How Teachers Use Data to Help Students Learn: Contextual Inquiry for the Design Of a Dashboard

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Abstract. Although learning with Intelligent Tutoring Systems (ITS) has been well studied, little research has investigated what role teachers can play, if empowered with data. Many ITSs provide student performance reports, but they may not be designed to serve teachers' needs well, which is important for a well-designed dashboard. We investigated what student data is most helpful to teachers and how they use data to adjust and individualize instruction. Specifically, we conducted Contextual Inquiry interviews with teachers and used Interpretation Sessions and Affinity Diagramming to analyze the data. We found that teachers generate data on students' concept mastery, misconceptions and errors, and utilize data provided by ITSs and other software. Teachers use this data to drive instruction and remediate issues on an individual and class level. Our study uncovers how data can support teachers in helping students learn and provides a solid foundation and recommendations for designing a teacher's dashboard.

Keywords: intelligent tutoring systems, dashboard, contextual inquiry

1 Introduction

Much recent research focuses on designing and evaluating instructor dashboards [1], [4], [13], [20], [21], [22], [25]. It is reasonable to assume that the large amount of student interaction data that is routinely collected by educational technologies can be helpful to teachers and instructors, when presented on a dashboard in concise and actionable format. It might inform key decisions that teachers make, such as deciding the focus of discussion for a class lecture or identifying students who need one-on-one attention, with potentially a positive effect on student learning. Dashboards have been designed for a large variety of educational technologies such as multi-tabletop learning [20], collaborative learning in digital learning environments [22], [25], web-based distance courses [21], online courses [18], Intelligent Tutoring Systems [14], etc. The use of data about students for instructional decision-making is not restricted to educational technology. For example, mastery learning, a highly effective data-driven instructional method, can be implemented without technology [15]. Also, in 2009 the Institute for Education Sciences (IES, part of the U.S. Department of Education) published a practice guide with recommendations for teachers on how to use data to inform instruction. The IES Practice Guide also points out, however, that there is limited scientific evidence that data-driven classroom practices actually improve educational outcomes, indicating a need for more research.

A very small number of studies suggest that a teacher dashboard can lead to improvements in students' learning outcomes. In one such study, the data-driven redesign of a statistics course yielded improved student learning in half the time [18]. A dashboard was one novel component of the redesigned course, but there were other changes as well, so the improvement cannot be attributed solely to the dashboard. Kelly et al. (2013) demonstrated benefits of teacher reports in a web-based tutoring system for middle school mathematics [12]. Relatedly, research with Course Signals system illustrates that using learning analytics to identify students who are falling behind, can have a positive effect on student retention [6]. In contrast to the current research, this project focused on university students and on feedback directly to students rather than teachers.

We are working towards creating a dashboard for middle and high school teachers who use an Intelligent Tutoring System (ITS) in their classrooms. ITSs are an advanced learning technology that provides detailed guidance to students during complex problem-solving practice, while being adaptive to student differences [5], [26], [29]. A number of meta-reviews indicate that ITS can enhance student learning in actual classrooms, compared to other forms of instruction [16], [19], [23], [24], [27]. ITS have also proven to be commercially viable [10]. Although ITSs typically produce a wealth of data about student learning, relatively little effort has been expended to investigate how this data can best be leveraged to help teachers help their students. Much more research has focused on how this information can be presented to students (e.g., in the form of an open learner model [9]).

A central assumption in our work is that in order to design an effective dashboard, it helps to understand how teachers use data about students' performance and learning in their day-to-day pedagogical decision-making. Therefore, we started off studying teachers' use of data using Contextual Inquiry, a method often used in user-centered design [8]. Although the use of user-centered design methods for dashboard design is quite common, we are unaware of prior studies that investigate teacher data needs through Contextual Inquiry, as we do in the current work. Some studies involved teachers as part of a user-driven design process that included interviews, prototypes and empirical evaluations of dashboard designs [20], surveys conducted to determine the information instructors may need [21], questionnaires used to evaluate and iterate on the features of a learning analytics tool for a web-based learning environment [3], or semi-structured interviews as part of the developing process of a web-based learning analytics tool with a dashboard component [7]. Another study applied participatory design and other design methods to create a dashboard for an educational game app [1]. Other studies do not mention teachers as part of the dashboard design, do not report on the methods used to interpret and select the data, or use theoretical work and previous literature to determine the appropriate design [4], [13], [25].

In this paper, we describe how we used Contextual Inquiry to better understand (1) what student data teachers need to be effective and (2) how teachers use data to inform and adjust their instruction. This work will inform the design of a teacher's dashboard in an ITS environment. We focus our design on Lynnette [17], [28], a tutor for middle school mathematics (grades 6-8) with a proven track record in helping students learn to solve linear equations.

2 Methodology

2.1 Gathering data on teacher practices

We conducted Contextual Inquiry interviews to study teacher practices in using student data to adjust or individualize instruction. Contextual Inquiry is a user-centered design process, part of the Contextual Design method [8]. Contextual Inquiry is widely used to gather field data from users with the aim of understanding who the users are and how they work in their day-to-day basis. During a Contextual Inquiry interview, the researcher meets one-on-one with the participant and observes the participant conduct one of their daily activities in the participant's workplace. In this process, the researcher is considered to take up the role of an "apprentice" and the participant takes on the role of the "master." The researcher does not actively interview the participant with a set of pre-determined questions; rather, she or he observes the participant conduct one of the daily activities or normal tasks. The researcher asks questions occasionally to clarify and understand what and why the participant is doing something. Contextual Inquiry allows gathering of detailed and highly reliable information. It can reveal knowledge and information about the user's work that they themselves are unaware of.

We recruited teachers from various schools in our area that had previously participated in studies with our institution. We also requested assistance from Carnegie Learning to recruit teachers who currently use the Carnegie Learning (CL) tutor [10], a mathematics Cognitive Tutor – Cognitive Tutors are a type of ITS grounded in cognitive theory [5] – for grades 6-12 (Figure 1). We ran Contextual Inquiry interviews with 6 teachers from 3 different schools in our area, namely, 4 middle-school teachers from a suburban, medium-achieving school (2 male and 2 female), 1 female high-school teacher from an urban, low-achieving school, and 1 female middle-school teacher from a suburban, medium-achieving school. Out of the teachers we interviewed, 2 teachers had used the CL tutor before in their classrooms and 1 teacher was using it currently. In addition, 2 other teachers had used in previous years other ITSs as part of various short-term studies from our institution. Lastly, all teachers used digital grade books or other technology in their classrooms. Thus, the teachers in our sample exhibit substantial variability regarding important variables such as whether they work in high- versus low-performing districts, whether they have experience with an ITS versus not, as well as the methods they devised themselves for using student data to guide their teaching, and their use of technology in their classrooms.

The focus of our Contextual Inquiry interviews was to observe the teacher in how and what data they generated on their students' performance (from materials such as exams, quizzes, assignments, etc.), and how they used this data to drive instruction and prepare for a class. After the Contextual Inquiry interview, we observed the teacher conduct the class they prepared for. During this process we silently observed in the classroom and followed up with an interview with the teacher with questions regarding the classroom observation. Due to constraints in the teachers' schedules, with some of the teachers we conducted the Contextual Inquiry interviews after doing a classroom observation, and then followed with an interview with the teacher with follow-up questions. With two of the teachers who participated in our study, we conducted Contextual Inquiry interviews on one teacher's previous use and another's current use of the reports generated by the CL tutor. These teachers reported that they used the CL tutor 2 days during the week, while the other 3 days they would have lectures in the classroom, outside the tutor environment. Lastly, we observed teachers' use of reports and other technology or software in the classroom. The Contextual Inquiry interviews were video recorded and resulted in a total of approximately 11.5 hours of recording.

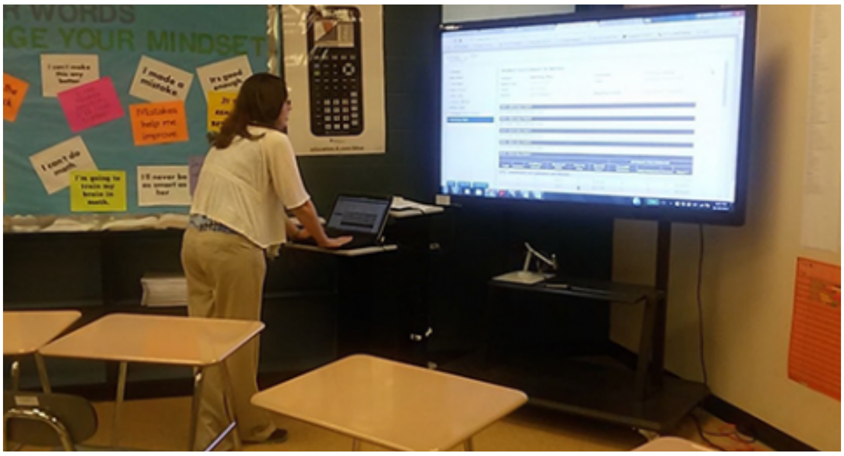

Fig. 1. Teacher during a Contextual Inquiry interview working on her laptop and smart screen with an ITS report.

2.2 Interpretation Sessions and Affinity Diagramming

The video recordings of the Contextual Inquiry interviews were transcribed to text. A team composed of a PhD student (the first author of this paper) and a Master's student, both from our institution, worked through the transcriptions to analyze and synthesize the data from the transcribed interviews. Two standard techniques from Contextual Design were used: Interpretation Sessions and Affinity Diagramming. Interpretation Sessions are team-based tasks aimed to create a shared understanding of the collected data by recording on post-it notes, simple observations and key issues and insights from the interviews of each participant. Affinity Diagramming is a widely-used method that aims to discover patterns that define the whole population by grouping and organizing the post-it notes based on content similarity into a hierarchy that reveals common issues and themes [8]. The way of clustering the post-it notes into an Affinity Diagram has an element of subjectivity. However, the categories in this diagram emerge from clustering the data and are not pre-defined. The Affinity Diagram process does not require a coding schema or inter-rater reliability.

From 11.5 hours of transcribed video interviews, we conducted several Interpretation Sessions, during which we walked through the transcribed video interviews for each participant and created post-it notes. We gathered approximately 2000 yellow notes, as illustrated in Figure 2 (the two rows from the bottom). We initially followed the traditional Interpretation Session approach and recorded the observations in physical post-it notes. Given the large amount of interview data we had collected, we decided to instead store the notes electronically in a Google Spreadsheet. We also approached the Affinity Diagramming in a traditional way first, namely, by using printed copies of the digital notes and organizing them on large sheets of paper. However, given the large number of notes, we resorted to creating and keeping the Affinity Diagram in a Google Spreadsheet as well, as shown in Figure 2.

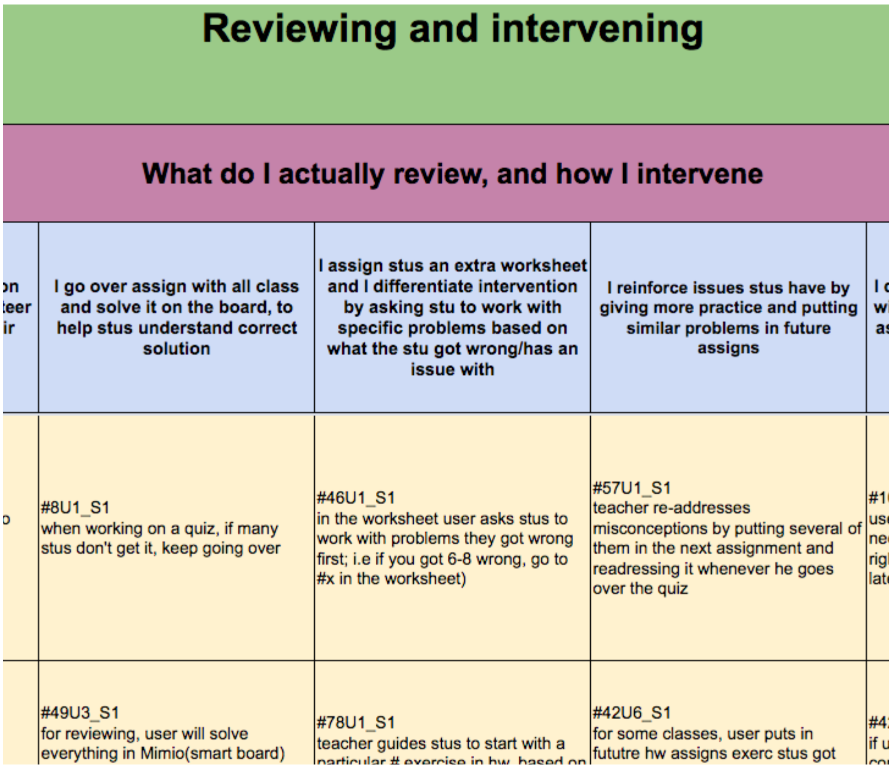

Fig. 2. Partial view of our final Affinity Diagram.

We organized the yellow notes into categories based on patterns we identified and similarities in their content. Following the Affinity Diagramming technique, for each category, we recorded the synthesized content of all the yellow notes within the blue categories (third row from the top in Figure 2). We then grouped together blue categories based on similarity of content and recorded the information they conveyed within the pink categories (second row from the top in Figure 2). Lastly, we grouped pink categories and synthesized their content within the green categories (first row from the top in Figure 2). Our final affinity diagram had 335 blue level categories (with 1-2 up to 12-14 yellow notes per category), 81 pink and 33 green level ones.

Based on the initial focus of our Contextual Inquiry interviews, namely how and what data teachers generate about their students' performance, and how they use this data to drive instruction and prepare for a class, we focused on the categories of the Affinity Diagram that contained the most important information relevant to this focus. We initially went through the final Affinity Diagram and selected the blue, pink and green categories that contained such information. We then recorded in two lists – what data teachers generated and how they use this data – a summary of the selected categories, in the form of short sentences and keywords. Each of the lists individually was then synthesized based on similarities in content, and our final results are presented in the following section.

3 Findings from the Contextual Inquiry interviews

3.1 What data do teachers use to help students?

From the Contextual Inquiry interviews, we found that teachers continuously generate and use data on the progress and performance of their students. They also use data generated by technology such as the CL tutor or other software they use as part of their classroom instruction.

Teachers gather data when grading written student assignments, as well as by having one-on-one interactions with students during or outside of class. In particular, teachers pay attention to whether the overall class or individual students have mastered particular concepts. A concept can be an entire problem that exercises a skill (e.g., finding the greatest common denominator) or one of the steps that leads to the solution of the problem (e.g., graphing the direction of an inequality in the number line as part of graphing the inequality itself on the number line). In addition, teachers try to understand, on a class and individual student level, what causes students the most trouble, i.e., what are the most common misconceptions and errors.

Data provided by technology includes reports and analytics on student progress and performance in the CL tutor or in other software used by the teachers. For example, among the many reports that are offered by this tutor, the teachers we interviewed made the most use of the reports that give information on the overall class performance and on the individual student performance in the tutor. Teachers also pay attention to the number of skills students have mastered or not mastered and, less frequently, to time spent working in the tutor.

We also found that teachers use many different ways to record, keep track and organize student data. Some data gets initially recorded on paper and then is transferred to software. For example, some teachers recorded and kept grades in a paper grade book before transferring that information to a digital grade book. Other data on student performance is initially generated through software (such as CL tutor reports or other software reports), and the teacher prints and stores it offline. It is challenging for the teachers to keep track of and integrate both offline and online data.

Some (though not all) of the teachers we interviewed kept track of student errors and misconceptions at a surprising level of detail, as illustrated in Figure 3. In the tally sheet on the left of Figure 3, a teacher keeps track of the frequency of particular misconceptions (shown in columns) for each problem in an assignment (shown in rows). As the teacher describes, "*I will go through each problem and will start writing down where they made their errors. And I will just put tallies. And where I see different things I make sure I circle them so I can focus there whenever I am reviewing that*", referring to the misconceptions that most students had and thus should be discussed with that class. In addition, the teacher writes, at the top right of the tally sheet (covered), the name(s) of the student(s) who had the most trouble with a particular concept or concepts. To be consistent across periods, the teacher initially grades all tests or exams for each period and then creates the tally sheet template from the first period, copying it to the tally sheet for other periods. The teacher finishes tallying the sheet for one period before they move on to the next period. If the teacher notices a different or miscategorized misconception in another period, they go back and correct the tallies for that misconception in all the other periods.

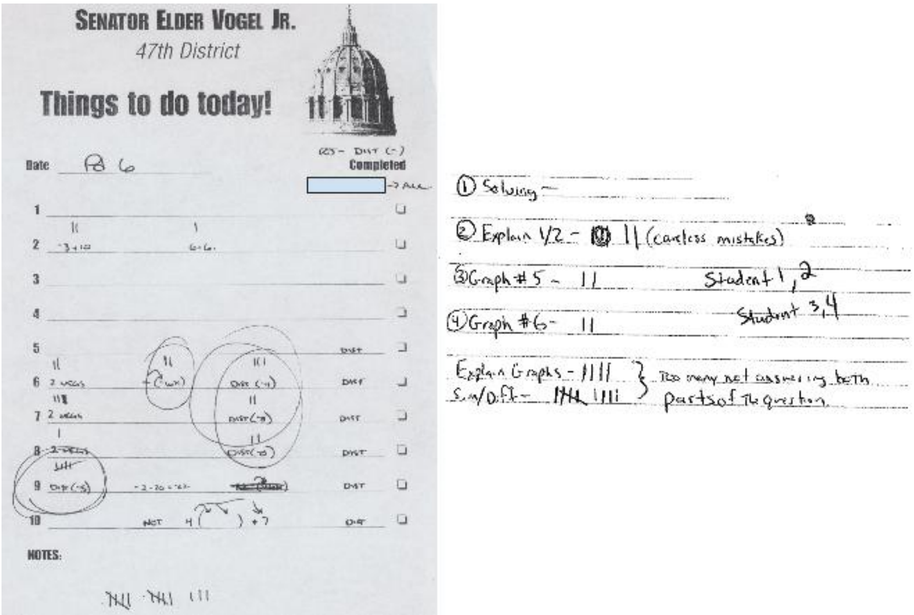

Fig. 3. Tally sheet from teacher 1 and teacher 2. Student identifiers have been removed.

Another teacher we interviewed uses the tally sheet on the right of Figure 3 to tally students who got a problem (or parts of a problem) wrong in an assignment. Each problem in this particular assignment represented a high level concept (for example, exercise 1 was related to solving two inequalities, while exercise 2 asked students to explain the steps to those solutions). For some exercises, the teacher also notes in the tally sheet the reasons the students made the mistakes (for example, careless mistakes or not answering both parts of the question). Lastly, the teacher writes down the names of the students who they want to call on in class (represented by student 1, 2 and student 3, 4 in Figure 3).

3.2 How do teachers use data to drive instruction and help students?

We found that teachers use data to drive and adjust their instruction in many ways. Most of the teachers differentiate how they use data and tune the level of detail to determine whether the best remedy is a classroom intervention or individual, one-on-one sessions with particular students.

3.2.1 Class-level decisions

Decide to move on to the next topic and build on current concepts. After generating data on the overall class performance in an assignment or test, the teacher analyzes it to assess the current status of the class and to decide whether to move on to the next topic. If, in the teacher's judgment, the majority of the class has mastered a concept or a set of concepts, the teacher decides to move on with the instruction and build on the current concept(s). As one teacher describes, "*there's times where I'm like 'Ok if they don't know this, I have to start here. But if they do know it, I can start here,' in a different position.*"

Determine that the class needs intervention. The teacher notices when many students have not mastered certain concept(s), or when there are many different errors and issues in an assignment. The teacher decides to intervene and devote more time and attention in class to specific concepts, misconceptions or errors to help students remedy their issues.

Identify the focus of intervention. Based on the number of students who have not mastered the concept(s), or have misconceptions and errors, the teacher determines what is important to cover during a class lecture. The teacher can also create worksheets with exercises to allow students to practice the concepts they are missing or having the most trouble with.

Plan what to discuss and cover in each period. The teacher compares performance on an assignment across periods and adapts instruction (or what to cover in class) based on that period's performance. Sometimes the teacher covers only the topics that a period has the most trouble with; in other cases, the teacher might decide to discuss issues noticed from other periods in every class period.

Display in class reports or analytics from software. As students were working with the CL tutor, one teacher displayed anonymized class performance reports in front of the classroom, on a smart screen. The teacher aimed to support the students' learning and progress by seeing where they were compared to the other students in the class. In addition, displaying the report in class helped the teacher monitor the students' progress as the teacher walked around the class, while students were working with the tutor. The same teacher also displayed on the smart screen class analytics on students' performance generated from other software.

3.2.2 Decisions regarding individual students or groups of students

Decide which individual students or group of students need special attention. The teacher identifies from the generated data individual students who have an issue with one or more concepts, have displayed the same misconception or error repeatedly, or are spending a lot of time but making little progress. The teacher records the individual students' names to work one-on-one with them. If the teacher notices that a group of students are having similar issues, the teacher might decide to work with them as a group.

Determine the focus of intervention. If the teacher does not know the reason why a student is having an issue, they spend time with that student trying to understand their problem(s). The teacher determines the focus of a mini-lecture or extra practice to help the student fix the issue and master the concept(s). The teacher will also call on the student during class time to prompt them to participate in discussion or problem solving for the concept(s) they are having trouble with. For groups of students, the teacher can decide to do a mini-lecture, or give practice worksheets, by differentiating intervention as to which student has to work with which exercise in the worksheet, based on individual issues identified.

Show and give students software reports. The teacher periodically shows, prints and gives students reports on their progress and performance over a given time period, in the CL tutor or other software used in the classroom. The teacher uses the data from these reports to update the students on their progress, what they still need to do, and what their grade is.

4 Breakdowns in current practices

From our interviews with the teachers, as well as from our data analysis, we noticed patterns of breakdowns in the current practices of generating and using data. We also noticed that the technology that some teachers use in the classroom is not always helpful, and can be inefficient.

Teacher adapts to technology, technology does not adapt to teacher. The CL tutor and other software provide more student data and reports than the teacher needs and can process. The teacher is selective in choosing among the provided reports, choosing only the data that is most useful to them. In addition, none of the technologies we observed provide data about misconceptions or student growth, which are hard to generate by hand. For example, one teacher used the Pennsylvania Value-Added Assessment System to see students' growth from year to year. However, the teacher could use such reports only once per year, making it impossible to intervene in classes that the teacher would not be assigned to teach anymore. Another teacher said this about CL reports: "*It would actually be very useful [to see errors and misconceptions] because … a lot of these reports I don't use frequently because it's not necessarily giving me what I need to know.*"

Generating data is time consuming and effortful. From grading student assignments to interacting with students on a class or individual level during and outside of class, the teacher continuously generates data on students. The teacher also spends time and effort in analyzing and drawing conclusions based on data from different sources, while differentiating the level of detail and instruction for the class or for individual students.

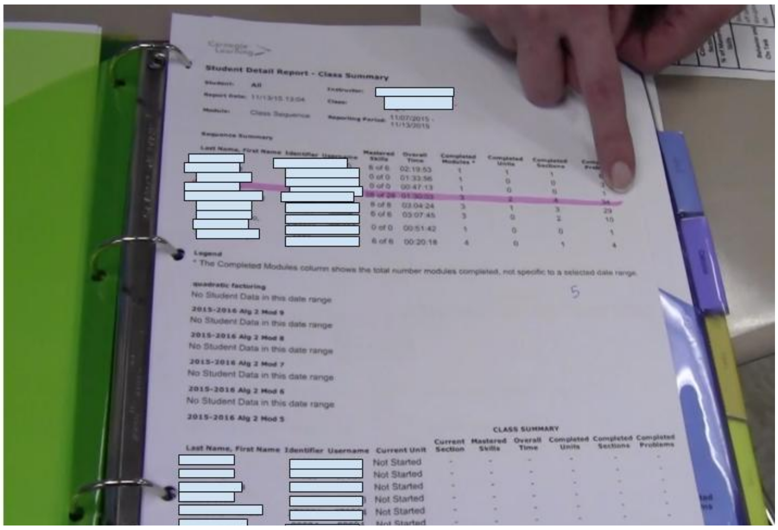

Fig. 4. Teacher prints and stores reports from CL tutor and other software in a binder offline. Student names and identifiers have been covered.

Organizing, integrating and remembering data from different sources is challenging. It takes time and effort to integrate data generated on paper with data from reports of tutors or other software. For example one teacher printed CL tutor reports and other software reports and organized them in a binder (Figure 4). This teacher also put post-it notes on the binder and wrote things to remember on the printed reports, or highlighted in color particular students. Even without technology, we noticed that teachers integrate student data from different assignments and interactions with the students and, most of the time, keep track of this information in their heads.

Creating materials for intervention is difficult. The teacher has to spend time and effort to create or find the necessary materials for a mini-lecture or problems and exercises for a practice worksheet. One teacher used various online sites to find and give problems to students to practice for standardized tests. Another teacher looked for individual exercises the student got wrong in the CL tutor, to print and give it to the student to complete on paper.

5 Opportunities and design implications

From the Contextual Inquiry interviews and findings, we identified opportunities for technology, such as a teacher's dashboard, to address current breakdowns.

Automate processes the teacher does by hand. The detailed information on student mastery of concepts, performance and progress that teachers generate themselves can be provided by technology. This would save teachers time, effort and attention that can be used to help students in other ways.

Adapt to teacher data needs. To be useful to the teacher, a new technology should provide data the teacher most needs in their instruction. This includes data that are difficult to generate by hand and that tutors or other software do not provide currently, but *could* provide, such as student misconceptions and growth over given periods of time, on the individual and class level.

Help the teacher integrate data from different sources. Instead of the teacher having to remember and coordinate data they generate themselves from different assignments and data provided by tutors or other software, technology can help the teacher easily keep track of and manage this data.

Suggest materials for intervention. Teachers can receive suggestions from technology on materials and exercises go over with students (individually or as a class), based on their performance with a topic. In addition, technology can create worksheets and assessments for the teacher by differentiating on the class or individual student's performance. Technology should allow the teacher to access the problem or problems the student(s) got wrong and reassign it (or them) to the student(s).

Provide data on hint requests and student errors. One teacher who used the CL tutor mentioned that they occasionally used the average hints and errors in the tutor reports to identify students who are goofing off or rushing through the problems, versus those who really need help. Hints and errors are important analytics that can help the teacher understand the performance of their students, and identify the need for intervention, while working with the tutor.

5.1 Towards the design of a teacher dashboard for ITSs

In an ITS environment, where a lot of student data is produced by the system, a dashboard can provide the teacher with the necessary analytics and functionality to help them help their students learn better. Based on our findings of how teachers use data to drive instruction and help students on the class and individual student level, we have brainstormed and designed preliminary scenarios where a dashboard can be integrated in an ITS environment and help the teacher in this process.

Teacher dashboard for the class level. Teachers could use this dashboard when preparing for the next lecture and deciding whether to move on to the next topic. In addition, the data provided by this dashboard would help the teachers identify the need for intervention by giving information on the class performance and progress in the ITS environment. The dashboard would help the teacher determine the focus of intervention, as well as suggest materials, such as example problems or practice worksheets for the class. Another scenario that teachers could use this dashboard for is when they quickly want to review where students' concept mastery stands, and whether a quick intervention or mini-lecture might be helpful. Teachers would use this dashboard when giving students a warm-up exercise at the beginning of class, or a short practice exercise at the end of a lecture. Lastly, the dashboard could provide teachers with real time data on students' performance during the time students are working with the ITS during class time. Teachers would be able to project the dashboard on a wall or screen in class, and would better focus their time and attention on students who need it the most, while other students independently work with the tutor.

Teacher dashboard for the individual or group level. Teachers would use the information and analytics provided by this dashboard to give one-on-one attention and help to individual students or a group of students with similar issues and problems. The data provided by this dashboard would help the teacher identify the need for intervention, as well as the focus area(s), while providing the teacher with suggested practice problems.

6 Discussion and future work

A key assumption in our project is that a teacher dashboard will be more effective if it is designed with a deep understanding of how data about students' performance and learning can influence teacher decision-making. In this paper we investigate ways in which teachers generate and use data to drive and adjust their instruction. Through Contextual Inquiry interviews with 6 middle and high school teachers, we found that teachers use data to a surprising degree to inform their teaching, both to make decisions at the class level and to plan interactions with individual students. Further, the data they use (and often, generate themselves, by hand) can have a surprising amount of detail, as shown in Figure 3. We also found that teachers use data provided by technology, when it is available. On the class level, teachers use this data to decide whether they need to spend more time on a certain topic and when to move to the next topic. In addition, teachers differentiate instruction across class periods focusing on each class' specific needs and performance. Teachers who use technology in their classrooms make use of reports and analytics provided by the technology, again both on the class and individual student level. However, we also found that teachers have to adapt to technology and are selective in deciding which types of reports and data provided by such technology to use. An interesting finding is that teachers differentiate instruction on the individual student level. They spend time, effort and attention to identify what individual students need most help with, what issues they are having and how to help them remediate these issue(s).

Our findings provide novel insights into what data teachers generate and how they use it to help their students. To the best of our knowledge, this is the first study that investigates, through the use of Contextual Inquiry together with Interpretation Sessions and Affinity Diagramming, how teachers use data in their day-to-day decision-making with or without technology. The findings may be useful for designers of dashboards and ITS more generally. Their import is not restricted to ITS, since the majority of teachers in the study did not use one with their students.

The next stage of our project is to use our results to inform the design of a teacher dashboard with student data collected from an ITS such as Lynnette [17], [28]. Focusing on specific use scenarios, the dashboard will take advantage of the rich analytics generated by the ITS, such as skill mastery, types of misconceptions, progress and time in the assignments, etc. Our findings will drive the decisions of what data is most important for the teacher in the given scenario and how it will be presented to the teacher in the dashboard in an easy-to-understand way. Continuing our user-centered design process, we will develop paper prototypes of the dashboard, which we will pilot and test with teachers. The ultimate product of our efforts will be a dashboard, fully integrated with CTAT/Tutorshop, our infrastructure for developing and deploying ITS [2]. Once it is fully implemented, we will conduct classroom studies to evaluate its effectiveness when used by teachers, in helping their students achieve better learning outcomes.

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