Scaffolding Teacher Learning During Professional Development with Theory-Driven Learning Analytics

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Abstract. It is claimed that the innovative use of educational technology combined with appropriate pedagogical strategies can lead to improved student outcomes. However, teachers face difficulties in adopting educational technology and novel pedagogical methods as this involves acquiring complex new knowledge. Combined with training, Learning Analytics dashboards – artifacts which mediate teachers' learning in technology-enhanced environments – can aid them in this task. Using student engagement as an example, we present the prototype of a theory-driven dashboard that can help teachers to better understand and implement new instructional methods in technology-enhanced learning environments. We describe here our needs analysis, design, and evaluation process and outcomes, reflecting upon how teachers can benefit from using thoughtfully-designed LA dashboards in professional development scenarios.

Keywords: Learning Analytics dashboard · Teacher-facing dashboard · Theory-driven dashboard · Teacher Professional Development

1 Introduction

In the last decade, access to and use of educational technology have increased significantly. More recently, the pandemic, too, has forced teachers to resort to ICT use for conducting what has been described as "emergency remote teaching" [1]. Therefore, concern has shifted considerably from whether technology is used in schools [2] to how effectively it is used by teachers and students [3, 4]. This effective use, however, is not easy to achieve: while educational technology and constructivist, student-centred pedagogies combined together can lead to improvement in a variety of student outcomes [5, 6], teachers often lack the technological and pedagogical knowledge required to teach in this manner.

Teacher professional development (TPD, or PD) programmes which introduce participants to new technology and accompanying pedagogical methods in an authentic context can be useful in encouraging effective technology integration in K-12 schools [7]. As the teachers are in entirely novel territory and expected to imbibe and then implement complex new technological and pedagogical knowledge, they can stand to benefit from the use of thoughtfully-designed Learning Analytics (LA) dashboards which

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leverage relevant student and classroom data to actively support them in monitoring, understanding, and improving the effects of the new instructional practices and tools on student outcomes. To design such a dashboard, it is important to study teachers' data needs and data use practices in demanding PD environments.

In the context of a PD programme designed to aid teachers in using technology to make mathematics lessons more engaging, we attempted to learn from teachers' experiences with data use to design a prototype for a theory-driven dashboard with a "scaffolding layer" that would help teachers better understand and monitor the new pedagogical methods they were experimenting with in their classrooms. This prototype was then tested with 24 teachers to gauge their perceptions of the usefulness of the scaffolding layer features added to aid interpretation of data and support teachers' pedagogical knowledge.

The questions which guided our work were as follows:

RQ1 What are the obstacles teachers face in using data to understand and improve novel technology-rich pedagogical practices in PD scenarios?
RQ2 What are teachers' perceptions regarding the usefulness of the scaffolding layer?
RQ3 How does teachers' unaided data use compare to what is emphasised and recommended in the scaffolding layer?

Below, we first describe some concerns raised in literature about LA tools and dashboards, followed by recent attempts at addressing the same. After a brief introduction to our research context, we introduce readers to our own analysis of challenges teachers face when working with data in a PD scenario in Sect. 5, and how this informed our dashboard prototype development in Sect. 6. Finally, we present the evaluation study, followed by a short reflection on lessons learnt and future directions.

2 Related Work

While LA tools and dashboards are expected to make the task of monitoring teaching and learning and subsequent decision-making convenient for educators, they have not yet fulfilled their potential due to significant shortcomings which have been pointed out in literature. First, several researchers [8, 9] have warned and recent reviews [10, 11] have confirmed that LA has so far not drawn sufficiently upon established educational theory. Data collected and analysed in the absence of guiding theory is of little use for both teachers and researchers. Second, it has been observed that teachers frequently do not make use of the data made available to them, often due to the data not being relevant to their actual practice [12]. It is suggested that greater weight be given to teachers' opinions and needs when LA tools and dashboards are developed [13, 14]. Third, while developments in technology have allowed the capture of more and varied kinds of data, this volume and complexity of data means teachers may be lacking in the data use skills necessary to draw useful inferences from and act upon the data, making LA tools a burden rather than an aid in the classroom [15, 16].

Informed by this criticism, some steps have already been taken in the right direction. A number of theory-driven LA tools have been described in recent literature, while other

researchers have tried various methods to aid teachers in understanding data in varied learning contexts. These are described in some detail below.

2.1 Theory-Driven LA

A significant number of studies involving theory-driven LA have been conducted in recent years, with much focus especially on self-regulation of learning (SRL). For example, a review of LA dashboards for supporting SRL found that nine papers relied on educational theories and models to develop dashboards (Open Learner Models, Automatic Emotion Recognition process, Learning and Study Strategies Inventory, etc.), though none explicitly employed SRL theories [11].

Theory-driven dashboards have also been developed for monitoring constructs other than self-regulation of learning. Recently, Kent and Cukurova [17] drew upon the collaborative cognitive load theory (rather than student learning outcomes) to design LA visualisations for informing instructors of collaboration in a MOOC.

2.2 Aiding Non-technical Users in Data Use

A number of researchers have focused on designing LA dashboards for supporting teachers' sense-making of data. In the field of LA for supporting computer supported collaborative learning (CSCL), especially, researchers have recognised that teachers face difficulties in employing data to effectively orchestrate classroom activities. A distinction is drawn between mirroring and guiding dashboards designed for CSCL scenarios, where mirroring dashboards merely display data collected, with interpretation left entirely up to the teacher, and guiding dashboards indicate struggling groups of students as well as the problems they might be facing [18]. Numerous innovative guiding dashboard prototypes have been described in LA for CSCL literature, such as one involving the use of smart glasses to convey relevant information to teachers [19]. While fewer in number, longitudinal dashboard use studies have also been successfully conducted in authentic settings in recent years [20].

Moving on from CSCL, some authors have differentiated between exploratory and explanatory data visualisations in LA dashboards, with the former "targeted at experts in data analysis in search of insights from unfamiliar datasets", while the latter emphasise the communication of useful insights to teachers and learners who are pressed for time and may also be lacking in data analysis skills [21]. They relied on a "Data Storytelling" approach guided by generic InfoVis guidelines and narrative storytelling principles combined with education-specific information drawn from Learning Designs (LD) to create LA visualisations that highlight aspects of data relevant to teaching. Similarly, there have been attempts at making Multimodal Learning Analytics (MMLA) data from collocated collaboration settings more user-friendly by arranging it into meaningful layers that tell different stories, guiding users' attention to key insights [22].

From the description above, it is clear that there is increasing interest in forging stronger connections between LA, educational theory, and actual practice with the help of carefully designed dashboards. However, so far, most of such research has been conducted in the context of higher education. Further, as far as we are aware, no studies have been conducted in the context of challenging PD programmes which require teachers

to learn about and work with unfamiliar pedagogical strategies and ICT tools: with the current study, we hoped to not only aid teachers in interpreting and reacting to data, but also to encourage the development/consolidation of pedagogical knowledge and data use skills.

3 Research Context

We had a first-hand glimpse into the above-mentioned concerns in LA literature as we worked on a design-based research project (DBR, see [23]) that involved the creation of certain interactive Digital Learning Resources (DLRs) followed by PD for mathematics teachers to encourage effective use of the same for engaging students in the classroom. During the PD, teachers were introduced to the DLRs and other online educational resources. Acquisition of pedagogical knowledge was also encouraged, as teachers were required to design, with guidance from university researchers, lesson plans that would make use of available ICT resources to create a more engaging learning environment for students. They were then expected to implement these in their classrooms at least once a month. To monitor and understand how the new instructional methods affected student engagement, teachers had access to students' self-reported engagement data.

Using teacher reflections, we analysed teachers' data use throughout the PD programme in order to understand how LA dashboards could better cater to their data needs in a scenario where they were required to understand and enact novel and complex pedagogical approaches for improving student engagement. Drawing upon this developing understanding of teachers' experiences with data use, we designed a dashboard prototype and later tested it with 24 teachers. In the following sections, we describe in detail these parts of our study.

4 Understanding Teachers' Data Use During PD

We first attempted to understand teachers' data use in PD scenarios. In this, we were guided by RQ1: What are the obstacles teachers face in using data to understand and improve novel technology-rich pedagogical practices in PD scenarios?

4.1 Method

20 high school mathematics teachers (19 female and 1 male, with between 3 and 38 years of teaching experience) participating in the PD programme were encouraged to collect students' reports about engagement twice a month, once after an intervention lesson and once after any conventional lesson. Students replied to a questionnaire adapted from multiple engagement self-report instruments [24, 25] using a 5-point Likert scale, and the tool LAPills was used to collect and visualise their responses. Using these simple visualisations, teachers were asked to monitor whether and how changes in engagement were related to the new instructional methods they used in the classroom. After collecting and reviewing data, the teachers were asked to record monthly responses to two data use questions using an online form provided to them:

- To what extent did you familiarise yourself with the LAPills results (students' engagement data) and what did you learn from them?
- Based on the data, what would you do differently next time?

Over the course of eight months, we received 53 responses to the data use questions, with 17 out of 20 teachers responding at least once. These responses were then analysed using inductive coding to discover obstacles that teachers faced during data use. The authors read and reread the teachers' responses to identify whether and how they struggled with data use. Teachers' issues were independently listed under several categories by both authors, who then reviewed these themes together, and then the writing of results was begun.

4.2 Results

It was found that despite the simplicity of the data visualisations, a few teachers faced difficulties in understanding them. The majority, however, were able to use data to effectively describe students' engagement and disengagement.

When it came to choosing pedagogical actions in response to data, only a couple of specific responses were received about encouraging cognitive engagement, such as, *"… students should be required more frequently to rephrase things. Currently … some of the students don't rephrase terms and don't perceive the importance of doing so. It should be regarded as … mandatory…"* Most teachers chose not to respond to this question, while a few mentioned rather general responses such as, *"I should think lessons through even more, but that is very time-consuming"*.

It should be noted that the teachers had received guidance in different aspects of data use: monthly PD sessions devoted time to researcher-led discussion of data from a randomly chosen classroom, including pedagogical responses to engagement problems.

The analysis of teachers' responses showed that choosing pedagogical actions in response to data was difficult for teachers. Some teachers also faced difficulties in distilling information from data visualisations. Our findings were in line with previous research, which found that the most difficult facet of data use for teachers is deciding how to respond to information gleaned from data [26].

These results obtained in an authentic PD scenario indicated that teachers who are learning about and experimenting with new pedagogies can benefit from support in the form of a LA dashboard that scaffolds them in understanding and enacting these instructional practices by providing insights into data and recommending appropriate pedagogical actions. It had been previously proposed that LA reporting systems should diagnose common problems and provide teachers with suggestions about how to handle them [27]. Accordingly, we proceeded with the design of our dashboard prototype, as described next.

5 Designing the Dashboard Prototype

This section briefly describes our design process for developing a LA dashboard capable of scaffolding teachers' understanding and adoption of new pedagogical methods for supporting student engagement in a PD scenario.

In our approach, the scaffolding took place via a "scaffolding layer": notifications and explanations about pedagogically important information and prompts recommending useful pedagogical actions to aid teachers' developing pedagogical knowledge and data use skills. In order to generate this scaffolding layer, we relied on rule-based analysis of data informed by educational theory in the form of peer-reviewed literature about engagement (this included literature about established conceptions of engagement, indicators of engagement, interventions that that have successfully supported student engagement, etc. [e.g., 28, 29, 30]), and also LD created by teachers. Figure 1 illustrates the dashboard structure and how dashboard use supports the goals of the PD programme. Table 1 contains some examples of the link between theory and rules for data analysis and scaffolding layer content generation.

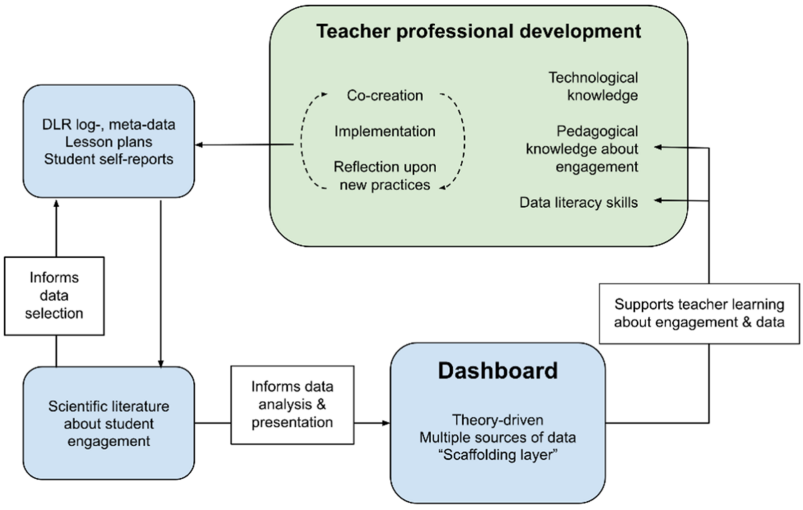

Fig. 1. Dashboard structure, and relationship to the PD programme.

Basic design principles were also kept in mind during the design process. Clutter was reduced, and colours were used judiciously to make certain data stand out and to group similar items together.

Table 1. Examples of theory-based data analysis and presentation rules

Data source	Ideal state	Message displayed in absence of ideal state	Message rationale
Students' collective responses to the engagement questionnaire	Score should be greater than 3 for all types of engagement (cognitive, behavioural, and emotional)	"To support students' cognitive engagement, which appears to be low, you can employ strategies such as helping students connect the current topic to prior knowledge, requiring them to state mathematical concepts in their own words and bringing forth examples from everyday life"	These are research-backed strategies for supporting cognitive engagement
Attendance and individual student responses to engagement questionnaire	Attendance should be higher than 90%, and behavioural engagement score should be greater than 3	"Student x has been missing classes and reports low behavioural engagement"	Student attendance is an indicator of behavioural engagement

6 Evaluating the Dashboard Prototype

The research questions chosen for the prototype evaluation were:

RQ2 What are teachers' perceptions regarding the usefulness of the scaffolding layer?
RQ3 How does teachers' unaided data use compare to what is emphasised and recommended in the scaffolding layer?

6.1 Method

46 high school and middle school mathematics teachers (20 from the PD course analysed above, and 26 from another iteration of the course) were randomly assigned to two groups and requested to complete certain tasks using the dashboard prototype which presented to them actual engagement self-reports from one classroom and fictitious but realistic LD and DLR log data. One group had access to the scaffolding layer of the dashboard, and the other group viewed the dashboard without such enhancements. Table 2 details the tasks and questions assigned to the two groups.

24 teachers responded to the questionnaire, 11 of them from the group with access to the scaffolding layer. Data analysis consisted of drawing up descriptive statistics for RQ1 and inductive coding of teacher responses for RQ2 in order to make possible comparisons with scaffolding layer content.

Table 2. Tasks and questions for evaluation study participants.

Condition	Scenario 1	Scenario 2
Scaffolding layer available	**Task** Reflecting upon usefulness of scaffolding layer content **Question** Do you think the emphasis on some information on the "Task 1" screen is helpful? Choose all options that apply • Yes. It saves time • Yes. I would not have noticed one or both problems on my own • No. The information does not help me teach better • No. I prefer to explore data on my own without external suggestions	**Task** Reflecting upon usefulness of scaffolding layer content **Question** Do you think the suggestion provided on the "questionnaire" screen for improving students' cognitive engagement is helpful? Choose all options that apply • Yes. The/Some strategies mentioned are new to me • Yes. This is a good reminder of engagement-supporting strategies for me • No. I don't think these strategies will help cognitive engagement • No. I don't need the suggestion because I already use these strategies in my class
Scaffolding layer absent	**Task** Interpreting log data about engagement and performance **Question** What information can you draw about class and individual student learning from the data shown on "Task 1" screen?	**Task** Interpreting and responding to students' self-reported engagement data **Questions** Based on the data from the "questionnaire" screen, what kinds of student engagement or disengagement would you choose to address immediately? Based on the data from the "questionnaire" screen, how would you try to improve students' cognitive engagement?

6.2 Results

For RQ2, most teachers reported that for both data navigation/interpretation of log data (Fig. 2) and choosing a response to self-reported engagement data (Fig. 3), the messages displayed were useful in some manner. *Thus, there is some evidence that teachers appreciate having access to the scaffolding layer.*

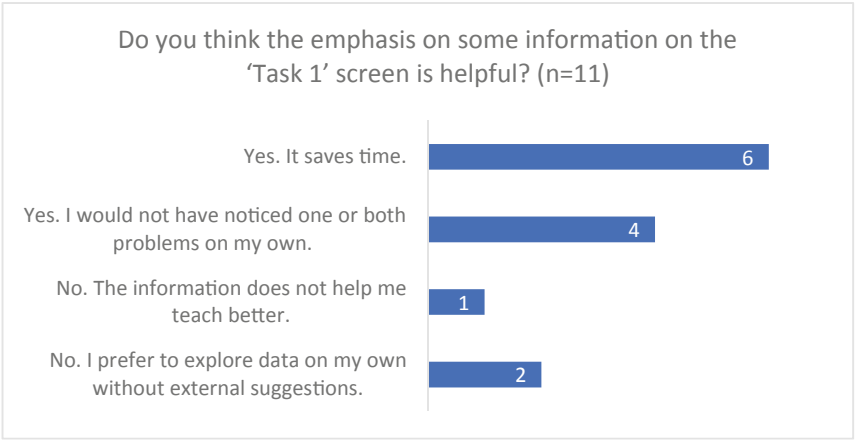

Fig. 2. Teacher perceptions of scaffolding layer usefulness for navigating data.

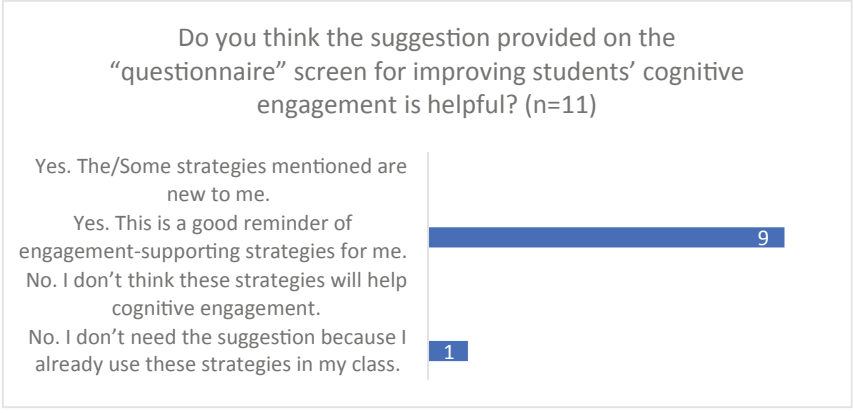

Fig. 3. Teacher perception of scaffolding layer usefulness for responding to data.

For answering RQ3, we compared teachers' responses, categorised by theme, to relevant scaffolding layer messages.

Scenario 1. In the first scenario, the scaffolding layer emphasised most students' struggles with Q3 and how one student might be guessing at answers (Fig. 4).

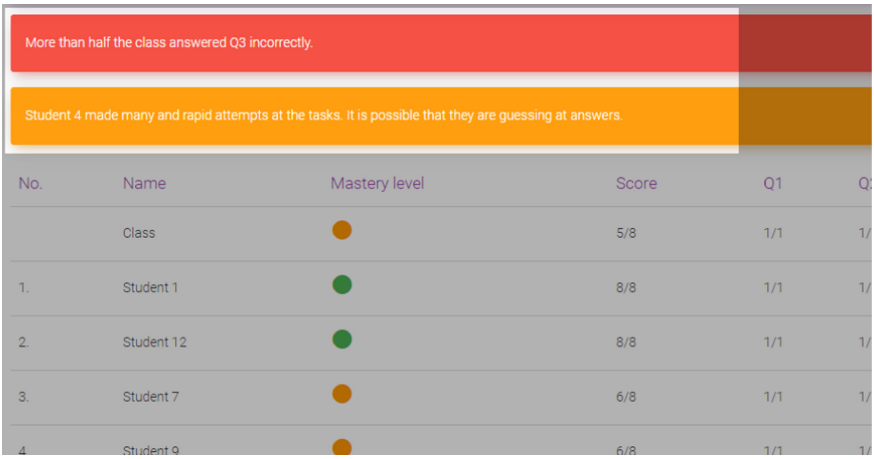

Fig. 4. Providing insights through the scaffolding layer.

Student Struggles with Q3. Out of 13, five teachers responded that they noticed Q3 was challenging and required further discussion. Two others wrote that they would try to improve student understanding, but did not specifically state the problem they noticed. The other five teachers' responses, though interesting, were not quite what we had wanted to elicit here. One teacher wrote, for example, *"If the class is large, then it isn't possible to get information about every student."*

Student 4 and Possible Guessing Behaviour. None of the teachers noticed possible guessing behaviour.

These results show that scaffolding layer content about student performance matched what some teachers noticed in data, and could have made the teachers' task less cumbersome by providing relevant insight. The prompt about possible guessing behaviour could have guided teacher awareness in a desirable direction, and at the very least, could have modelled for teachers a novel way to look at data.

Scenario 2. In the second scenario, the scaffolding layer content indicated that reported cognitive engagement was low and listed some strategies popular in engagement literature for supporting it.

Interpreting Engagement Data. The teachers were first required to infer engagement problems using self-reported engagement data. Using a visualisation embedded in the dashboard (Fig. 5), as expected, 11 out of 13 teachers identified that urgent support was needed for cognitive engagement. Surprisingly, 6 teachers responded that the level of emotional disengagement was concerning for them, with 2 of these 6 choosing emotional disengagement levels as the only immediate problem they noticed.

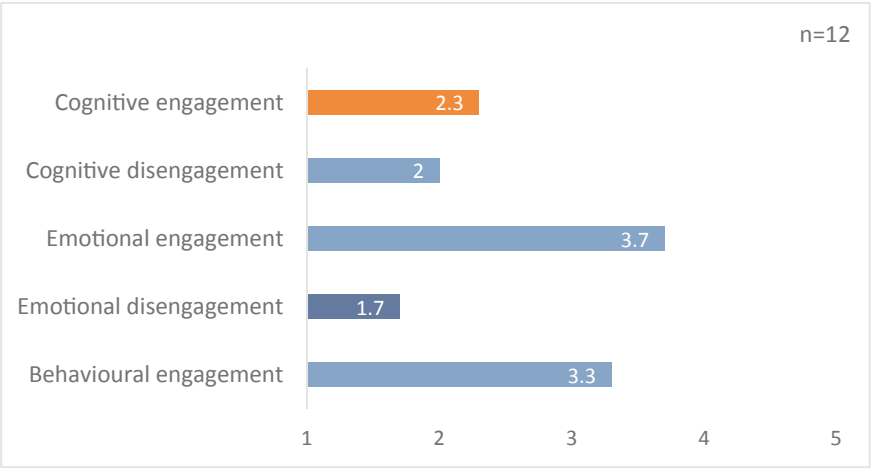

Fig. 5. Students' self-reported engagement data, as displayed in the dashboard prototype.

This result indicates incorrect interpretation of the visualisation, perhaps because of an improper understanding of the term "disengagement". It is interesting that the use of colours – shades of orange and blue – for emphasising data attributes did not aid data interpretation. In this instance, scaffolding layer content could have guided these teachers to focus mostly on cognitive engagement.

Strategies for Supporting Cognitive Engagement. The strategies suggested in the scaffolding layer had been introduced to the teachers during PD, and were each mentioned by at least a couple of teachers. Encouraging students to rephrase concepts in their own words was the most popular research-backed strategy, listed by three teachers. Another proven strategy, eliciting and making connections to prior knowledge was mentioned by two teachers. A third strategy, linking mathematical concepts to real life examples was also listed by two teachers. However, three teachers mentioned only non-specific strategies, such as spending more time on discussion and assigning varied tasks to students. Finally, one teacher wrote that she could not understand the cognitive engagement visualisation.

It is clear that while most of the teachers were familiar with at least one good strategy for supporting cognitive engagement, suggestions/reminders of more strategies could have been useful for all of them and could also encourage the adoption of the pedagogical practices.

7 Conclusion

From the discussion above, we can conclude that our dashboard prototype can scaffold teachers' learning when working with novel instructional methods in technology-enhanced learning environments. Teachers with access to the scaffolding layer perceived it as an aid to their practice. An analysis of the responses of teachers who interacted with

data in the absence of the scaffolding layer showed that they would have interpreted data correctly and insightfully, and become aware of numerous suitable instructional methods had they had access to the scaffolding layer.

We also learnt from the prototype evaluation that support for teachers could go further: more explanations about the data visualisations and engagement terminology seem to be required by some teachers. Teacher responses also seem to indicate that the option to hide the scaffolding layer may be useful for some. We had assumed that as teachers learnt more about data interpretation and gained confidence in the use of new pedagogical methods, they would not need some of the scaffolds anymore, while others would still help by making data use more convenient. Finally, strong links between data, theory and LD could be another area to focus on, leading to suggestions of good instructional practices for teachers as they plan lessons.

In the near future, we hope to make the dashboard available, with authentic data, to PD participants as they enact their new pedagogical knowledge in their classrooms. This should help us better understand its applicability to teachers' practice and the ways in which it can assist them in learning about and adopting new pedagogical and data use practices.

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