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How teachers make dashboard information actionable

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Abstract— This study investigates how teachers use dashboards in primary school classrooms. While learners practice on a tablet real-time data indicating learner progress and performance is displayed on teacher dashboards. This study examines how teachers use the dashboards, applying Verberts' learning analytics process model. Teacher dashboard consultations and resulting pedagogical actions were observed in 38 mathematics lessons. In stimulated recall interviews, the 38 teachers were asked to elaborate on how they reflect on and make sense of the information on the dashboard. The results showed that teachers consulted the dashboard on average 8.3 times per lesson. Teachers activated existing knowledge about students and the class to interpret dashboard information. Task and process feedback were the pedagogical actions most often used following dashboard consultation. Additionally, teachers who consulted the dashboard more often activated more and more diverse pedagogical knowledge to interpret the data and, consequently, gave more and more diverse feedback. These results indicated that teacher dashboards were indeed influencing teachers' pedagogical actions in their daily classroom activities. This study provided the first evidence that dashboards progressively impact teaching practice and initiate more profound behavioral changes as teachers become more proficient in using them.

Index Terms— Adaptive learning technologies, learning analytics, dashboards, technology enhanced learning

1 Introduction

EVEN though the recent influx of tablets into primary education is part of the vision that adaptive learning technologies, empowered by learning analytics, will revolutionize education, empirical results supporting this claim are scarce [1, 2, 3]. Learning analytics are often thought of as the distinction between embedded and extracted analytics [4]. On the one hand, embedded analytics refer to cases where the learning technology directly uses data, for example providing exercises to adjust students' performance. On the other hand, extracted learning analytics refer to instances in which data is made available for different actors, such as teachers or students. Teacher dashboards are an often-used example of extracted analytics [5]. It has been proposed that information on dashboards can help teachers to improve their daily teaching practice.

Dashboards can be considered a new instrument for teachers. Integrated into adaptive learning technologies, dashboards offer the possibility for teachers to visualize students' performance and progress in real time [5, 6]. This gives teachers additional insights to enable them to adequately respond to students' needs during the learning process. Hence, dashboards provide opportunities for teachers to adapt their pedagogical actions to the needs of individual students [7, 8]. However, data on dashboards is not always 'actionable'. This means that data does not always make it clear what actions should be taken to improve teaching [9]. Interpretation of the data provided would be expected to influence how teachers use dashboards and how this affects their teaching practices. This paper therefore focuses on the question of how teachers decide what actions to take based on dashboard information in their daily classrooms. First, we theoretically frame the notion of dashboards as instruments for teachers in distributed cognition theory and the learning analytics process model.We then discuss the different stages teachers go through in deciding on pedagogical actions based on dashboard data, i.e. how teachers make dashboard information actionable.

1.1 Dashboards as an instrument for teachers

How teachers use dashboard can theoretically be grounded in distributed cognition theory. This theory states that instruments can support professionals when these instruments fit seamlessly into the activities of the professional [10]. Extensive research in domains ranging from aviation to medicine shows that the connection between instruments and the professional's routine is of great importance for the successful uptake of new instruments [11]. For example, a new instrument in an aircraft must fit seamlessly into the daily routine of the pilot and his crew to support safe flying and prevent accidents. In classrooms a dashboard can be considered a 'new' instrument that supports the selection of effective pedagogical actions by teachers [9]. Whereas distributed cognition theory provides a research paradigm to frame the use of instruments in professional's work, Verberts' learning analytics process model is used to investigate how teachers use dashboards in daily classroom contexts.

Verberts' learning analytics process model specifies different stages during which users interpret data from the dashboards to decide on meaningful actions [5]. Four stages are distinguished in this model. First, in the awareness stage the user becomes aware of the dashboard and the data available. Second, in the reflection stage the user interprets the data by asking themself questions and evaluating the relevance of these questions. In the third,

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sense making, stage the user answers the relevant questions to further understand the value of the data. Finally, in the impact stage how the user understands the data is used to change their behavior. This model will be applied to teachers and their use of dashboards in their teaching practices [5].

Teacher dashboards help teachers to better understand students' ability, learning progress and performance. Often dashboards represent information about students' progress toward different learning goals and show students' correct and incorrect answers for exercises [5]. In the awareness stage, teachers become consciously aware of data on the dashboards. For example, they explore what information is shown on the dashboard. Next, in the reflection stage, teachers start asking themselves questions about the data. For example, "how can I see if students are understanding the material?". Teachers answer these questions in the sense making stage in order to understand how the data are informative for their teaching. For example, "is this student struggling or is he/she still discovering a new approach?". Finally, in the impact stage, teachers determine which pedagogical action to perform in response to their interpretation of the data. In this stage the translation of data into pedagogical actions takes place. In the next section we define the pedagogical actions and elaborate on how teachers reflect on and make sense of the data and how their existing knowledge plays an important role in this process.

1.2 The translation of dashboard data into pedagogical actions

During their daily practice teachers constantly make decisions leading to pedagogical actions [12]. These actions are based on teachers' pedagogical knowledge base which consists of knowledge, skills, and perceptions of students and of the class. Important knowledge elements are an understanding of individual student's abilities and their current level of domain knowledge and skills, but also more general knowledge about developmental problems that students face and how these problems relate to their learning. At the class level knowledge entails understanding of social dynamics within the group and the progressive development of knowledge and skill. These knowledge elements form the basis required to understand students' behavior and development and are central to teachers' decision making leading to appropriate pedagogical actions.

Pedagogical actions are defined as interventions that teachers take to support students' learning, for example providing feedback to improve the progress of individual students. Feedback is heavily researched in educational sciences and is defined as information provided by a teacher regarding aspects of students' performance or understanding [13, 14]. Different types of feedback are distinguished, such as task-related feedback, process-related feedback, personal, metacognitive and social feedback. Task-related feedback helps students to succesfully fulfill the task at hand whereas process-related feedback indicates how students handle their learning [14]. Personal feedback deals with comments on the personal aspects of a student's behavior whereas social feedback supports cooperative learning skills. Finally, metacognitive feedback is comments related to the way students control and monitor their learning.

Based on teachers' perception of the students performance and teachers' existing knowledge teachers select appropriate feedback for individual students. Information on dashboards may add to the teacher's knowledge base at both the individual and class level. Therefore, when teachers go through the stages of the learning analytics process model to interpret data on the dashboards, it is likely that they activate their existing pedagogical knowledge. Hence, to further understand how teachers make dashboard data actionable, it is important to understand what additional knowledge teachers activate to reflect on and make sense of the data and how this informs their pedagogical actions.

2 This Study

Dashboards provide teachers with concurrent information about students' abilities, progress, performance, and errors made. Yet, teachers can only act on dashboards when they are aware of the data. As such, teacher awareness is the start of the learning analytics process model and is expected to impact the other stages. When teachers are aware of the data, it can be used to adjust pedagogical actions, but only when teachers are able to interpret the data properly and translate this understanding into appropriate pedagogical actions. After this requirement is met, different stages of the learning analytics process model are necessary for teachers to turn dashboard data into actions. Accordingly, this study explores how teachers go through the different stages of the learning analytics process model. This increases our understanding of how teachers use dashboards in the classroom. The following research questions are examined in relation to the learning analytics process model:

1. Awareness: How often do teachers consult the dashboards during a lesson?
2. Reflection and sense making: Which pedagogical knowledge do teachers activate to interpret the data on the dashboards?
3. Impact: Which pedagogical actions do teachers take after consulting the dashboards?

These research questions directly relate to the phases of the learning analytics process model. The awareness stage is measured by how often teachers consult the dashboards during lessons. In the reflection and sense making stage, we examine which pedagogical knowledge teachers activate to interpret the data provided on the dashboard. The pedagogical actions that teachers take after consulting the dashboards provide first insights into the potential impact of dashboards on teachers' practices.

Next, we consider our expectations of how awareness of teachers influences the other stages of the learning analytics process model.

4. How does the awareness of teachers influence their knowledge activation in reflection and sense making phase and their pedagogical actions in the

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impact phase?

Finally the relation between the knowledge activation in the reflection and sense making stage and the pedagogical actions in the impact phase are explored.

5. To what extend is there a relation between activated pedagogical knowledge and pedagogical actions?

It is important to note that dashboard consultation and pedagogical actions are directly observed in the classroom context, whereas the knowledge activation is assessed after the lesson in a stimulated recall interview with the teacher.

3 Method

3.1 Sample

In total, 38 teachers from 8 different primary schools participated in this study. 30 teachers were female and 8 were male. The participating teachers taught at varied age levels ranging from Grade 2 (8-year-old students) to Grade 6 (12-year-old students). On average teachers had 19 years of teaching experience and 2 years experience with tablet education. Each teacher was observed during a 50-minute mathematics lesson, dealing with topics from the mathematics curriculum the school follows. Teachers agreed to participate in the study and were interviewed directly after the lesson.

We distinguished three groups of teachers. A group of teachers who consulted the dashboard often (>+1SD above average; between 10 and 20 dashboard consultations per lesson; N = 10), a group whose consultations were around the average (between -1SD and +1SD; between 6 and 10 dashboard consultations; N = 15), and a group that consulted the dashboard only a few times (-1SD and below; between 0 and 5 dashboard consultations; N = 13). We refer to these groups as the high, average and low consultation groups.

3.2 Adaptive educational technology

The adaptive learning technology used in this research is called 'Snappet'. This technology is mainly used for mathematics and spelling across primary schools in the Netherlands [15]. The mathematics and spelling exercises in 'Snappet' are comparable to those used in traditional paper workbooks. This educational technology software runs on tablet computers and features both adaptive exercises (embedded analytics) and dashboards (extracted analytics). Children receive immediate feedback (knowledge of results) after finishing each exercise. As well as pre-selected exercises that are the same for all students in a class, the technology features adaptive exercises, which are adjusted automatically to student's performance levels. The technology uses a derivative of the Elo rating system to adapt exercises to the current ability level of the individual student [16, 17]. The algorithm models the probability of a student answering a question correctly by calculating a student's ability score, which is the representation of a student's knowledge on a particular learning objective. Based on this ability score the expected outcome for a given exercise with a specific difficulty level is calculated and the next exercise with a matching difficulty level is selected. Once the student finishes an exercise, the ability score is re-calculated using the difference between the expected and actual outcome.

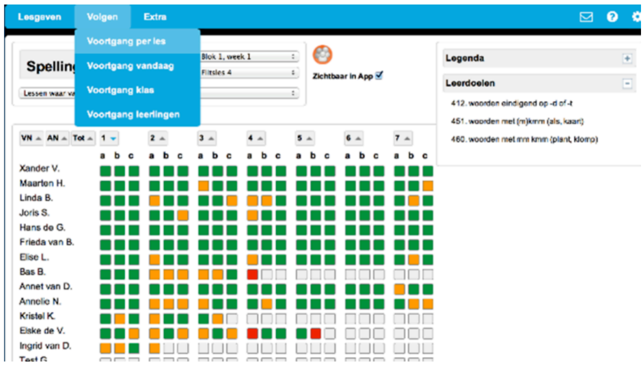

Fig. 1. Teacher dashboard lesson overview.

Teachers use this technology in blended educational scenarios in which traditional instruction is combined with practice on the tablet computer. Class-wide teacher instruction plays an important role in this scenario. After the teacher has explained a new learning goal to the class, all students initially practice with the same pre-selected exercises. Next students work on the adaptive exercises in which the sequence of exercises is adjusted to the ability level of the student.

The dashboards

The software captures real-time data on learner performance, which is displayed in real time to the teachers on dashboards. The system includes three different dashboards for teachers. The lesson overview dashboard indicates the performance of students on the pre-selected exercises, see Figure 1. Teachers can monitor this dashboard to see whether students' answers are correct or incorrect. Green blocks indicate that a student has answered an exercise correctly. Orange blocks denote that a student eventually answered the question correctly after one or more incorrect attempts. Red blocks indicate that the student did not manage to give a correct answer. Finally grey bloks show that the student has not yet attempted the exercise. As this dashboard is updated continuously while students practice, it also provides information on the pace of the students. The class overview dashboard provides an overview of the performance of the students compared to all other students using the system, indicating to which decile each student belongs (10% best students, 20% best students, etc.). Finally the progress dashboard is used when students work on adaptive exercises. This dashboard indicates which students are progressing on their learning goals, are stable, or slowing down in their progress.

3.3 Design

In this study, we can observe directly how often teachers consult the dashboards and which pedagogical actions are taken as a consequence. Reflection and sense making cannot be observed directly and are measured in a

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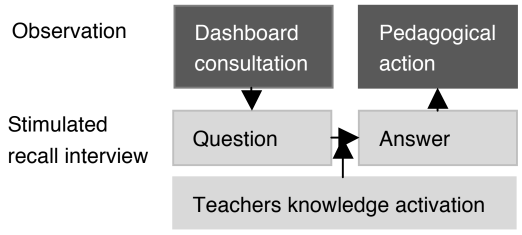

Fig. 2. The design of the study

stimulated recall interview directly after the lesson, see Figure 2.

3.4 Measurements

The observations

To examine how often teachers consult the dashboards during a lesson, classroom observations were performed by trained research assistants who were seated in the classroom. They observed the tablet or computer screen of the teacher and were logged into the adaptive learning technology to see the same dashboard as the teacher. Every time the teacher consulted a dashboard, the observer wrote down the time, made a screen shot of the dashboard and coded the pedagogical action (see Table 1) that followed. The actions were classified into five types of feedback: task, process, metacognition, personal, and social feedback [13, 14]. In addition, the "no action" category was checked when the teacher consulted the dashboard and did not engage in a pedagogical action directly afterwards.

TABEL 1
PEDAGOGICAL ACTIONS

Pedagogical knowledge	Explanation	Example
Knowledge of the student	Refers to the teachers' knowledge about students' knowledge or personal characteristics	"This student is weak in math but has a high general intelligence"
Error analyses	Refers to the analysis of mistakes to determine the reason of these errors	"Peter has a wrong conceptualization of double digit numbers"
Progress of the student	Refers to students' advancement, for example, the number of exercises made	"This student did fewer exercises compared to the other students"
Characteristics of the class	Refers to the teachers' knowledge of the class' characteristics and knowledge	"This class has many dyslexic students"
Agreements with the class	Refers to the agreements that were made with a class, for example, we respect each other's opinion	"Every lesson consult with your neighbor student for 5 minutes"
Progress of the class	Refers to the class' advancements	"The whole class has worked well today"

Stimulated recall interviews

After each observation session, the research assistant discussed all dashboard consultations in a stimulated recall interview with the teacher. The teacher was asked to indicate what knowledge they used to assess the data on the dashboard. By means of a grounded analysis the answers that the teachers gave were classified in the following categories: knowledge of the student, characteristics of the student, progress of the student, error analysis, knowledge of the class, characteristics of the class, and agreements with the class, see Table 2.

TABLE 2
PEDAGOGICAL KNOWLEDGE ACTIVATION OF THE TEACHER

Pedagogical actions	Explanation	Example
Task	Actions in which the teacher comments on how well exercises are understood or performed. Task feedback is related to content of the exercise.	"Please do not forget to add the numbers you have to keep in mind"
Process	Actions in which the teacher provides feedback on the way children handle their exercises.	"Tim, you can move on to the next exercise"
Personal	Actions in which the teacher comments on a student as a person.	"You are doing well!"
Metacognition	Actions in which the teacher comments on students' schedule or evaluation.	"How are you are going to divide the tasks over the lessons?"
Social	Actions in which the teacher comments on cooperative and social skills of student.	"Helen, can you try to help Susan with that exercise"
No action	Teacher did not perform a pedagogical action after consulting the dashboard	The teacher takes no action

4 Results

4.1 Awareness: dashboard consultation

During the 38 lessons that were observed teachers consulted the dashboards a total of 317 times. On average teachers looked at the dashboards 8.34 times per lesson with a standard deviation of 5.22 times.

4.2 Reflection & sense making: Pedagogical knowledge activation

The data from the stimulated recall interviews showed that teachers indeed reflect on the data when consulting dashboards. Teachers activated their existing pedagogical knowledge to interpret the dashboard data. Figure 3 provides an overview of the different types of pedagogical knowledge that teachers activated.

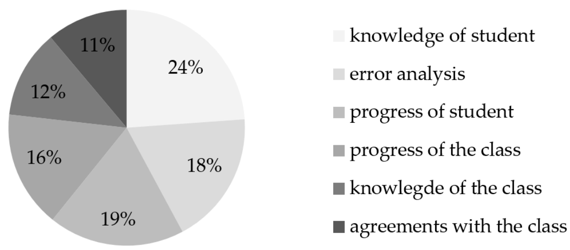

Fig. 3. Relative frequencies of different types of pedagogical knowledge activated following dashboard consultation (in

On average teachers activated 3,84 (SD = 1,34) different types of knowledge during a lesson. 'Knowledge of the student' was activated most often, after 73 of the 317 dashboard consultations. For example, a teacher explained 'This child has an ability level in-between two groups, so I keep an eye on him'. Teachers analysed 'students' progress' after 57 dashboard consultations. One teacher said 'I saw on the dashboard that Jenna was falling behind and was doing fewer exercises than the other

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children'. Analysis of the 'type of errors' students made occurred after 56 dashboard consultations. Often this was used to determine which type of support a student needed. A teacher explained 'Robert had a red block where he had made a calculation error, but I could see that he hadn't tried to correct it'. Teachers analyzed 'progress of the class' after 49 consultations. For example 'I checked the progress of the class and whether I needed to motivate them to work harder'. Knowledge of the class was activated 37 times. A teacher indicated that 'I checked whether these difficult exercises weren't too hard for the students because they have just started with these kinds of exercises'. Finally 'agreements made with the class' were used after 34 consultations. For example 'not everyone was dong the exercises in the agreed order'. In sum the results indicate that teachers activate different types of pedagogical knowledge to understand the data on the dashboard.

4.3 Impact: Pedagogical actions

The pedagogical actions that followed the 317 dashboard consultations are shown in Figure 4. On average teachers performed 1.95 (SD = .66) different types of pedagogical actions during a lesson. Two pedagogical actions were most likely to occur after dashboard conslutations. Progress feedback was given 126 times (for example 'You can move on to exercise four') and task feedback was given 118 times (for example 'Liza, you have to subtract these numbers'). Personal feedback was provided only 14 times, for example 'You are doing well!'. No metacognitive or social feedback was given by the teachers after dashboard consultations. In 59 cases the dashboard consultations were not followed by any pedagogical action.

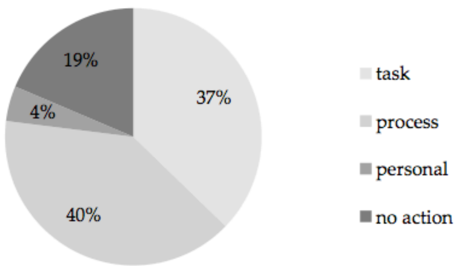

Fig. 4. Relative frequencies of different types of pedagogical actions following dashboard consultation (in percentages).

Pedagogical actions following dashboard consultations were directed at individual students 52% of the time (N = 165) (for example 'Tom, you can move on the next exercise'), 5% at groups of students (N = 17) ('Liza and Ben, you are working well, good job'), and 43% at the class level (N = 135), 'Please, listen everyone, we still have 10 minutes until the end of the lesson'.

4.4 The impact of awareness on pedagogical knowledge and actions

In this section, we examined whether teachers in low, average and high consultation groups differed with regard to the types and diversity of knowledge activated and pedagogical actions executed.

First, we examined whether the dashboard consultation rate was correlated with diversity of activated knowledge. A three-way ANOVA analysis indicated that there was a significant difference between teachers in the low, average, and high consultation groups on the diversity of activated knowledge, $F(2,35) = 25{,}17$, $p < .001$. Post-hoc Bonferroni analysis indicated that there were significant differences between all three groups. Teachers in the low consultation group activated fewer different types of knowledge (M = 2.62, SD = .87), than teachers in the average consultation group (M = 4.00, SD = 1.00), who in turn activated fewer different types compared to teachers in the high consultation group (M = 5.20, SD = .63).

Additionally, differences between the groups were found in all types of knowledge activation (see Figure 5). With regard to knowledge of the students ($F(2,35) = 3.57$, $p = .039$), Bonferroni post-hoc analysis showed that the high consulting group activated this type of knowledge significantly more often than the low consulting group.

With regard to error analysis ($F(2,35) = 8.61$, $p = .001$), the process of students ($F(2,35) = 10.68$, $p < .001$), the process of the class ($F(2,35) = 10.09$, $p = .003$), and the agreement with the class ($F(2,35) = 6.98$, $p = .003$), Bonferroni post-hoc analyses showed that the high consulting group activated these types more often than the average and low group. Finally, with regard to knowledge of the class ($F(2,35) = 3.96$, $p = .028$), Bonferroni post-hoc analysis showed that the average consulting group activated this type more often than the low consulting group.

In summary, whereas low consulting teachers mostly relied on knowledge of the student, average and high consulting teachers also engaged in error analysis and more frequently activated progress information of both class and students.

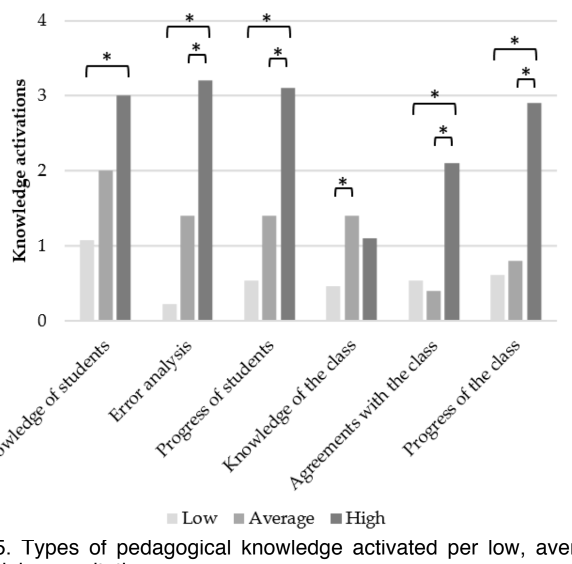

Fig. 5. Types of pedagogical knowledge activated per low, average and high consultation group

Next we examined whether the dashboard consultation rate was correlated with the types and diversity of the pedagogical actions. The three-way ANOVA analysis indicated that there was a significant difference between the low, average, and high consulting groups $F(2,35) = 8.41$, $p = .001$. Post-hoc Bonferroni analysis showed that there were significant differences between all three

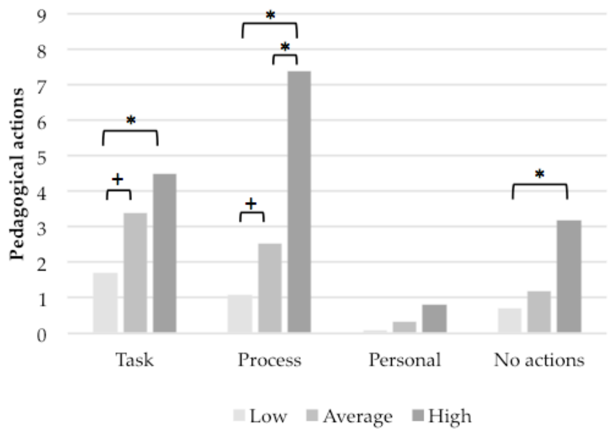

Fig. 6. Types of pedagogical actions per teacher low, average and high consultation group

groups. Low consulting teachers on average took 1.92 (SD = .64) different actions, average consulting teachers took 2. 73 (SD = .70) different actions, and high consulting teachers took 3.00 (SD = .80) different actions.

Additionally, differences between the groups were found in the types of pedagogical actions taken (see Figure 6). With regards to task feedback ($F(2,35) = 6.99$, $p = .003$), Bonferroni post-hoc analysis showed that the low consultation group gave marginally less task feedback than the average group ($p = .056$), and significantly less than the high group. Regarding process feedback, ($F(2,35) = 40.95$, $p < .001$), Bonferroni post-hoc analysis showed that the high consulting group took more process actions than the average and low consulting groups, and the average consulting group also took marginally more than the low consulting group ($p = .095$).

Although no significant differences were found between the consulting groups with respect to the personal actions taken ($F(2,35) = 2.39$, $p = .106$), a trend was observed ($F(1,35) = 4.73$, $p = .036$). A higher number of dashboard consultations was associated with increased personal feedback. Finally, we also examined the category "no actions" after dashboard consultations, and found significant differences between the three groups of teachers, $F(2,35) = 4.94$, $p = .013$. Bonferroni post-hoc analysis showed that teachers in the high consulting group refrained from actions more frequenctly after consultating the dashboard compared to the low consulting group, and marginally more than the average consulting group.

In summary, average and high consulting teachers gave more feedback, especially on the task and process and high consulting teachers also refrained from action after consulting the dashboard more often. Low consulting teachers mostly gave feedback on the task.

4.5 From sense making to impact: the relation between knowledge activation and pedagogical actions in different teacher groups

In order to understand the sense making process of teachers better, the relation between knowledge activation and pedagogical actions was assessed for the three most common pedagogical actions. In Table 3 the correlations between activated knowledge types and pedagogical actions are shown. Task feedback was related to activation of knowledge about students or the class. This showed that teachers add existing knowledge to information on the dashboard to determine the appropriate support. Process feedback was related to knowledge of agreements with the class, for example, "you are working as I suggested, well done!". Error analysis and progress of students and the class were also associated with process feedback. Finally, when no action was taken, teachers often simply confirmed that the class was making appropriate progress or that they assessed the errors and felt no immediate need to intervene.

TABLE 3
CORRELATIONS BETWEEN PEDAGOGICAL ACTIONS AND TEACHER ACTIVATED KNOWLEDGE

	Pedagogical actions		
Activated knowledge	Task	Process	No actions
Knowledge of students	.56**	.19	.04
Error analysis	.26	.42**	.71**
Progress of students	.3	.72**	.14
Knowledge of the class	.36*	.02	.08
Agreements with the class	.24	.65**	-.09
Progress of the class	-.13	.48**	.65**

* significant at 0.05, ** 0.01*** 0.001
note. N = 317 dashboard views

In order to understand the sense making process of teachers better, Table 4 shows the correlations between activated knowledge types and pedagogical actions for the low, average and high awareness teachers. These data should be regarded with caution because, expecially for low consulting teachers, some cells have only a few data points.

In the low consulting group process feedback was related to the activation of knowledge about agreements made with the class. This indicates that this group of teachers often gave process feedback in relation to earlier agreements made with the class. Moreover in this group no action was associated with error analysis, which indicates that often, after an error analysis, the teachers did not engage in any pedagogical actions. No significant relations were observed for teachers in the average consultation group.

In high consulting teachers activation of knowledge about the student was related to task feedback, which might indicate that this group of teachers augments the information in the dashboard with existing knowledge of students to determine which task feedback is most appropriate. Moreover, activation of knowledge about the progress of the class was negatively associated with task feedback. Thus, teachers that consulted the dashboard often did not provide task feedback based on process information of the class. Process feedback in this group was often elicited by teachers analyzing the progress of students. Even though this seems a straightforward relation, we only found this association for high consulting teachers. Finally, instances of no actions for high consulting teachers were related to error analysis or analysis of progress of the class. This may indicate a simple confirmation that the class was making appropriate progress. In

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sum, the different groups of teachers showed different associations between knowledge activation and related pedagogical actions, which points towards profound shifts in how teachers interpretate dashboards.

TABLE 4
CORRELATIONS BETWEEN PEDAGOGICAL ACTIONS AND TEACHER ACTIVATED KNOWLEDGE PER CONSULTATION GROUP

	Pedagogical actions								
	Low			Average			High		
Activated knowledge	Task	Process	No actions	Task	Process	No actions	Task	Process	No actions
Knowledge of students	-.11	-.01	.46	.47	.19	-.21	.67*	-.54	-.31
Error analysis	-.22	-.47	.80**	-.01	-.25	.17	-.06	-.04	.74*
Progress of students	.50	-.17	-.22	-.25	.22	.24	.01	.68*	-.36
Knowledge of the class	.35	-.08	.22	.26	-.40	-.18	.19	-.22	.06
Agreements with the class	-.27	.86**	-.17	.04	.35	-.24	.18	.46	-.53
Progress of the class	-.04	.24	-.04	-.35	.24	.40	-.81**	.10	.68*

* significant at .05, ** .01*** .001
Note. N low = 46, average = 112, high = 159 dashboard views

5 CONCLUSION

This study examined how teachers use teacher dashboards during mathematics lessons. The results showed that teachers were aware of the dashboards and consulted them on average more than 8 times in a 50-minute lesson. Teachers did reflect on the data and activated additional pedagogical knowledge to interpret the data as suggested by Verberts' learning analytics process model [5] and Roelofs' pedagogical knowledge bases model [12]. Teachers mostly activated knowledge at the individual student level, such as knowledge of the student, progress of the student and error analysis of the student's work. As well as knowledge on the individual student level, knowledge at the class level, such as the progress of the class and agreements made with the class, was used by teachers to make sense of the dashboard data.

The dashboard impacted the pedagogical action of teachers. Both progress and task feedback were common actions after dashboard consultations. Personal feedback was less common and there were no instances of social and metacognitive feedback. This is in line with earlier research that showed that social and metacognitive feedback is less applied by teachers [14]. Moreover, the current generation dashboards provide few indications for this type of feedback. Surprisingly, about a quarter of the dashboard consultations were not followed by any explicit teacher action. This seems to indicate that dashboards are also used to confirm teachers'own assessment of student and class progress. These results showed that Verberts' learning analytics process model is useful to understand teachers' use of dashboard data.

It is important to note that a large diversity in dashboard consultations was found among the teachers. As awareness is the beginning point in the learning analytics process model, differences between low, average and high consulting teachers were expected to impact other phases of the model. Indeed, results showed that teachers who consulted the dashboard more often also activated more diverse types of pedagogical knowledge to interpret the data. Consequently, they also engaged in more diverse pedagogical actions.

Specifically teachers in the high consultation group more often activated knowledge about a particular student to interpret the dashboard information compared to teachers in the average and low consolation group. This can be indicative of more advanced integration of the dashboard in the professional routine of these teachers. Both high and average consulting teachers activated knowledge about students' errors, student and class progress and agreement with the class more often compared to teachers with low consultation frequencies. This was associated with more task and process feedback in both groups and also to more instances in which the teacher did not engage in any action. This suggests that higher awareness is associated with more reflecting on and sense making of the dashboard data and more diverse pedagogical actions.

Moreover patterns between activated pedagogical knowledge and different types of pedagogical actions provided insights into teachers reasoning about data. A stable finding among all groups was that error analysis was related to no actions. This indicates that, after analyzing the type of mistakes that students made, teachers decide that no support was needed. A possible explaination could be that the mistakes made were actually skips instead of errors. Futhermore, the association between knowledge activation and the pedagogical actions of teachers in the high consultation group points toward a more advanced usage of the dashboard information. These teachers learned to combine dashboard information with their own knowledge of the student to provide task feedback. The differences in reasoning patterns between the groups of teachers suggests that dashboards progressively impact teaching practice and more profound behavioral changes seem to follow as teachers become more proficient in using dashboards.

Overall, this study shows that teachers were indeed using the dashboards and this influenced their daily teaching practices. Interpreting our results in the light of the distributed cognition theory, we can conclude that information in the dashboard connects to the professional routine of teachers and teachers are indeed able to successfully use these new tools. The stages of Verbert's learning analytics model supported the analysis of how teachers use dashboards. The data drove reflection and sense making and teachers used their existing pedagogical knowledge to come to new understandings, which in turn lead to pedagogical actions.

There are practical implicatons of this study for both development of teacher training and improvement of dashboards. Initial patterns between activated pedagogical knowledge and types of feedback provide preliminary insights into teachers' reasoning about data. The differences in reasoning patterns based on teachers' awareness of the dashboard can especially provide a basis for professional programs to train teachers to handle dashboards in classroom situations. As indicated by the learning analytics process model, this would begin by making teachers more aware of the data. Also, modeling how expert teachers interpret data within their existing pedagogical knowledge might help novice teachers to transfer into more advanced dashboard usage.

Additonally the distributed cognition theory emphasizes the connection between the instrument (dashboard) and the professional's knowledge to support successful dashboard usage in daily classroom practice. This connection can be improved by adding new recommendation services to the existing dashboards, for example highlighting important information or proposing potential pedagogical actions. The associations between the knowledge activation of teachers and the data provides an empirical basis for the development of these services. For example, the fact that error analysis often results in no action could be resolved by a distinction between slips and errors in the dashboard. Therefore, we suggest the development of a recommendation service that models advanced teachers reasoning to support novice teachers in using dashboards.

In summary, we conclude that dashboards indeed impact the way teachers teach and have the potential to support advanced educational effectiveness. The diversity between teachers, as indicated by the differences between low, average and high consulting teachers, and related differences in reflection, sense making and impact are indicative of progressive development of dashboard usage. More research is needed to further explore the way teachers are using dashboards to come to a more profound understanding of the associations found in this exploratory study. The developments in teacher usage of dashboards over time, as well as the role of experience and possible interactions with professional skills, need to be explored in future research. This type of research on the subject of dashboards usage in classrooms is essential to improve human-technology interaction and hence to optimize students' learning.

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