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Using Epistemic Network Analysis to Explore Discourse Patterns across Design Iterations of a Teacher Dashboard

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Abstract: Providing high-level support to students on NGSS inquiry practices can be challenging; however, teacher dashboards can help teachers provide just-in-time instruction to students, both in-person and online. Prior work has shown some success with a dashboard that alerts teachers in real time on students' science inquiry difficulties, but teachers differed in their use of the alerts. To further support teachers, we designed a second iteration, in which the alerts included actionable, evidence-based Teacher Inquiry Practice Supports (TIPS), a series of suggested scaffolds that teachers can use to support students on the practices with which they are struggling. In this study, we investigate how the discursive support patterns from one teacher differed when using the dashboard alerts *without* TIPS followed by *with* TIPS. Findings suggest that TIPS influenced how the teacher incorporated different types of support for her students, and further, that the support given varied across different virtual lab stages.

Introduction

With increased efforts to boost national science achievement, 44 states and D.C. have adopted the Next Generation Science Standards (NGSS Lead States 2013; NGSS, henceforth), which outlines core science inquiry practices that, when richly integrated with content, reflect competencies that students need for future success in STEM careers (National Research Council, 2018). However, teachers have found inquiry to be difficult to implement in their science classrooms for many reasons, including: time, space, or material constraints (Lo et al., 2014; Zinger et al., 2020); the lack of authentic, empirically tested resources (Krajcik, et al., 2000; Schneider, et al., 2005); the time-intensive, subjective nature of grading inquiry (Deters, 2005); the arduous burden of grading multiple authentic inquiry assignments (Gobert et al., 2018); and the lack of immediate actionable data for identifying student difficulties (Kuhn, 2005).

Due to these difficulties in teaching *and* assessing inquiry, teachers need real-time, fine-grained data about their students' inquiry competencies that are typically not visible within the constraints of the class (Martinez-Maldonado, et al., 2015). One technological development that can address this need is a dashboard, a monitoring tool that provides data on student performance and progress (Dillenbourg, 2013; Holstein et al., 2019). Alerting dashboards can provide detailed, contextual information to teachers to identify and diagnose students' difficulties and to support students' learning in real time (Roschelle et al., 2017).

Although a number of dashboards consider students' content understanding or collaborative interactions in science (e.g., CK Biology curriculum dashboard; Acosta & Slotta, 2018; WISE dashboard, Matuk et al., 2016; SAIL Smart Space's tablet tool, Tissenbaum & Slotta, 2019), these tools are not designed or technologically-instrumented to gather and analyze students' science inquiry practice competencies emphasized as critical by policy documents such as the Next Generation Science Standards (NGSS, 2013). Furthermore, these science dashboards either do not provide alerts (e.g., Acosta & Slotta, 2018; Matuk et al., 2016) or only provide alerts about activity completion (e.g., Tissenbaum & Slotta, 2019), rather than providing real-time alerts about student difficulties. Thus, for NGSS to be realized, there is a need for alerting dashboards that provide teachers with actionable data about their students' inquiry competencies so that teachers can provide instruction on inquiry practices to students as they work in real-time, when deep learning is optimal (Koedinger & Corbett, 2006).

About Inq-ITS and Inq-Blotter

The Inquiry Intelligent Tutoring System (Inq-ITS) is an intelligent tutoring system platform that uses patented, educational data-mined and knowledge-engineered algorithms (Gobert et al., 2013) to assess students' competencies on key scientific inquiry practices outlined in the Next Generation Science Standards (NGSS, 2013). To better help teachers provide support to students as they are conducting inquiry within the virtual labs in the Inq-ITS environment, a teacher dashboard, called Inq-Blotter, was developed (Gobert et al., 2018). With Inq-Blotter, teachers receive real-time alerts based on the data gathered from the fine-grained automated assessments built into Inq-ITS. In the original design iteration of Inq-Blotter, these alerts provided textual descriptions and visualizations about both individual and whole-class student performance, including information on the activities students completed, progress bars with scores on each of the inquiry practices, and fine-grained data about students' difficulties on each of the practices (Gobert et al., 2018). To our knowledge, this is the only dashboard that provides alerts based on rigorous, fine-grained assessment of students' scientific inquiry competencies.

To test this first design iteration of the alerts in Inq-Blotter, Sao Pedro et al. (2019) conducted a randomized controlled study comparing the effects of teacher support elicited by Inq-Blotter with alerts versus without alerts (i.e., no performance data) and found that students supported by a teacher using alerts improved more than students helped by a teacher without alerts. While these alerts were helpful in notifying teachers about the specific ways in which individual students were struggling, additional studies have shown that, when provided with the basic alerts alone, teachers may tend to deliver lower levels of support to students (e.g., telling students which variables to hold constant in an investigation; Dickler et al., 2019, 2021). Although the lower levels of support may help students in the short term, the students who received more sophisticated combinations of high-level inquiry support (e.g., explaining what controlled variables are and why they are important) showed more robust improvement in their inquiry practice performances over time (Dickler et al., 2019, 2021).

Therefore, for the second design iteration of the alerts, we used high-level exemplars of teacher support that were associated with student improvement (Dickler et al., 2019) to develop Teacher Inquiry Practice Supports (TIPS; Adair et al., 2020). Embedded directly into the alerts, TIPS offers suggestions on *how* teachers can provide inquiry support to a student for the specific practice with which they are struggling. Due to its importance for teachers' instruction of NGSS practices, more in-depth research is needed to determine how TIPS influence the types of support that teachers provide when guiding their students' scientific inquiry.

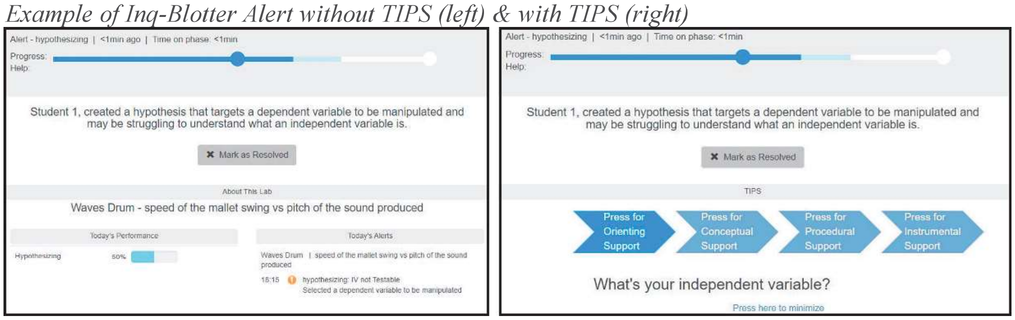
In the present case study, we build on our prior work that used Epistemic Network Analysis (ENA; Shaffer et al., 2016) to examine teacher discourse when using Inq-Blotter (Dickler et al., 2019, 2021). Specifically, we use these same methods to deeply examine the discursive support patterns of one teacher, Mrs. A, and compare the ways in which those patterns change when the Inq-Blotter alerts contain TIPS versus when they do not. In short, we seek to understand: *How do the discursive patterns of support differ when Mrs. A uses the teacher dashboard alerts with TIPS versus without TIPS?*

Method

Participants include one teacher, Mrs. A, and her eighth-grade physical science students from a Title 1 middle school located in the Northwestern United States. Mrs. A reported that, of her 157 students, 97% receive free/reduced lunch, 74% are English Language Learners, and 83% identify as students of color. Mrs. A has six years of teaching experience, including five years using Inq-ITS in her classroom. However, she had no experience with Inq-Blotter prior to the data collection days.

Data was collected over two days in January 2021, during which Mrs. A was conducting synchronous classes fully remotely via Zoom due to the COVID-19 pandemic. The school followed an alternating A/B schedule, in which students on "Schedule A" had class with Mrs. A on Tuesdays and Thursdays, while students on "Schedule B" had class with Mrs. A on Wednesdays and Fridays. In total, 65 students logged in and worked on at least one stage of the virtual lab during the two data collection days – 30 students on Day 1 (Tuesday) and 35 *different* students on Day 2 (Wednesday).

Figure 1
Example of Inq-Blotter Alert without TIPS (left) & with TIPS (right)



Materials

The students used Inq-ITS to conduct an NGSS-aligned virtual inquiry investigations on the topic of waves, related to NGSS Performance Expectation MS-PS4-2. The goal of the investigation was to determine how the speed of a mallet striking a drum influences the pitch of the sound produced. As part of the inquiry investigation, the students complete four stages: (1) asking questions/hypothesizing, (2) carrying out investigations/collecting data, (3) analyzing/interpreting data, and (4) constructing explanations/communicating findings. For the first three stages, students are automatically assessed in real time through algorithms built into Inq-ITS, which then trigger fine-grained alerts for the teacher to view on Inq-Blotter (Gobert et al., 2013, 2018). Development of the automated scoring and dashboard alerts, for the communicating findings stage is still on-going (Li et al., 2017).

On both data collection days, Mrs. A used Inq-Blotter (Gobert et al., 2018) to receive real-time alerts about her students' difficulties on specific inquiry practices as they were working on the lab. Specifically, on Day 1, the teacher used the original version of Inq-Blotter *without* the instructional support of TIPS, and on Day 2, the teacher used the iterated design version of Inq-Blotter *with* the instructional support of TIPS embedded into the alerts (see Figure 1). The TIPS (Teacher Inquiry Practice Supports; Adair et al., 2020) are a series of suggested scaffolds, which were modeled from the supports (Adair et al., 2020) that teachers had generated in real time when responding to the first design iteration of Inq-Blotter alerts and that were shown to improve student inquiry performance in prior studies (Dickler et al., 2019, 2021).

Measures

All teacher-student interactions during the designated class times over the two data collection days were audio-recorded via the video conferencing platform Zoom. Audio recordings were transcribed, and 211 teacher-spoken segments were identified from across the class sessions. A segment was considered a new segment if the teacher: (a) shifted from addressing one individual student to another, or (b) shifted to addressing the whole class rather than an individual student or vice versa. Two researchers coded all teacher-spoken segments, with 86% agreement initially between the researchers. Disagreements were discussed and clarifications to the codebook were made until 100% agreement was reached. The agreed-upon codes were used for analyses.

The codebook included seven types of support (see Table 1) developed and used in prior studies with Inq-Blotter (Dickler et al., 2019, 2021). The first four types of support (orienting, conceptual, procedural, and instrumental) are scaffolds that are implemented specifically in supporting students on inquiry practices, whereas the last three types (scientific content, evaluative, and technical) are not directly related to inquiry support. Codes were not considered mutually exclusive and could co-occur within teacher-spoken segments. Each teacher-spoken segment was also labeled according to the inquiry stage on which the student was being helped. Of the 211 teacher-spoken segments, 113 segments occurred on Day 1 and 98 on Day 2.

Table 1
Types of Teacher Support

Type	Description	Example
Orienting	Direct student attention to components of inquiry practice	"Let's look at your goal"
Conceptual	Explain key terms and components of inquiry practice	"The dependent variable is the thing we're going to measure."
Procedural	Provide guidance on the steps involved with an inquiry practice	"You need to be changing one thing at a time."
Instrumental	Tell exact actions needed to move forward on an inquiry practice	"So, we need to pick the one that says, 'does not support my hypothesis.'"
Scientific Content	Explain information about a scientific concept or phenomenon	"Pitch has to do with how high or low the note sounds to you."
Evaluative	Provide comments on the quality/accuracy of student work	"It looks like you're having some trouble…"
Technical	Help with online challenges (scrolling, screensharing, etc.)	"Oh, will you scroll up a little bit?"

Analysis

First, we addressed whether there were differences in the patterns of support provided by Mrs. A throughout all teacher-spoken segments on Day 1 (when the Inq-Blotter alerts did not include TIPS) versus Day 2 (when the alerts included TIPS). To do so, we compared the proportions of the types of support across the two conditions and conducted chi-squared tests to determine the significance of the associations between the condition (i.e., the presence of TIPS) and the occurrences of the types of support.

Additionally, we conducted an epistemic network analysis (ENA; Shaffer et al., 2016) for all 211 teacher-spoken segments (see "Comprehensive Epistemic Network Analysis" in the Results section). To further understand if and how the discourse patterns differed across the different inquiry stages with TIPS versus no TIPS, we conducted additional epistemic network analyses to compare how Mrs. A's support patterns differed for each condition on each inquiry stage (i.e., Hypothesizing, Collecting Data, and Analyzing Data).

We created the epistemic network graphs using an online graphical tool (Marquart et al., 2018). In the graphs, the nodes represent the types of teacher support (see Table 1), and the thickness, or strength, of the lines connecting the nodes represents the frequency of co-occurrence between the two types of support. We evaluated the differences between the networks quantitatively using t-tests on the mean centroid values, which are determined by the average strengths of the connections between the types of teacher support in the network, as well as qualitatively by visually comparing the strengths of the connections in the subtracted networks.

Results

Overall, we found that Mrs. A provided her students with different types of support (see Table 1) when TIPS were embedded in the alerts versus when they were not. In particular, the proportions of all four types of inquiry support (orienting, conceptual, procedural, and instrumental) that occurred in the teacher-spoken segments with TIPS (Day 2) *increased* from the proportions of inquiry support that occurred without TIPS (Day 1). A chi-squared test showed that there were significant relationships between the presence of TIPS and the occurrences of the orienting, conceptual, and procedural supports, but not between TIPS conditions and instrumental support. These results suggest that the availability of different types of inquiry support embedded directly into an alert (see Figure 1) helped the teacher to include these supports more frequently in the guidance she provided to her students.

Additionally, there was a significant relationship between the presence of TIPS and the occurrence of evaluative support. One explanation for the increase in evaluative remarks with TIPS (Day 2) is that the teacher referenced the dashboard more, and, as a result, she more often led conversations with individual students by directly commenting on a particular aspect of the practice with which they were struggling (e.g., "It looks like you've been changing a lot of variables") rather than asking the student about their general progress (e.g., "How is it going?"). Although she had access to alerts both days, TIPS may have lessened the acute complexity inherent in addressing frequent and on-going student needs, and in turn, provided pedagogical support for assessment conversations at the boundaries of curriculum, instruction, and assessment (Duschl & Gitomer, 1997).

However, we found no significant association between the condition and the occurrence of scientific content support or technical support. A Fisher's exact test was used to test the relationship between the condition and scientific content support due to the limited number of instances in which the teacher used this type of support. These results are not surprising since the TIPS embedded in the alerts provide suggestions for *inquiry*, rather than scientific content support and are categorized into the four types of inquiry-related support. Also, Mrs. A had five years of teaching experience with Inq-ITS, and the very few instances of scientific content support may have been due to her familiarity with the system and her understanding that the NGSS (2013) emphasizes competencies with the practices that can be transferred across science domains.

Table 2
Proportions of Each Type of Support Occurring in Teacher-Spoken Segments

Type of Support	Without TIPS (N = 113)	With TIPS (N = 98)	Statistics
Orienting	19.5%	35.7%	$X^2(1) = 7.025$, $p = .008$*
Conceptual	8.0%	21.4%	$X^2(1) = 7.801$, $p = .005$*
Procedural	25.7%	46.9%	$X^2(1) = 10.369$, $p = .001$*
Instrumental	23.9%	31.6%	$X^2(1) = 1.577$, $p = .209$
Scientific Content	2.7%	0.0%	$p = .250$, Fisher's exact test
Evaluative	22.1%	40.8%	$X^2(1) = 8.603$, $p = .003$*
Technical	48.7%	51.0%	$X^2(1) = 0.116$, $p = .734$

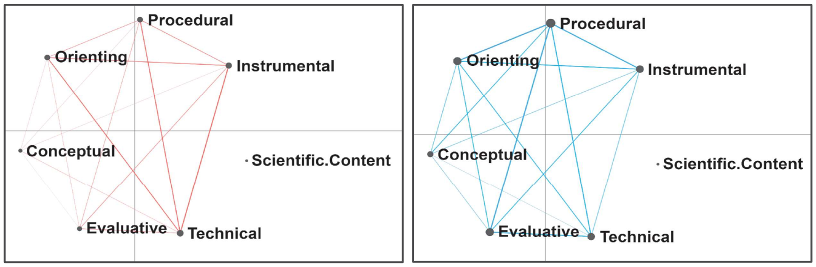
Findings from the Comprehensive Epistemic Network Analysis

We conducted an ENA (Shaffer et al., 2016) to compare how the 112 teacher-spoken segments that occurred on Day 1 (without TIPS) differed from the 98 teacher-spoken segments that occurred on Day 2 (with TIPS) in terms of the types of support provided. When comparing the mean centroid values of the networks (see Figure 2), the ENA revealed a significant difference in Mrs. A's support patterns when she used the alerting dashboard with TIPS ($M = -0.12$, $SD = 0.40$) versus without TIPS ($M = 0.10$, $SD = 0.27$; $t(164.39) = -4.58$, $p < 0.00$, $d = 0.65$).

Moreover, the subtracted networks show that conceptual and procedural supports co-occurred more often with the other types of inquiry support on Day 2 than on Day 1. That is, when responding to alerts with TIPS, the teacher used and integrated more of the different types of *inquiry* support than she did when responding to alerts without TIPS, demonstrating greater complexity of support appropriate for the sophistication of the practices.

Figure 2

Comprehensive Support Networks Day 1 (Without TIPS; red; left) vs. Day 2 (With TIPS; blue; right)



Findings from the Epistemic Network Analyses for Each Inquiry Stage

We also sought to understand how the teacher's support patterns changed depending on the inquiry stage with which the student was being helped. To do this, we identified the teacher-spoken segments associated with each of the four inquiry stages and used the same ENA technique, comparing the teacher-spoken segments that occurred on Day 1 (without TIPS) to the ones that occurred on Day 2 (with TIPS) for each of the four inquiry stages.

For the first three inquiry stages (i.e., Hypothesizing, Collecting Data, and Analyzing Data), the ENA revealed significant differences in the patterns of support provided by the teacher when she had access to alerts with TIPS versus without TIPS (see Table 3) when comparing mean centroid values of the networks (see Figures 3, 4, and 5), indicating that TIPS influenced Mrs. A's pedagogical discourse on Day 2. However, for the last stage (i.e., Communicating Findings), there was *not* a significant difference in the patterns of support provided by the teacher on Day 2 versus Day 1 when comparing the mean centroid values of the networks. Because automated scoring for the Communicating Findings stage is still in development, alerts were not available for this stage. Nonetheless, the teacher may have used a combination of her pedagogical content knowledge for both inquiry (Magnusson et al., 1999) and for communicating findings (McNeill & Knight, 2013) as well as knowledge of the alerts and TIPS from the previous stages to inform the kind of support that she would provide her students on this last stage. Though we do not see a significant difference between the two conditions here, future work is needed to determine if and how the alerting dashboard could further augment teacher support on communicating findings during inquiry, especially given the importance of this inquiry competency.

Table 3

Epistemic Network Analysis on Discursive Support Patterns for each Inquiry Stage

	No TIPS			TIPS			
Inquiry Stage	Mean	SD	N	Mean	SD	N	Statistics
1. Hypothesizing	0.52	0.53	22	-0.45	0.81	25	$t(41.80) = -4.90$, $p = 0$*, $d = 1.39$
2. Collecting Data	0.92	0.37	8	-0.57	1.15	13	$t(15.60) = -4.31$, $p = 0.00$*, $d = 1.58$
3. Analyzing Data	-0.77	1.63	7	1.08	0.92	5	$t(9.67) = 2.50$, $p = 0.03$*, $d = 1.33$
4. Comm. Findings	0.37	0.79	10	-0.28	0.82	13	$t(19.89) = -1.92$, $p = 0.07$, $d = 0.80$

ENA for Inquiry Stage 1: Hypothesizing

For the first inquiry stage (Hypothesizing), an examination of the subtracted networks (see Figure 3) shows a similar change in Mrs. A's discursive patterns as we had seen in the overall networks (see Figure 2), which showed stronger connections between more types of inquiry support when TIPS were embedded in the alerts. For example, when helping a student on the first inquiry stage *without* TIPS in the alerts, Mrs. A said:

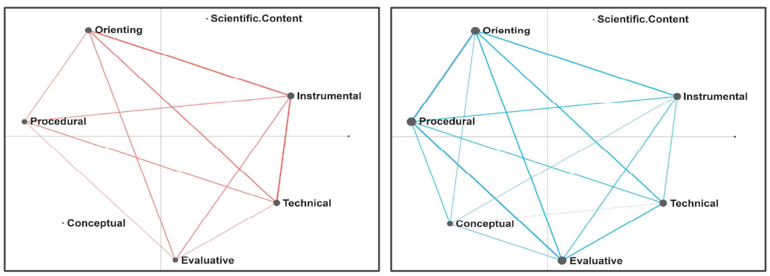
> Will you scroll up…so we can see the goal on your screen? [Technical; Orienting] Okay…it says determine how the mallet speed influences the pitch of the sound produced. So first, we're going to look at the mallet speed. And then second, we're going to look at the pitch. [Orienting] So in the first box where it says, "What I Will Change," you're gonna find...the option that says mallet speed [Instrumental]...And then we're gonna see how it influences the pitch of the sound. [Procedural] So then…in the box [where] it says, "What Will Happen," you're gonna find the one that says pitch of the sound. [Instrumental] There you go…Perfect [Evaluative].

In this example, the teacher employs both non-inquiry supports (evaluative and technical) as well as inquiry supports (orienting, procedural, and instrumental). However, the inquiry support focuses on low-level instrumental support, in which the teacher is telling the student exactly what to select in the virtual lab. In contrast, when helping a different student on the same stage but *with* TIPS, Mrs. A said:

> Okay, so let's start by looking at your goal. [Orienting] The goal says determine how the mallet speed influences the pitch of the sound produced. So, in that goal is where you are going to get your independent and your dependent variable. [Procedural] So the independent variable is the thing that you're going to change. [Conceptual] So that's what you're going to click in that "What I Will Change" box [Instrumental]. If you're not sure what's supposed to change, you can look at the goal [Orienting]…usually, the independent variable is listed first. [Procedural]

Instead of telling the student the exact answer as she did in the previous segment, Mrs. A provides a combination of targeted inquiry supports (i.e., orienting, procedural, and conceptual). Moreover, through explaining what an independent variable is, Mrs. A implements a high-level *conceptual* support, which is typically associated with greater student improvement (Dickler et al., 2021).

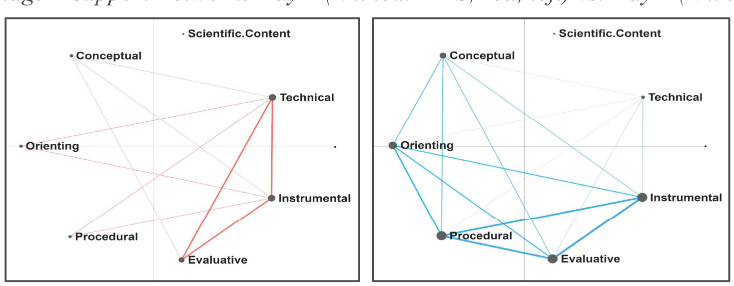
Figure 3
Stage 1 Support Networks Day 1 (Without TIPS; red; left) vs. Day 2 (With TIPS; blue; right)



<u>ENA for Inquiry Stage 2: Collecting Data</u>

For the second inquiry stage (i.e., Collecting Data), an examination of the networks (see Figure 4) shows that, on Day 1 (without TIPS), Mrs. A mainly provided support with technical, evaluative, and instrumental components. On Day 2 (with TIPS), we see stronger connections between evaluative, instrumental, and procedural supports, as well as some increased strength in the connections to orienting and conceptual supports. The stronger connections toward the other inquiry support types on Day 2 show that Mrs. A shifted to include more elaborate supports to help students *notice* aspects involved in conducting investigations (i.e., orienting support) and piece together *how* (i.e., procedural support) and *why* (i.e., conceptual support) they should conduct investigations, without providing direct instruction of exactly what to do in the virtual lab (i.e., instrumental support).

Figure 4
Stage 2 Support Networks Day 1 (Without TIPS; red; left) vs. Day 2 (With TIPS; blue; right)

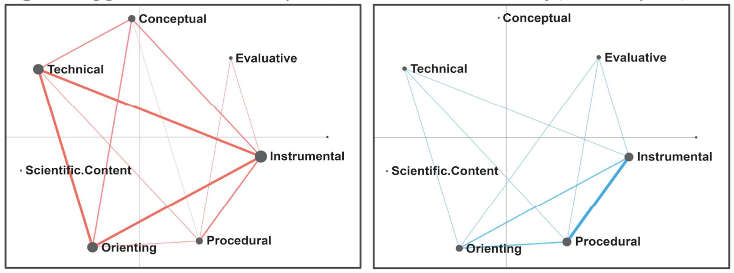


<u>ENA for Inquiry Stage 3: Analyzing Data</u>

Lastly, for the third inquiry stage (i.e., Analyzing Data), an examination of the subtracted networks (see Figure 5) shows that, on Day 1 (without TIPS), Mrs. A mainly provided support with technical, instrumental, and orienting components (similar to the types of support she provided on the previous stages), but she also combined conceptual support into the guidance she provided to her students as well. However, Mrs. A focused primarily on instrumental and procedural support on the analyzing data stage on Day 2 (with TIPS).

Figure 5

Stage 3 Support Networks Day 1 (Without TIPS; red; left) vs. Day 2 (With TIPS; blue; right)



While the shift to include more procedural support when using TIPS is consistent with the shifts that we see in the previous stages (i.e., Hypothesizing and Collecting Data), it is perhaps surprising that no conceptual support occurred in the teacher-spoken segments on Day 2 since we would expect that Mrs. A would use TIPS to implement conceptual support more often for the Analyzing Data stage as she had done for the previous inquiry stages. One explanation is that the teacher had fewer opportunities to provide conceptual support on this stage because several students (approximately 13% of the students on Day 1 and 26% on Day 2) did not reach this stage of the virtual lab. Moreover, the complexity involved with the data analysis stage may have led the teacher to choose certain types of support over others. Further work is needed to determine why a teacher chooses to use certain supports, whether some supports are more effective than others on different inquiry stages, and if and how teachers would incorporate the conceptual support suggestions offered in TIPS when given more opportunities.

Discussion

With the rollout of the NGSS (2013), there is a need for resources that help teachers in assessing and supporting their students' competencies with science inquiry practices (Kuhn, 2005; Pruitt, 2014). Alerting dashboards, when paired with a system like Inq-ITS that is instrumented to provide fine-grained data in real time on students' inquiry difficulties (Gobert et al., 2018), can be helpful to teachers' instruction of NGSS and, in turn, to students' learning of these competencies (Dickler et al., 2019). However, even with fine-grained data about students' difficulties, teachers still may not provide support at the level of sophistication needed to help students improve on the practices (Dickler et al., 2021) without pedagogical guidance in the form of TIPS (Adair et al., 2020).

In this study, we addressed how instructional guidance in the form of TIPS could influence a teacher's pedagogical discourse practices related to science inquiry. We found that, for Mrs. A, a teacher with five years of experience teaching with the virtual lab investigations in Inq-ITS, there was significant evidence of her pedagogical content knowledge for inquiry (Magnusson et al., 1999), since, even without TIPS, she prioritized inquiry support. Nevertheless, she still benefitted from TIPS, as they allowed her to more frequently blend high-level inquiry supports (i.e., conceptual and procedural), which tend to be associated with student improvement on inquiry practices (Dickler et al., 2021). As revealed through the ENA, the more frequent co-occurrences of the high-level supports in the *with*-TIPS condition demonstrates that TIPS helped Mrs. A in growing the sophistication and complexity in her informal formative assessment practices, which are essential for fostering effective scientific inquiry learning (Ruiz-Primo & Furtak, 2006).

This research not only provides a rich example of how iterative design and research-based improvements can improve alerting dashboards, but also furthers understanding of how to support and optimize teachers' use of alerting dashboards. These findings suggest that alerting dashboards, like Inq-Blotter, that include actionable data through real-time alerts as well as instructional support for teachers (such as, in the form of TIPS), have great potential for helping teachers in realizing the vision of the NGSS (2013).

Lastly, since TIPS were modeled from the supports (Adair et al., 2020) that were generated by real teachers in real-time when responding to first design iteration of Inq-Blotter alerts and that were shown to improve student inquiry performance (Dickler et al., 2019, 2021), future work will address if and how teachers' continued usage of TIPS over time supports student improvement on the inquiry practices.

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