Exploring Teacher Adaptive Expertise in the Context of Elementary School Science Reforms

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The Next Generation Science Standards (NGSS) require an epistemic shift in the classroom (Berland et al., 2016; Reiser, 2013). Although many activities have changed over time in the science classroom, the view of the nature of science pedagogy remains stubbornly stuck (Abd-El-Khalick et al., 2004). Teachers and textbooks deliver science explanations, but students rarely construct explanations. The NGSS represent a commitment to move the goal of science learning from knowing about natural phenomena to developing explanations about natural phenomena (Reiser, 2013). During this time of transition, we must address challenges at all levels including curricular design (Bismack, Arias, Davis, & Palincsar, 2014) and professional development (PD) design that encompass fundamental changes in science pedagogy (Reiser, 2013). For some teachers, these changes contradict years of science classroom experience (Kelly, 2000). The framework of teacher adaptive expertise (TAE) offers a promising approach for conceptualizing ideal practice that is able to situate NGSS reforms in a classroom. Unifying many well researched aspects of science education, TAE rests on a foundation of both content and pedagogical expertise and encompasses flexible engagement of emergent student understanding that adapts to differing student needs and contexts.

This paper aims to illustrate the opportunities and challenges of implementing NGSS lessons in the elementary school classroom by using the lens of TAE. Below, we describe relevant research on TAE in elementary science classrooms and propose a theoretical framework that can be used to help teachers as they integrate NGSS into elementary science classrooms. We, as educators and researchers, are in the midst of the reform process as we design professional development (PD) and curriculum to support teachers in transitioning to NGSS classrooms. The TAE framework and a close analysis of recent NGSS implementations can provide timely details for NGSS curriculum and PD design work. This study contributes to the existing literature on NGSS implementation and elementary science teacher practices in three ways and proceeds as follows. First, we synthesize existing literature and refine a working model of TAE for elementary science education. Second, we provide a qualitative analysis of five elementary school classrooms using the framework of TAE. Lastly, we reflect on what our analysis and the TAE framework reveal about important elements of PD and shifts towards the NGSS in the classroom.

Literature Review

Standards-Based Reforms and Teaching Practices

Transitioning from traditional science teaching practices to reform-based practices poses a challenge for in-service teachers. Studies done during previous reform initiatives indicate that many teachers lack reform-based pedagogical skills (Schneider, Krajcik, & Blumenfeld, 2005). Although, some studies show that reform-inspired curriculum aids teachers in implementing reforms (Davis, 2002; Remillard, 2000), other studies illustrate that changing science teaching practices is difficult, even with carefully designed PD and curricular supports (Knapp, 1997; Peterson, 1990). Schneider et al. (2005) note that PD and curricular support remain incomplete until teachers apply them in the classroom to "create instruction" (p. 287). As reform does not end with well-designed materials and PD, the goal of shifting teacher practices presents a pressing need to investigate teaching in the midst of reforms.

Although not previously referred to as teacher routine expertise, traditional science teaching practices that remain resistant to reform-based shifts exhibit TRE characteristics. Teacher routine expertise (TRE) includes teacher-centered approaches such as didactic teacher talk (Mulvey, Chiu, Ghosh, & Bell, 2016) and following the same script for all classes with little reaction to differing student needs and understanding (Hammerness, Darling-Hammond, & Bransford, 2005). Schneider et al. (2005) conducted a study of four middle-school teachers' enactments of a reform-based science unit and reported that curricular materials helped two of the four teachers to enact new practices. These teachers' classrooms were characterized by opportunities for students to do and think and teacher questions and examples that responded to students' ideas. These two teachers exhibited TAE which will be discussed in more depth later. The other two teachers remained resistant to change with classrooms characterized by prompts for definitions and quick task completion as well as a lack of response to students' ideas. Here the classroom characteristics of these two teachers can be considered TRE. Another example study of 27 high school teachers enacting reform-inspired curriculum similarly saw teachers resistant to changes in teaching practices (Roehrig, Kruse, & Kern, 2007). Roehrig et al. (2007) characterized traditional science teaching as not allowing students to formulate their own questions or draw their own conclusions and teachers providing information directly, driven by teachers' assumptions that inquiry-based pedagogy takes too much time and runs the risk of students not arriving at the right answer. These examples illustrate TRE in both the resistance to change (Bransford, Derry, Berliner, & Hammerness, 2005) and the particular classroom characteristics shaped by the teachers (Hammerness et al., 2005; Mulvey et al., 2016).

The current iteration of science education reform approaches science learning through science and engineering practices (NRC, 2012). The integration of these practices in the NGSS represents a commitment to present science as a knowledge building activity. Building scientific knowledge through practice requires teachers to help students develop explanatory ideas from observed or experienced phenomena (Berland et al., 2016; Reiser, 2013) Catalyzed by NGSS, the vision of effective teaching in the science classroom shifts. Table 1 summarizes the shifts from the traditional science classroom (column 1) to the NGSS science classroom (column 2) (Reiser, 2013).

Currently, conceptual and theoretical literature dominates the discussion about NGSS implementation (Bybee, 2014; Pruitt, 2014; Reiser, 2013). A few studies have looked inside the classroom as teachers grapple with the shifts that they are being asked to perform as a consequence of reform (Bismack et al., 2014; Merritt, Chiu, Peters-Burton, & Bell, 2018). Bismack et al. (2014) show that teacher interpretation of practices varied even when supplied with reform-based curriculum and that teachers eschewed practices that would provide opportunities for students to explain science phenomena themselves (Bismack et al., 2014). Findings from Merritt et al. (2018) parallel those of Bismack et al. (2014), in that they found that teachers faced challenges during implementation of inquiry-based instruction often defaulting to traditional practices such as emphasizing *the* scientific method.

Using teacher interviews, reflections, and surveys, Allen and Penuel (2015) conducted a case study of three teachers in the midst of NGSS reforms. One teacher reported that the administration at her school valued teaching vocabulary and information at the start of the unit which did not align with the project-based NGSS curricula that she was striving to implement. Additionally, results from a survey administered to 10,000 science teachers across the U.S. showed that “over 80 percent of elementary science teachers agree that students should be given definitions for new vocabulary at the beginning of instruction on an idea” (Trygstad, Smith, Banilower & Nelson, 2013, p. 5). This teaching philosophy persists despite research that suggests students should be exposed to phenomena first and then develop their own definitions, practicing and using words often in context (Brown & Ryoo, 2008; Schwartz & Raphael, 1985;

Young, 2005). In addition to traditional science practice beliefs, competing demands and lack of support such as lack of time for science, lack of science PD, and assessments or pacing guides that are not aligned with new standards or curricula inhibit reform implementation causing teachers to adhere to existing practices (Allen & Penuel, 2015; Trygstad et al., 2013).

The above studies suggest that implementation of NGSS may be hindered by teaching practices or expectations that follow the script of traditional science classrooms. These stubbornly stuck practices can be considered TRE (Table 1). The framework of TAE offers a promising approach for conceptualizing teacher practices that situate NGSS reforms in a classroom. Thus, the next section reviews literature that frames a teacher as an adaptive expert.

Teacher Adaptive Expertise

Hatano and Inagaki (1986) first conceptualized adaptive expertise in contrast to routine expertise. Routine experts exhibit speed and accuracy in solving any problem that falls into well-established patterns previously experienced. Schwartz, Bransford, and Sears (2005) claim adaptive expertise to be a balance between innovation and efficiency. Too much efficiency restricts and hardens teaching into unresponsive, reenacted scripts as discussed earlier (Schwartz et al., 2005). High quality teaching practices emerge from the tension between structures (curriculum, time) and improvisation (creatively responding to students) (Sawyer, 2011), and teacher moves that balance those tensions exhibit TAE.

Research studies employing the conceptual framework of adaptive expertise span a variety of fields to include organizational leadership (Charbonnier-Voirin, El Akremi, &Vandenberghe, 2010), workplace training (Stokes, Schneider, & Lyons, 2010), medical education (Mylopoulos & Woods, 2009), and mathematics education (Baroody, 2003). Despite the widespread use of the conceptual framework of adaptive expertise in studies regarding learning generally, few research studies have used adaptive expertise exclusively in framing teacher practice (Yoon, Koehler-Yom, Anderson, Lin & Klopfer, 2015).

In one case study, Yoon et al. (2015) use adaptive expertise as a conceptual framework, operationalizing adaptive expertise in a classroom. They applied an adaptive expertise lens to a NGSS lesson enacted by three high school biology teachers, exploring teachers' flexibility, deep level of understanding, and deliberate practice (Yoon et al., 2015). Yoon et al. (2015) contend that adaptive expertise can help researchers understand practices that allow teachers to navigate the ill-structured and novel problem-solving nature of teaching and the increased ambiguity that reforms like the NGSS add to their practice.

Inspired by Yoon et al. (2015) and the salience of adaptive expertise for understanding in-service teachers' practices during reform, we reviewed literature related to adaptive expertise in teaching elementary school science. Science education researchers have applied adaptive expertise as a lens for viewing teacher practices but have not used adaptive expertise as a focal framework. Four specific practices have been described in literature on TAE: reacts to students in the classroom and through curricular design (Allen, Matthews, & Parsons, 2013; Mulvey et al., 2016); allows student agency (Lee, Chalmers, Chandra, Yeh, & Nason, 2014; Zhang, Hong, Scardamalia, Teo, & Morely, 2011); commits to continuous improvement of practice (Lee et al., 2014; Mulvey et al., 2016); and develops a deep understanding of content and related pedagogy (Lee et al., 2014; Mulvey et al., 2016). The adaptive expertise framework shows promise in science education research; however, there remains a need to apply the construct to elementary school classrooms.

Real-time response to emergent student understanding. This indicates adaptive expertise in several studies (Allen et al., 2013; Mulvey et al., 2016; Nariman & Chrispeels, 2015;

Yoon et al., 2015; Zhang et al., 2011). Allen et al. (2013) detail adaptations made by an exemplary second grade teacher. In one episode, students garnered unexpected results in an experiment that made it difficult to draw conclusions about the process. Instead of "righting" their results, their teacher adapted the originally planned lesson. She asked the students to formulate their own conclusions about the experiment's outcome. She then led a class discussion where students presented their findings and their conclusions; she used the lesson to guide their understanding of using data to question each other's findings (Allen et al., 2013).

Facilitating student-centered science discourse. Teachers with adaptive expertise are also able to facilitate student-centered discourse (Mulvey et al., 2016; Yoon et al., 2015). Zhang et al. (2011) provide an example of a teacher, Matt, facilitating a student-centered discussion. Matt guided the discussion from within the group. He referenced what other students said, allowing students to build from one another's ideas, and he asked new questions to the group to push the discussion forward. He capitalized on opportunities to build on student emergent understanding and respected the group's ability to discuss a problem (Zhang et al., 2011). Other studies consider teachers to be less effective at facilitating student-centered discourse if their classrooms included more didactic teacher talk than student discussion and if discussion consisted of responding to simple-to-answer questions (Mulvey et al., 2016; Yoon et al., 2015)

Allowing student agency. Supporting student agency is a necessary ingredient in teaching with adaptive expertise (Allen et al., 2013; Lee et al., 2014; Nariman & Chrispeels, 2015). In a study involving a PD intervention among 100 primary school teachers in China, Lee et al. (2014) found that teachers entered PD initially describing student learning as internalizing and reproducing science content transmitted by teachers and textbooks (Lee et al., 2014). After the PD, many teachers acknowledged that students were not previously treated as individual thinkers, and that through their experience in PD, they saw that each student may be "right" even if they are not the same (Lee et al., 2014). Additionally, allowing student agency helped teachers to appreciate the astonishing capability of their young students (Makar, 2007; Mulvey et al., 2016; Vokatis & Zhang, 2016).

Adaptive lesson planning (Allen et al., 2013; Mulvey et al., 2016) and development of a deeper understanding of pedagogical and content knowledge (Mulvey et al., 2016; Nariman & Chrispeels, 2015; Zhang et al., 2011) surfaced as additional TAE characteristics in the literature. These two characteristics were not seen within our data set and will not be detailed here as they are outside the scope of our study.

Taken together, the above studies indicate that TAE characteristics include responding to emergent student understanding; facilitating student-centered science discourse through building on student comments, guiding student-to-student interactions, and encouraging student explanation of phenomena; allowing student agency; adapting lesson plans; and developing a deeper understanding of content and pedagogy. Strengthening support for these characteristics, other studies employing frameworks such as ambitious science teaching (Windschitl, Thompson, Braaten, & Stroupe, 2012), responsive teaching in mathematics and science (Robertson, Atkins, Levin, & Richards, 2016), and productive disciplinary engagement (Engle & Conant, 2002) see similar characteristics as important for reform. For example, ambitious science teaching highlights adaptive lesson planning through the construction of big ideas (Windschitl et al., 2012), and responsive teaching emphasizes recognizing and responding to student emergent understanding through taking a responsive stance to students' thinking (Robertson et al., 2016). Productive disciplinary engagement specifically stresses student agency through releasing authority to students (Engle & Conant, 2002). All three frameworks similarly emphasize the importance of facilitating student-centered disciplinary discourse (Engle & Conant, 2002, Robertson et al., 2016; Windschitl et al., 2012). We see TAE as bringing together many of the elements detailed by each framework.

The unique contribution of TAE is two-fold. First, it combines and equally emphasizes important elements of each of the above frameworks, and second, it holds special importance during times of transition for in-service teachers. Studies of adaptive expertise highlight the ability of adaptive experts as well as the inability of routine experts to respond to novel problems and changing environments (Hatano & Inagaki, 1986; Yoon et al., 2015). TAE stands on the theoretical foundation of adaptation in response to not only students but also to the complex, ill-structured, and novel environment created by reform (Yoon et al., 2015). We suggest that TAE provides a theoretical framework well suited to understanding in-service teachers' practices during reform-inspired transitions.

Research Design

Research Questions

To understand specific instructional moves related to TAE during NGSS lesson enactment and to examine different teachers' enactments of a lesson with regards to TAE and TRE, we use TAE to frame the enactment of the same lesson across five classrooms. We ask: (a) What specific TAE instructional moves do teachers employ during enactment of NGSS lessons? and (b) How do teachers' enactments of the same NGSS lesson differ with regards to TAE and TRE? To address these questions, we employ a multiple-case replication design (Yin, 2007). We look closely at five teachers' enactments of the same NGSS lesson compiling characteristic of TAE across all cases and highlighting individual cases of TAE and TRE.

Context and Participants

The five teacher participants were part of the same cohort in the Connect Science (CS) program. Connect Science is a grant-funded program supporting the development of curricular materials for students and PD for teachers, and the CS curriculum contains 30 lessons. Professional development consisted of four days, one coaching session, and a classroom visit by a service-learning expert. During PD, several lessons were enacted by the facilitators, modeling pedagogical approaches. The PD did not focus specifically on TAE and did not explicitly address TRE. However, many pedagogical practices that embody TAE, like student construction of definitions through experience and exploration, were modeled and discussed. The science curriculum included eight lessons focused on NGSS concepts about energy and renewable and non-renewable resources. Producing Electricity consists of three segments and was designed with the NGSS classroom shifts in mind that are described in Table 2.

The participants were five of the nine teachers who volunteered for the CS pilot study. We selected all five participants who submitted a comprehensive video of Producing Electricity. Although the four remaining teachers submitted a video, they submitted only one segment of the lesson and did not submit other parts that were critical for our analyses. Therefore, they were not included in our study. Teachers were from public schools in two different states in the Eastern United States. Table 3 provides more detail about each teacher and their classroom.

Method

Data sources. We analyzed teacher reflections of a lesson called Producing Electricity as well as video and transcripts of the five different classes enacting the lesson. The videos were taken and submitted by each teacher as part of the larger study. There was a total of eight hours of video for the five teachers. Three teachers spent about one and a half hours on the lesson; Ivy and Zoe spent three days on the lesson in 30-minute blocks while Teresa spent five days in 20-

minute blocks. Wendy spent the most time, two hours, enacting the lesson over three days in 40-minute blocks, and Melissa spent the least time, enacting the lesson over three days in 25-minute blocks. We focused our analysis on the first and last segments of the lesson as the middle segment was videoed with differing levels of clarity, making careful comparison difficult.

Data analysis. We employed qualitative content analysis (Miles & Huberman, 1994). Our analytic process was iterative with three phases of analysis. At the end of each phase, we met with the third author and an additional CS researcher to debrief our ideas with others familiar with the study but not coding (Creswell & Miller, 2000). In our first phase of code development, the first and second author reviewed the entire corpus of work for each teacher. We each wrote notes about events and themes that seem to reoccur throughout each teacher's lesson guided by our understanding of adaptive expertise (Miles & Huberman, 1984). Then, we met to compare themes, discuss discrepancies in interpretations, and consider alternative explanations (Creswell & Miller, 2000). We re-read the transcripts for each teacher while constantly comparing to the ongoing notes to include new understandings derived from reading and watching all lessons (Glaser & Strauss, 2017).

In the second phase, we compared our notes to the operationalization of the characteristics of adaptive expertise from the literature as detailed in the previous section. Next, we created a codebook that included both themes from the literature and from data (DeCuir-Gunby, Marshall, & McCulloch, 2011). We decided not to include the categories adapts to students in lesson planning or developing deep understanding mentioned in the literature review. Our classroom data did not adequately address those TAE characteristics which are better understood through other data sources.

In the final phase, author one and two blindly coded two transcripts with the newly refined codes. Then, we came together to negotiate any differing interpretation of the data and come to complete consensus before the remainder of the transcripts were coded by the first author (Creswell & Miller, 2000). Through conversations between the first and second author, we developed an additional new code (no response) based on what we saw in the data. Our final codebook can be seen in Table 4.

Findings

TAE and TRE Across Cases

This first section of findings looks across the multiple cases at examples of TAE and TRE instances in the context of reform lesson enactment. This section elaborates on the characteristics of TAE and TRE outlined in Table 4 by presenting empirical examples of each characteristic with sub-categories.

Adapts to emergent student understanding. Adapting to emergent student understanding occurs through lesson changes or discussions sparked by student confusion or interest (Allen et al., 2013; Mulvey et al., 2016; Nariman & Chrispeels, 2015; Yoon et al., 2015; Zhang et al., 2011). We saw three major ways that teachers responded to emergent student understanding in our study: adaptively, routinely, and no response (see Table 4 for frequency of codes). Teachers exhibited adaptive reactions by guiding students through an explanatory process without explaining the phenomena themselves. Teresa showed adaptive responses 17 times; here Teresa adaptively prompts students for a coherent explanation:

> Teresa: So, what did you and your partner talk about? What is this picture showing you? How does it relate to the video that we just watched?

Student 1: Probably it's showing us…the dam right there is trying to block the water from coming this way.

Teresa: Ok. Can you tell me more?... add on to what Barbara was saying.

Student 2: The dam doesn't let the water go because its going through the thing that rotates the thing.

Teresa: This turbine (points to label on diagram), ok, gets rotated…

Student 2: After that it makes electricity then it goes through the cables then it goes back to the river.

Teresa: Ok. Add on or continue what he was saying…

Student 3: When the turbine spins it rubs something around copper and creates electricity.

As with many of her class examples, Teresa shows adaptive expertise in two ways. First, she allows students to discuss the artifact supplied with the lesson giving students time to explore their own understanding (student ideas emerge), and second, she refrains from lecturing on the "correct" interpretation. Instead, Teresa listens carefully responding to their emergent understanding, in this case by facilitating elaboration.

Others reacted routinely by supplying direct information to students. Ivy's class included five instances of direct information:

Student: What's the difference between a power plant and a nuclear power plant?

Ivy: The type of energy they're storing.

Here a student is curious about different ways of producing electricity. Nuclear energy was not part of the lesson, but the student seems to be drawing on prior knowledge. Although Ivy does respond, she exhibits TRE as she does not deviate from the lesson (there was nothing about nuclear energy) to deepen student emergent understanding or to follow a student's lead and address a topic of interest.

Lastly, with regards to adapts to student emergent understanding, all of the teachers missed the opportunity to respond to emergent student understanding a total of 24 times (Table 4). This last type of reaction was not previously mentioned in the literature around TAE. One example of a missed opportunity surfaced during the presentations in segment three of the lesson. Here a student is asking another student:

> Student 1: Well, do you know which? I know that my group studied coal, but we didn't find this part out. Do you know what turns it into electricity? Like is it the wire that does something? Or is it the generator?
>
> Student 2: Well when the coal goes in, it like, it disintegrates and turns into steam. And then it goes through the generator.
>
> Zoe: Does that answer your question?
>
> Student 1: Sort of.

Zoe left this discussion at this point, and the class discussion continued with unrelated questions posed by other students. From our point of view (the curricular designers) this was an important question that centered directly on a key concept of the lesson. Additionally, the above exchange shows that Student 1 was trying to fill in missing parts to her understanding of electricity production, and Student 2 was trying to provide pieces that they did not quite have yet. Here would have been a good point to facilitate a discussion about generators, wires, and producing electricity as students themselves were trying to mediate that discussion but needed guidance. That discussion would serve to extend students' emergent understanding. We considered this and other cases like it to be missed opportunities. We don't characterize missed opportunities as either TAE or TRE, but we do contend that it indicates lack of TAE in fostering emergent student understanding.

Facilitating student-centered science discourse. Building on student comments (Zhang et al., 2011), asking open questions that elicit explanatory responses from students (Yoon et al., 2015), and less didactic teacher talk (Mulvey et al., 2016) all contribute to student-centered discourse of science phenomena and exhibit adaptive expertise. We saw numerous adaptive and routine examples of each of these in our classroom data. We added to and refined this TAE characteristic by further characterizing sub-sets of this category like building on comments as well as developing the sub-category of explanation of phenomena as seen in Table 4 under facilitating science discourse.

Explanation of phenomena. The NGSS emphasize a shift from students' learning about phenomena to explaining phenomena (Reiser, 2013). We saw two categories of explanation of phenomena, one by the student and one by the teacher. Often teachers took up long blocks of time providing students with an explanation of a phenomena before the students had a chance to experience the phenomena and explain themselves (117 times). For example, Ivy provided the following explanation without eliciting students' prior knowledge first (as suggested explicitly in the lesson plan):

> Okay. So, guys, every power plant that you see or go by uses an energy source to get electric current moving through the wires just like the battery was used to get electric current moving. However, power plants are definitely different in the way they use different kinds of energy sources to produce electricity—they don't use batteries—in how they transmit the electricity and in how much electricity is actually produced to run into the neighborhood through your homes.

Contrast the above example with how Melissa introduced the same lesson:

> Melissa: Now you guys have had experience in taking a battery and wire and making light, right? So Kaylee just turned the light off and then she turned it back on again. What happened? How did she do that?
>
> Student: Because the light switch took the energy from some energy source and took it to the light.

Ivy employs teacher didactic talk before students have time to explore the concept, and after, she moves on to the next part of the lesson. Melissa opens with questions and an experience (the light switching on and off). After, Melissa facilitates a discussion leading to the concepts that Ivy directly taught. Melissa gives time for students to make connections and fosters discussion that makes student emergent understanding transparent whereas direct teaching limits those opportunities. In these contrasting examples, Melissa exhibits TAE while Ivy exhibits TRE.

Although student explanation of phenomena was seen in all classrooms during the presentations as dictated by the curricular material (114 times), this occurred less (55 times) in the first segment of the lesson where student explanation of the phenomena would be left to individual teaching styles (see Table 2 for lesson segment details). The student presentation section of the lesson often saw this type of explanatory exchange between students:

> Student 1: Um, how is, what's it called, gas, what's that?
>
> Student 2: That's just like, they take… the trash they put in landfills, they take that and they burn it. And that's called landfill gas.
>
> Student 3: How do crops get to be electricity?
>
> Student 2: They burn.

Interactions such as this were common in the third segment with students facilitating each other's thinking, and student questions, after the presentation, providing opportunities for students to work through gaps in their explanations.

Not only did student explanation occur more often in the third segment of the lesson, but it was also seen in high numbers in classrooms where it was rare in the first segment. For example, Zoe's class had two student explanations in the first segment and 27 in the third segment of the lesson. This disparity indicates that student explanation in the third segment might be driven by the task designed in the curriculum (student presentations) as opposed to TAE of the teacher. All of our teachers employed teacher explanation of phenomena to some extent in the first segment of the lesson for a total of 112 times (Table 4). We consider teacher explanation that happens prior to student explanatory response to be TRE while high frequencies of student explanation of phenomena in the first segment indicates TAE.

Build on student comments. Teachers built on student comments' in three ways: encouraging student-to-student building, building on student comments themselves to clarify and connect, and building on student comments themselves to explain phenomena. First, we saw 21 examples (Table 4) as demonstrated in the literature of teachers using phrases like, "Ok, who wants to add on to what Owen said?", to encourage student-to-student comment building. Second, we saw teachers build on student comments themselves. Here, they would connect and clarify previous student comments showing TAE, as seen in Teresa's classroom:

> So, making our kind of connections… Michael said… you can make things out of other plastic things. Like plastic bottles you can make into something…. Edwin said that chickens produce eggs. The chicken makes the egg… then Michael said that fossil fuels produce electricity. We use the fossil fuels to make electricity.

Building on and connecting student explanations provides students opportunities to elaborate on their own explanations and respects the students' abilities to discuss phenomena (Zhang et al., 2011). This type of TAE teacher comment building was seen 70 times across all participants.

Other times, teachers would build on student comments with additional information, so much so, that they engaged in teacher explanation of phenomena showing TRE. This move was seen 16 times in Wendy's class, here is one example:

> Wendy: Ok, so um, somebody try to remember, and try to remind me because I've almost forgotten—what we learned about in electrical circuits?
>
> Student: There are many ways to do it.
>
> Wendy: Many ways to do it. We discovered lots of different ways to do it. To make that circuit. Yes?
>
> Student: You have to use one on negative and one on positive.
>
> Wendy: Right, negative and positive. Right. Yes?
>
> Student: You have to connect it to the light bulb.
>
> Wendy: Very good. And we discovered a number of different ways to do that though, didn't we? But in each case, we had to have the circuit, remember that? The pathway for the electricity to flow.

Above, Wendy engaged her students in a discussion about what they learned in their electric circuit lesson, but she had a particular answer in mind. When student comments did not supply that answer, she supplies that answer herself (a circuit is a pathway for the flow of electricity). This closed, TRE approach to discussion, using easy to answer questions, did not produce as much student explanation as did Teresa's and Melissa's more open, TAE approach.

Allows student agency. Previous studies around TAE operationalize student agency as students in the same class having different products (Lee et al., 2014). In our case, the curricular material encouraged this as it had student groups research different energy sources and construct their own models, so we did not count this as TAE. In segment three, student agency was seen 23 times as compared to the 13 times it was seen in segment one. Also, in segment three, all teachers had either 4 or 5 examples of differing student products whereas some teachers had one or none in the first segment. The only examples of allowing differences in student products prompted by the teachers in the first segment of the lesson revolved around vocabulary instruction. In two classes, students were expected to copy teacher-provided definitions, indicating that the teachers expected to see the same definition replicated in each notebook. This exchange typifies routine expertise around vocabulary:

> Zoe: Ian can you read the next vocabulary word and what it means?
>
> Student: Energy source
>
> Zoe: And what does it mean?
>
> Student: (reading) Materials such as oil, wood, coal used to produce electricity.

In fact, Zoe writes that she purposefully changed this part of the lesson because:

> I believe that there is great value in pre-teaching science vocabulary, especially when students will be reading text independent from the teacher (as they will in the producing electricity lessons). I felt it important to pre-teach the vocabulary so students could understand the videos as well. I also intend on reviewing the words daily.

Despite explicit instructions in the lesson plan and modeling in PD, Zoe chose to introduce this lesson with vocabulary memorization. From her reflection, we understand that she clearly sees vocabulary taught explicitly as a best practice, indicating TRE. This is reminiscent of the example in the literature review where administrators seemed to espouse support for this practice despite its misalignment with project-based curricula (Allen & Penuel, 2015).

Three other classes allowed students to work out definitions through conversation and did not require that each student produce the exact same definition. Exhibiting features of an adaptive expert, Teresa facilitates a discussion about the meaning of the word produce:

Teresa: Where have you heard the word produce before? Edwin?

Student 1: Like a chicken produces eggs.

Teresa: A chicken produces eggs. So it makes the eggs…

Student 2: Like how, this has to do with the energy, like how fossil fuels produce energy

Teresa, Melissa, and Ivy gave students freedom to conceptualize the new vocabulary words through their experiences as modeled in PD and suggested by the literature (Brown & Ryoo, 2008; Schwartz & Raphael, 1985; Young, 2005), exhibiting TAE. As the above findings section across the cases aims to develop and support TAE through empirical examples, we show additional examples for each characteristic in Table 5.

Variation Within and Between Cases

As part of the multi-case replication design, we focus on each teacher's classroom to get an integrated sense of TAE and TRE. Variance with regards to TAE in each classroom allows us to explore the way that characteristics of TAE and TRE combine during implementation. To look at variance within and between each teacher's enactment**,** we created a fingerprint comparison of teacher practices represented by our TAE codes (Figure 1). This fingerprint acts as a visual representation of the variance seen in each classroom; looking across the bars shows the relative frequency of each activity in each classroom. Reading down the bars and taking note of bar color for each teacher, we see how each classroom spent their time. This graphic represents variance in the first segment of the lesson only as enactment of later segments closely followed the curricular material showing less variance.

Figure 1 shows that Teresa's class saw the most TAE. These TAE occurrences were part of the whole-class discussion facilitated by Teresa. This classroom discussion did not center on Teresa due to her well-placed attempts to encourage student-to-student comment building (9 times). This practice, as well as her willingness to explore student comments deeply (adaptive response, 16 times) culminated in a high, relative frequency of student explanation of phenomena. In fact, in this first segment across all teachers, students explained phenomena 57 times with Teresa's class representing 61% of those occurrences (Figure 1). For this section, Teresa exemplifies TAE.

Zoe's class, on the other hand, showed the least amount of student explanation of phenomena (2), and this can be attributed to Zoe's choice to replace classroom discussion with vocabulary instruction. In this part of the lesson, students read vocabulary words and definitions from the board and copied them into their notebooks. We observed low frequencies of student explanation (2), high frequencies of negative student agency (8), and a lack of student (0) and teacher building (0) on student comments. For this section, Zoe exemplifies TRE.

A third example provides yet another view of teacher enactment in the same lesson. Wendy conducted whole class discussion and asked students to copy vocabulary twice. Wendy frequently built on student comments herself, both adaptively (30) and routinely (12). This manifested as a series of questions and answers between Wendy and individual students ending with Wendy's explanation of phenomena (43 times). This approach made her whole class discussion teacher-centered, and while she did exhibit adaptive responses often (10 times), the low rate of student explanation of phenomena (4) compared to the high rate of teacher explanation of phenomena (43) shows TRE. Here, we consider Wendy to be more adaptive than Zoe but more routine than Teresa.

There is a continuum of adaptive expertise, exemplified by various practices exhibited over time. It would not be accurate to label a teacher a routine or adaptive expert through observing a single lesson. All teachers showed both TRE and TAE to differing degrees in segment one of the lesson, indicating that even teachers who appear to be more routine experts can enact TAE moves.

Discussion

Through this study, we developed and refined characteristics of TAE and TRE. Most of our findings reinforce characteristics and teaching practices found in other studies that include TAE as a model (Allen et al., 2013; Mulvey et al., 2016; Nariman & Chrispeels, 2015; Yoon et al., 2015; Zhang et al., 2011) and studies concerning best practices for reform (Engle & Conant, 2002; Robertson et al., 2016; Windschitl et al., 2012). We extend prior work by illustrating allows student agency and refining responds to emerging student understanding during lesson enactment.

Previous studies using adaptive expertise defined student agency as allowing for different student products (Lee et al., 2014). Here we supply specific, empirical examples of some products that might need to differ for student agency to be achieved including vocabulary “definitions” and student artifacts. As encouraged in PD, most of our teachers allowed students to discuss and define vocabulary in their own words, making student emergent understanding transparent as well as allowing student sense-making time (Young, 2005). Consistent with other studies (Bismack et al., 2014; Schneider et al., 2005; Remillard, 2000), we found that carefully designed curriculum aided in enactment of reformed practices as the student presentation task in the third segment increased instances of student explanation of phenomena across all teachers regardless of the level of TAE they displayed in the first segment of the lesson.

Teachers in our study responded to emergent student understanding adaptively, routinely, or not at all. Both adaptive and routine responses have been previously characterized (Allen et al., 2013; Mulvey et al., 2016; Yoon et al., 2015), but no response has not previously surfaced. We clearly saw many missed opportunities to extend or untangle student thinking. In summary, a TAE classroom can be recognized by differing student products, frequent student explanation of phenomena, students building on other students' comments, and teachers recognizing and guiding student emergent understanding. Alternatively, a TRE classroom can be recognized by no differences among student work, frequent teacher explanation of phenomena, little student-to-student interaction, and teachers reacting to student emergent understanding by providing information.

Our findings suggest that routine expertise choices may challenge NGSS shifts in classrooms (Table 1). We consider TRE practices to be stubbornly stuck as they have persisted throughout reform efforts, remaining in place despite recommendations supported by research (Allen & Penuel, 2015; Bismack et al., 2014; Roehrig et al., 2007; Schneider et al., 2005). Routine expertise is a type of expertise and as such has evolved in the school system ecology (Anderson, 2002). Some aspects of TRE may have developed in response to science assessments focusing on recall of facts and decoding science words (Bybee, 2014; Anderson, 2002).

Findings from our study suggest that TRE may be particularly prevalent among experienced teachers. The teacher with the least experience, Teresa, exhibited the most TAE whereas the other teachers, all with 15 or more years of experience, exhibited TRE more often.

TRE moves as seen in our study seem to be types of hardened scripts enacted over time as teachers provide students with information to prepare them for tests that ask for information (Schwartz et al., 2005). Despite new curricular material and PD that emphasizes more student explanation of phenomena and student agency, our most experienced teachers intentionally add vocabulary memorization and habitually employed direct teaching.

Implications

Our research suggests that shifting science classroom practices toward NGSS can be accomplished in part with NGSS-aligned curricular material. Specifically, teachers need lessons including tasks that create several opportunities for student-to-student science discourse and allow for differing student products. The other side of the shift centers on teacher practices.

Particularly, teachers need to be able to recognize and respond to student emergent understanding, introduce new vocabulary through student experience, encourage more student-to-student interactions, and make room for more student explanation of phenomena prior to direct instruction. Curricular material and PD should include explicit suggestions and training around vocabulary instruction and facilitating student-centered discourse. These represent areas of science teacher practice that may be stubbornly stuck for some teachers.

Additionally, if we hope to move from student recall of facts to student explanation of phenomena (Reiser, 2013), PD experiences may need more time dedicated to helping teachers reduce missed opportunities by recognizing student emergent understanding and creating opportunities for students to make sense of phenomena (Bybee, 2014). Professional development may need to include more than just common student misconceptions and how to “fix” them. Student emergent understandings are building blocks to science concept development (Campbell, Schwarz, & Windschitl, 2016), and PD should help teachers make sense of a range of student understandings.

Further, our study suggests that PD pedagogy should include eliciting prior practice as TRE needs to be explicitly addressed when working with in-service teachers on reform. Frameworks around best teaching practices, TAE included, indicate that students' ideas and previous experiences need to be included as part of learning new concepts. The years of experience and the practices that in-service teachers have developed need to be acknowledged and used as a foundation for making shifts in practice. As we see working from teachers' experiences in PD as essential to shifts, another productive PD pedagogy is rehearsal. Here teachers can apply reform pedagogy to previous classroom episodes and rehearse them directly in PD connecting previous experience to needed shifts in teaching practices (Kazemi & Hubbard, 2008; Lampert, 2010).

This exploratory study represents a modest beginning to the development and application of TAE; to further cement TAE as an overarching framework, work needs to be done in compiling foundational science education ideas within the TAE framework and adding more empirical examples to each characteristic. Many of our findings center around science discourse, but we suggest that this is a limitation of our study not a limitation of the framework of TAE; our data-set and context provided insight primarily through classroom discussion. Future studies with teacher-designed lessons and data sources that illuminate teacher actions outside of the classroom can add non-discourse examples to many of the TAE characteristics found in the literature. We see this work around TAE to be worthwhile for the investigation of transitions of practice particularly salient to those working with experienced, in-service teachers.

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Table 1

Science Classroom Shifts from Traditional to Next Generation Science Standards (NGSS)

Science should NOT be (traditional)	Science should be (NGSS)
A sequence of topics pursued by traditional curricula	Work driven by questions arising from natural phenomena
Simple hypothesis testing	Guided by the goal of constructing explanatory models
Investigations that end with only correlation of two variables	Investigations that end with an explanatory account
Students learning the next assigned topic	Students working on answering explanatory questions
Emphasize only procedural skills in doing experiments	Teachers supporting knowledge building aspects of practice
Focused on explanations of analysis or phenomena by textbook or teacher	Focused on argumentation and consensus building after investigation and analysis
In a classroom culture of waiting for the right answers to be given by a teacher or a text.	In a classroom culture where students are normally responsible for figuring out through collaboration with peers

Note. Adapted from text in “What Professional Development Strategies are Needed for Successful Implementation of the Next Generation Science Standards?” by B.J. Reiser, 2013, Paper prepared for K12 Center at ETS Invitational Symposium on Science Assessment, p. 11. Copyright 2013 by ETS.

Table 2

Outline of Producing Electricity Lesson Plan with Links to Intended Next Generation Science Standard (NGSS) shifts

Lesson Segment	Description of Segment
Intended NGSS shift designed for: Work driven by questions arising from phenomena	
Segment One	
Link to prior knowledge	Students share background knowledge about electricity production by answering questions like: When you turn on a light at home or at school, where do you think the electricity comes from? They also explore the meaning of produce: We say that power plants produce electricity. How have you heard the word produced before? What do you think it means?
Demonstrate a hand-held generator	Elicit student ideas as you demonstrate the generator with questions like: How do you think it works?
Watch video and discuss hydroelectricity	Watch the provided video and have students talk with partners about what is happening in the video. Possible prompts for discussion include: What did you observe happening at the hydroelectric power plant? Where does the energy come from? How does the flow of water produce electricity? And where does the energy go?
Intended NGSS shift designed for: Guided by the goal of constructing explanatory models	
Segment Two	
Small Group Research.	Allow students to choose an energy source based on their interests. Research resources were provided for coal, biomass, hydroelectricity, solar and wind. For the selected energy source each student should create a diagram that illustrates how electricity is generated from their source and a definition of that type of energy. Before drawing or writing, they should discuss what

	they see to each other until everyone understands. They should work together to plan a presentation for their classmates. Circulate to support students as they collaborate to learn.

Intended NGSS shift designed for: Focused on argumentation and consensus building after investigation and analysis

Segment Three

Whole class group presentations	Provide each group with time to present. Encourage students to ask each other questions and remind them that scientists ask each other questions to understand each other's ideas. Consider these questions: Can you tell me more about how that part works? How is that power plant similar to yours? How is it different? Does the model explain how your energy source produces power? What other details are needed? Are there new words that you learned?

Table 3

Teacher and Classroom Data

Teacher	Years Teaching	Highest Degree	Grade	Number of Students	Socio-demographics of Classroom
Teresa	4	Bachelors	4	21	38 % ELL 5% African American 5% Asian 10% Caucasian 80% Hispanic
Zoe	23	Masters	4	24	0 % ELL 12.5 % African American 4% Asian 50% Caucasian 12.5% Hispanic 21% Other
Wendy	22	Masters	4	16	0 % ELL 0% African American 19% Asian 81% Caucasian 0% Hispanic
Ivy	15	Masters	4	22	5 % ELL 5% African American 5% Asian 72% Caucasian 18% Hispanic
Mellissa	27	Masters	4/5	21	8 % ELL 12.5% African American 0% Asian 67 % Caucasian 12.5 % Hispanic 8% Other

Table 4

Code Book with Teacher Adaptive Expertise (TAE) and Teacher Routine Expertise (TRE) Characteristics

Characteristic	Code Definitions and Categories	Total Code Frequency[a]
Responses to emergent student understanding	Adaptive: Recognizes and prioritizes emergent student understanding. Responds in real-time to student confusion, frustration, or tenuous understanding with guidance. (TAE)	29
	Routine: Prioritizes following the lesson plan over exploring emergent student understanding. Can be seen by directly providing student with information when they are confused. (TRE)	22
	None: Does not recognized and/or respond in real-time to student confusion, frustration or tenuous understanding.	24
Facilitates science discourse		
Explanation of phenomena	Student explains phenomena in own words before the teacher explains it. (TAE)	169
	Teacher explains phenomena before students. (TRE)	117
Builds on student comments	Teacher encourages students to build on other student's comments in discussion. (TAE)	21
	Teacher builds on student comments herself to clarify and connect. (TAE)	70
	Teacher builds on student comments herself by providing additional information or explanation. (TRE)	23
Allows student agency	Accepts variance in student products. (TAE)	36
	Lack of agency seen when student products are expected to be identical. (TRE)	11

Note. [a]Indicates frequency across the first and third segment of the lesson for all teachers.

Table 5

Additional Examples of Teacher Adaptive Expertise (TAE) and Teacher Routine Expertise (TRE)

Characteristic	Example
Responses to emergent student understanding	
Adaptive (TAE)	The video about hydroelectricity was quite short and fast. In Zoe's classroom, her students expressed frustration with being unable to understand the video. She replayed the video twice, and on the last time, she paused the video at specific points so students could discuss what they had heard and understood in small groups.
Routine (TRE)	Student: Is the generator out of battery? Teresa: Nope, it doesn't use batteries.
None	Student 1: Okay I did mine on biomass. Biomass is manure also known as cow poop. The manure gets steamed into energy which goes to the turbine which goes to the generator. The generator makes the energy for the power of poo. Melissa: Any questions for Amy? Student 1: Clara? Student 2: So like what happen to the poo? Student 1: So the poo gets into the generator, I mean, not a generator, but steamer which makes the energy and goes to the generator. Max? Student 3: How does steam turn into the generator? Student 1: Well we didn't get that far into reading. Melissa: Does anybody else want to share? (Moves on to next group without discussion of above).
Facilitates science discourse	
Student explains (TAE)	Student (Ivy's Class): The greater the intensity of the sun, the greater the current of the electricity, even on cloudy days your solar panels will absorb sunlight.
Teacher explains (TRE)	The class watches a video about hydroelectricity. Directly after: Wendy: So we kind of interrupted the flow of water temporarily, we borrowed the water for a little bit, it did its thing, it made electricity, and then it went on its happy, merry way. Renewable

	energy, that's pretty cool. So can anybody tell me what just happened?
Builds on student comments	
Encourage student to student (TAE)	Melissa: Can anybody add something to that?
Teacher builds (TAE)	Wendy: Alright, so what we need for all of our power plants. Doesn't matter, so somebody said its coming from the sun, somebody from the wind, somebody mentioned coal, and all of these things are energy sources.
Teacher builds (TRE)	Wendy: What else do we notice? Student 1: The spinner. Wendy: Yeah, and what was it doing? Student 1: Spinning Wendy: It was making it spin, absolutely. So, and what power was I actually using to get my generator going? Student 2: Like, Adam's arm. Wendy: Adam's arm. Adam's birthday arm was the power behind the generator. Absolutely. And then we went to our hydroelectric…video and we saw that it was water, not the arm power, that was powering up that generator. Remember all that? Ok.
Allows student agency	
Student agency + (TAE)	Ivy: Where have you heard the word produce before? Student 1: I heard it with food Ivy: Food! Like fruit and stuff. Like Brad is the produce manager at Kroger's when he's in charge of all the fruits and vegetables, right? Anyone else heard it a different way? Student 2: Well its kind of the same as Andrea, but when you go into the store and they have, like a produce aisle a variety of fresh produce. Ivy: Right! Yeah, I get it. Naomi? Student 3: Um, like when people produce movies. Ivy: Producers of movies. Yep. Producers, so they're making something. Student 4: Um, like plants, some plants produce their own food and energy.
Student agency – (TRE)	Zoe: My first direction was to take out your vocabulary words.

We're going to review them very quickly. So, Casey, could you read the first work and tell us what it means? We need to know these works to do our next activity.
Student: Circuit
Zoe: Okay, what does it mean, what's a circuit?
Student: (reads the definition from the board while other students copy down the definition in their notebooks).

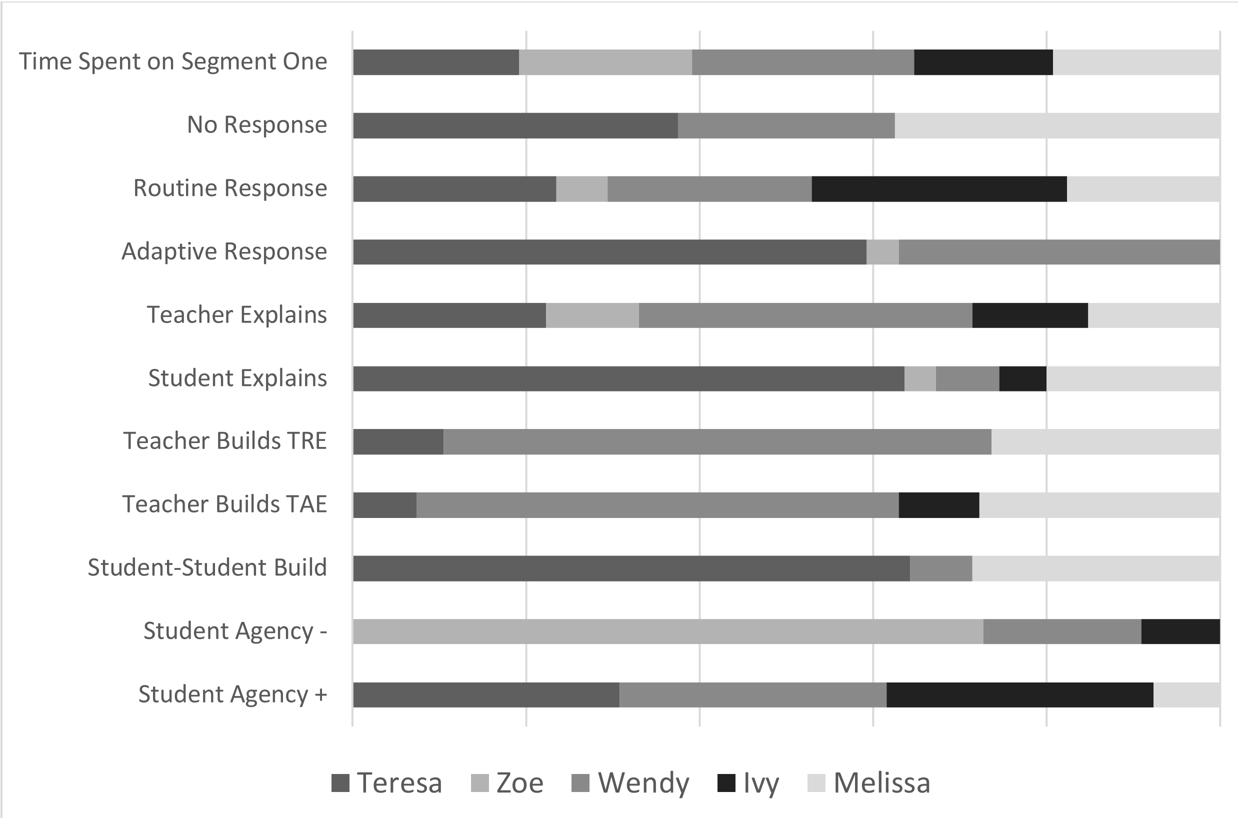

Figure 1. Variance in teacher adaptive and routine moves. This figure shows the relative frequencies of TAE and TRE moves in the first segment of Producing Electricity for each teacher.