in high levels of thinking and sensemaking (see Kang et al. 2016; Stein et al. 1996; Tekkumru-Kisa et al. 2019). Simultaneously, current research indicates that cognitively demanding tasks set the stage for high-level student thinking during their implementation while low-level tasks provide limited opportunities for students' thinking. Thus, more research is needed to investigate science teachers' implementation of cognitively demanding science tasks to provide a more complete depiction of students' opportunities for learning in science classrooms. Future research can include analysis of students' work on these tasks, an area that we started to explore in our current research (see Tekkumru-Kisa et al. 2019) informed by the studies of assessing instructional quality by drawing on student work (e.g., Boston 2014; Matsumura et al. 2008).

While not directly, the study findings also bring attention to who has access to cognitively demanding tasks in science classrooms. Our analysis revealed that the proportion of 3D science tasks is significantly higher than the proportion of tasks that are not 3D in classrooms with mostly high-achieving students. Moreover, coded written responses of survey participants revealed that students' prior experiences and preparedness influenced teachers' reasoning to decide on the cognitive demand of a task. These patterns are alarming since students who are perceived to be low-achieving or students who are placed in low-achieving track might be given limited access to cognitively demanding tasks that can engage them in sensemaking opportunities. This is consistent with the patterns observed in prior research, which indicate limited opportunities provided for low-performing students to get access to rigorous instructional opportunities (Banilower et al. 2018; Gorski 2015). We believe that one way to support shifting toward equitable sensemaking opportunities is to rethink the tasks that are assigned to students across diverse classroom contexts.

References

Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., & Hayes, M. L. (2018). *Report of the 2018 NSSME+*. Chapel Hill: Horizon Research, Inc..

Blumenfeld, P. C. (1992). The task and the teacher: Enhancing student thoughtfulness in science. *Advances in Research on Teaching, 3*, 81–114.

Boston, M. D. (2014). Assessing instructional quality in mathematics classrooms through collections of students' work. In Y. Li, E. A. Silver, & S. Li (Eds.), *Transforming mathematics instruction* (pp. 501–523). Switzerland: Springer International Publishing.

Carroll, J. B. (1963). A model of school learning. *Teachers College Record, 64*(8), 723–733.

Cartier, J. L., Smith, M. S., Stein, M. K., & Ross, D. K. (2013). *5 practices for orchestrating productive task-based discussions in science*. Reston: National Council of Teachers of Mathematics.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: a theoretical framework for evaluating inquiry tasks. *Science Education, 86*(2), 175–218.

Doyle, W. (1983). Academic work. *Review of Educational Research, 53*(2), 159.

Doyle, W. (1988). Work in mathematics classes: The context of students' thinking during instruction. *Educational Psychologist, 23*(2), 167–180.

European Commission. (2015). *Science education for responsible citizens*. Luxembourg: European Union. https://doi.org/10.2777/12626.

Floden, R. (2002). The measurement of opportunity to learn. In A. Porter & A. Gamoran (Eds.), *Methodological advances in cross-national surveys of educational achievement* (pp. 231–266). Washington, DC: National Academy Press.

Förtsch, C., Werner, S., von Kotzebue, L., & Neuhaus, B. J. (2018). Effects of high-complexity and high-cognitive-level instructional tasks in biology lessons on students' factual and conceptual knowledge. *Research in Science & Technological Education, 36*(3), 353–374.

Gamoran, A., Porter, A. C., Smithson, J., & White, P. A. (1997). Upgrading high school mathematics instruction: Improving learning opportunities for low-achieving, low-income youth. *Educational Evaluation and Policy Analysis, 19*(4), 325–338.

Germann, P. J., Haskins, S., & Auls, S. (1996). Analysis of nine high school biology laboratory manuals: Promoting scientific inquiry. *Journal of Research in Science Teaching, 33*(5), 475–499.

Gorski, P. C. (2015). *Reaching and teaching students in poverty: strategies for erasing the opportunity gap*. New York: Teachers College Press.

Greeno, J. G., & Gresalfi, M. S. (2008). Opportunities to learn in practice and identity. In P. A. Moss, D. Pullin, J. P. Gee, G. Haertel, & L. J. Young (Eds.), *Assessment, equity, and opportunity to learn* (pp. 170–199). NewYork: Cambridge University Press.

Haberman, M. (1991). The pedagogy of poverty versus good teaching. *Phi Delta Kappan, 73*(4), 290–294. https://doi.org/10.1177/003172171009200223.

Hiebert, J., & Wearne, D. (1993). Instructional tasks, classroom discourse, and students' learning in second-grade arithmetic. *American Educational Research Journal, 30*(2), 393–425.

Hiebert, J., & Grouws, D. A. (2007). The effects of classroom mathematics teaching on students' learning. *Second Handbook of Research on Mathematics Teaching and Learning, 1*, 371–404.

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: foundations for the twenty-first century. *Science Education, 88*(1), 28–54.

Jackson, K., Garrison, A., Wilson, J., Gibbons, L., & Shahan, E. (2013). Exploring relationships between setting up complex tasks and opportunities to learn in concluding whole-class discussions in middle grades mathematics instruction. *Journal for Research in Mathematics Education, 44*(4), 646–682.

Jones, M. T., & Eick, C. J. (2007). Implementing inquiry kit curriculum: obstacles, adaptations, and practical knowledge development in two middle school science teachers. *Science Education, 91*(3), 492–513.

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.

Krajcik, J., Codere, S., Dahsah, C., Bayer, R., & Mun, K. (2014). Planning instruction to meet the intent of the next generation science standards. *Journal of Science Teacher Education, 25*(2), 157–175.

Marx, R. W., & Walsh, J. (1988). Learning from academic tasks. *The Elementary School Journal, 88*(3), 207–219.

Matsumura, L. C., Garnier, H., Slater, S. C., & Boston, M. D. (2008). Toward measuring instructional interactions "at-scale". *Educational Assessment, 13*(4), 267–300.

Miles, M. B., Huberman, A. M., Huberman, M. A., & Huberman, M. (1994). *Qualitative data analysis: An expanded sourcebook*. Thousand Oaks: Sage Publishing.

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

National Research Council. (2012). *A framework for K-12 science education: practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

National Research Council. (2015). *Guide to implementing the next generation science standards*. Washington, DC: National Academies Press.

Remillard, J. T. (1999). Curriculum materials in mathematics education reform: a framework for examining teachers' curriculum development. *Curriculum Inquiry, 29*(3), 315–342.

Robertson, A. D., Scherr, R., & Hammer, D. (Eds.). (2016). *Responsive teaching in science and mathematics*. New York: Routledge.

Roth, K., & Garnier, H. (2006). What science teaching looks like: an international perspective. *Educational Leadership, 64*(4), 16.

Russo, J. A. (2015). How challenging tasks optimise cognitive load. In *Annual conference of the International Group for the Psychology of mathematics education 2015* (pp. 105–112). Praha: International Group for the Psychology of Mathematics Education.

Schmidt, W., McKnight, C., & Raizen, S. (1997). *A splintered vision: an investigation of U.S. mathematics and science education*. Dordrecht: Kluwer.

Schneider, R. M., Krajcik, J., & Blumenfeld, P. (2005). Enacting reform-based science materials: the range of teacher enactments in reform classrooms. *Journal of Research in Science Teaching, 42*(3), 283–312.

Schwarz, C. V., Passmore, C. M., & Reiser, B. J. (2017). Moving beyond "knowing" science to making sense of the world. In *Helping students make sense of the world using next generation science and engineering practices* (pp. 3–21).

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*(1), 50–80.

Stein, M. K., Grover, B. W., & Henningsen, M. (1996). Building student capacity for mathematical thinking and reasoning: an analysis of mathematical tasks used in reform classroom. *American Educational Research Journal, 33*(2), 455–488.
Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction, 4*(4), 295–312.
Tekkumru-Kisa, M., Stein, M. K., & Schunn, C. (2015). A framework for analyzing cognitive demand and content-practices integration: Task analysis guide in science. *Journal of Research in Science Teaching, 52*(5), 659–685.
Tekkumru-Kisa, M., Schunn, C., & Coker, R. (2017). Promoting teachers' learning to select cognitively demanding science tasks. In *Paper presented at the meeting of European science education research association (ESERA)*. Dublin: Ireland.
Tekkumru-Kisa, M., Schunn, C., Stein, M. K., & Reynolds, B. (2019). Change in thinking demands for students across the phases of a science task: An exploratory study. *Research in Science Education, 49*(3), 859–883.
Weiss, I. R., Pasley, J. D., Smith, P. S., Banilower, E. R., & Heck, D. J. (2003). *Looking inside the classroom: a study of K−12 mathematics and science education in the United States*. Chapel Hill: Horizon Research.