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# Differentiated Teaching with Adaptive Learning Systems and Teacher Dashboards: The Teacher Still Matters Most

Trynke Keuning and Marieke van Geel

***Abstract*—Although many schools in the Netherlands have purchased adaptive learning systems (ALSs) to reduce workload and improve differentiated instruction, the use of ALSs with teacher dashboards in the classroom does not in itself necessarily improve differentiated instruction. The question is, what skills and knowledge do teachers need to provide differentiated instruction with the help of ALSs with teacher dashboards and how does this differ from a context in which such technologies are not used? By means of a cognitive task analysis (CTA), consisting of classroom observations, interviews and several expert meetings, teachers' skills and knowledge necessary for providing differentiated instruction when using teacher dashboards and ALSs were disentangled. These findings were and compared with the skills and knowledge needed by teachers providing differentiated instruction without these tools. Results show that teachers' dashboards can support teachers when providing differentiated instruction by providing up-to-date information about students' progress. Nevertheless, coping with the new information provided on the dashboards also requires new skills and knowledge such as interpreting information from the dashboard and understanding how the information in the ALS is calculated. Although there are some differences, the core principles of differentiated instruction—1) being goal-oriented, 2) continually monitoring, 3) adapting instruction and assignments, 4) being ambitious, 5) stimulating students' self-regulation—are critical for high-quality differentiated instruction regardless of the available tools in the classroom.**

***Index Terms*—Adaptive learning systems, cognitive task analysis, differentiated instruction, teacher dashboard, technology-enhanced learning.**

## I. Introduction

PROVIDING adaptive education that meets the needs of all students in a classroom is one of the core elements of effective teaching [1] but it is also a very complex teacher skill [2]–[4]. In order to provide effective differentiated instruction, teachers need to master a whole set of skills and have adequate knowledge about both their students and the subject matter [5]–[7]. In the Netherlands, many schools have invested in adaptive learning systems (ALSs) for students, including real-time monitoring dashboards for teachers, under the assumption that these software tools will support teachers in differentiating [8]–[10]. However, it is unclear whether these new technologies genuinely decrease the complexity of providing differentiated instruction. To gain more insight into this differentiated teaching with ALSs, in this study, the skills and knowledge teachers need to master in order to differentiate in a classroom where ALSs and teacher dashboards are used are compared to those needed for differentiation in what we will call "more traditional classroom settings." Note that "traditional" instruction can be with or without the use of information and communication technology (ICT); the main difference lies in the availability of a real-time teacher dashboard. We use "traditional" for any type of classroom where teachers do not have access to such a real-time dashboard.

### A. Differentiated Instruction

In our previous research, a cognitive task analysis (CTA) was performed in order to disentangle what is involved in the complex skill of "providing differentiated instruction" in the context of primary school mathematics [6]. In an iterative process, results from classroom observations, stimulated recall interviews, and an expert meeting with nine teachers working with textbooks and without a dashboard were combined with results from an expert meeting with subject-matter experts (e.g., experts from the Inspectorate of Education and teacher training institutes, and educational consultants). It was clear that differentiation during the lesson cannot be separated from the phases of lesson preparation and evaluation. Four chronological stages of differentiation that are closely interrelated could be distinguished: a teacher prepares a lesson (stage 2) on the basis of the evaluation of the previous lesson (stage 4) and on the basis of the preparation for the school term (stage 1). This preparation enables the teacher to adequately address the differences between students during the lesson (stage 3). Within

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each of these stages, several constituent differentiation skills can be distinguished. For example, in order to prepare a lesson, a teacher needs to set goals for the group as a whole and determine instruction for subgroups, while in order to enact a differentiated lesson and provide adaptive instruction, a teacher needs to monitor the progress and achievement of students during the lesson [6].

In this previous study, two types of knowledge were found to be essential for being able to differentiate. First, the teacher needs knowledge about the students, such as knowing their level of achievement, the problems they encounter, and their educational needs. And second, the teacher needs subject matter knowledge, for identifying students' zone of proximal development, making decisions regarding curriculum materials and assignments, and knowing how to explain difficult topics properly. Overall, this study supported the notion held by other researchers that differentiation is a complex teaching skill [2], [3].

In addition to the required knowledge and skills, five underlying "principles for differentiation" decisive for the quality of the differentiation were identified (see Fig. 1): 1) being goal-oriented, 2) continually monitoring students' progress and understanding, 3) adapting instruction and assignments to the students' needs, 4) being ambitious and challenging all students on their own level, 5) stimulating students' self-regulation. The application of these five

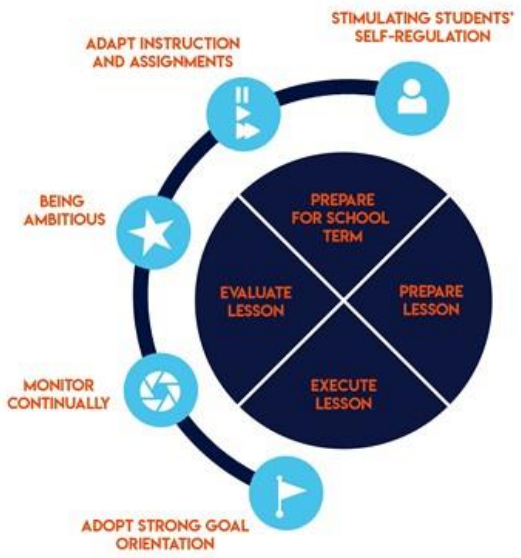


Fig. 1. Four stages and five underlying principles for differentiation.

principles is required in all four phases for provision of high-quality differentiated instruction [11].

### *B. Adaptive Learning Systems and Teacher Dashboards to Support Differentiated Instruction*

Worldwide, schools are implementing technological tools for educational change or for overcoming challenges [12]. In the Netherlands, one commonly implemented tool is ALSs and teacher dashboards [13]. In these systems, students work in a (partially) adaptive environment, the students get immediate feedback, and a teacher dashboard is provided (see example in


Fig. 2. Screenshot of a teacher dashboard during the non-adaptive part of the lesson. A green dot indicates a correct answer, a red dot indicates an incorrect answer, and a green dot with a red bottom indicates that the student responded incorrectly on the first attempt, but then gave the correct answer.

Fig. 2). It is generally assumed that these ICT tools support teachers when differentiating and reduce teacher workload. Various companies offer ALSs. All of these ALSs provide students with individual exercises adapted to their level, and typically provide students with formative feedback (therefore, in the literature, these systems are also called "digital formative assessment tools[8]). " ALSs are often combined with a teacher dashboard that enables teachers to track the progress of their students before, during and after the lesson [9].

Introducing ALSs with teacher dashboards into the classroom looks promising for differentiated instruction and might support teachers with the previous mentioned "principles for differentiation:"

- *Being goal-oriented:* learning goals are visible for both teacher and students.
- *Monitoring continually:* the teacher dashboard enables the teacher's ongoing monitoring of student progress and performance, at the individual or class level.
- *Adapting instruction and assignments:* the ALS provides students with exercises matching their performance level.
- *Being ambitious:* an ALS is by definition independent and helps teachers to review their (unconscious) expectations of students. Low-performing students may be challenged more often in this way because the software shows when they do master certain domains. In addition, high-performing students can quickly move on to a higher level and be challenged by the software, without the teacher having to put in too much effort.
- *Stimulating students' self-regulation:* students are provided with individual formative feedback and thereby are encouraged to reflect on their own work; moreover, the software makes students aware of the goals they are working on.

In their study of ALSs, Molenaar *et al.* [9] concluded that uses of ICT tools "impact the way teachers teach and have the potential to support advanced educational effectiveness" (p. 8). Other research into the effect of ALSs on student performance is cautiously positive: Faber, Luyten and Visscher [8] found a positive impact of ALSs on mathematics achievement and student motivation in grade 3. They also found that using an ALS was most effective for high-performing students. Teachers reported having a better overview of how lessons progressed,

and of students' understanding of assignments. Moreover, teachers reported that they were able to respond more quickly and purposefully to students' questions and learning needs (p. 91). Faber *et al.* [8] concluded that teacher professional development is recommended to promote teacher use of ALSs, in order to increase the effects on student achievement. Based on the small to medium positive effects of computer-based differentiation in their review of the use of computerized systems as a differentiation tool, Deunk *et al.* [2] concluded: "Software can be used to take care of some of the assessment and diagnosing, and may provide suggestions for tailored instruction, content, or materials. However, it is still the teacher who implements the differentiation practices" (p. 44). They therefore advocated for coaching and support for teachers when implementing differentiation using software.

### C. Research Questions

Although many schools have purchased ALSs to reduce workload and improve differentiated instruction, the implementation of ALSs with teacher dashboards within the classroom does not in itself necessarily improve differentiated instruction [2]. Various researchers (e.g., [2], [8], [14]) have emphasized the importance of training teachers in the use of these systems in order to realize their full potential. Since the use of these technologies is relatively new, working with ALSs is not yet part of pre-service teacher training [15]. Furthermore, in-service training mainly focuses on "clicking the right buttons" in the system, rather than conscious and reasoned ALS use to improve differentiated instruction. It seems there is a gap in our understanding of what teachers need to know and need to be able to, in order to optimize their lessons with the help of ALSs. The current study is therefore aimed at answering the research question: what skills and knowledge do teachers need to provide differentiated instruction with the help of ALSs with teacher dashboards, and how does this differ from a context in which such technologies are not used?

## II. Method

### A. Cognitive Task Analysis

A cognitive task analysis (CTA) is a technique for identifying, analyzing and structuring the skills and knowledge used by experts to perform a complex task [16], and leads to an integrative, coherent description of everything required to perform professional tasks adequately [17]. In our study, skills and constituent skills are identified by means of lesson observations and a cued retrospective interview with various expert teachers, and summarized in a skills hierarchy. In two expert meetings, one with the teachers involved in the observations and one with subject-matter experts, the findings from the observation and interview sessions were verified. In the following sections, the CTA procedure is described in greater detail.

### B. Sample

For the purpose of this study, we searched for primary school teachers (grades 1 to 6) who were experienced in differentiated instruction supported by an ALS with a teacher dashboard.

TABLE I
Characteristics of Teachers at the Time of the Classroom Observation

| Name | Grade | Number of students | Years of teaching exp. | Years of teaching exp. with ALS | ALS Version[b] |
|---|---|---|---|---|---|
| Anthony[a] | 6 | 16 | 13 | 4 | OGL |
| Charles[a] | 5 | 31 | 23 | 3 | TbB |
| Dennis | 4 | 21 | 9 | 1 | OGL |
| Eric[a] | 5/6 | 26 | 13 | 2 | OGL |
| George[a] | 5 | 31 | 14 | 3 | TbB |
| Isabel | 4/5 | 24 | 12 | 2 | OGL |
| Josephine[a] | 5/6 | 27 | 19 | 4 | TbB |
| Maggie[a] | 5/6 | 27 | ? | 4 | TbB |
| Sophie | 1/2/3 | 12 | 5 | ? | TbB |
| Wendy | 5/6 | 33 | ? | 1 | OGL |

The names of the teachers are fictitious to safeguard their anonymity.
[a]Present at the expert meeting
[b]OGL = One-goal-per-lesson, TbB = Textbook-based

Teachers were recruited via a network of school inspectors, educational consultants, school boards, ALS companies and teacher training institutes. Ten teachers (5 male and 5 female), participated in this study. An overview of teacher characteristics is provided in Table 1. Most teachers taught in the upper grades of primary education (students from the ages of 9 to 12), which is representative of the use of digital devices in primary school, as these are mainly used in the upper grades.

Although there are several companies offering ALSs, all teachers in the sample used "Snappet." This system was the first on the market and therefore teachers are the most experienced with it.

Schools can choose from two versions of this ALS: textbook based (related to specific curriculum material and textbooks), and one goal per lesson (in which one goal is central to each lesson). In the textbook-based version, the sequencing of the lesson goals follows the order of the traditional textbook material. Having one lesson be focused on multiple goals is typical for this version. In the one-goal-per-lesson version, one learning goal is central to each math lesson. Each version has its pros and cons: the one-goal-per-lesson version is more goal-oriented, but in the textbook-based version, students rehearse previous goals more often. In this study, five teachers had implemented the one-goal version, and the other five teachers worked with the textbook-based approach.

In general, a math lesson with Snappet, either textbook based or one goal per lesson, has more or less a fixed structure. The lesson starts with whole-class instruction, for which specific exercises are provided by the software. After the whole-class instruction, all students work on the same set of exercises. The teacher can track students' progress on their dashboard and based on this, can determine who needs extra instruction and who can continue to work independently in the adaptive part of the software environment. There are two options in this phase: students can practice with adaptive exercises related to the current lesson goal (adaptive practice), or students can work on other learning goals they have not mastered yet, which are selected by the teacher for each student (individual goals). In most schools, students first work on a fixed number of exercises related to the lesson goal, and then start working on their

individual goals.

*1) Subject-matter experts*

In addition to the participating teachers, a group of 11 subject-matter experts was gathered. These subject matter experts were experts in the field of differentiated instruction and/or in the field of working with ALSs. The group included three educational consultants in the field of math education, one school inspector who evaluates differentiation, four educational consultants who provide training courses in differentiated instruction with the help of ALSs, and three researchers who study differentiation.

### C. Procedure

Two mathematics lessons were observed for each teacher and recorded with two cameras to capture the view from both the front and the back of the classroom. After each observation, a semi-structured stimulated-recall interview—a retrospective method that is suitable for mapping decision-making moments and thought processes—was performed in the afternoon [18]. The researcher selected three to 10 situations from each lesson that appeared to appeal to the teacher's differentiation skills. To gain insight into the teacher's actions and underlying considerations, the researcher asked questions such as, “What are you doing here? For what purpose?,” “What do you do with the information you get from X?,” “X is happening, what action do you take based on that?” [18]. To obtain a complete picture of differentiated teaching, several general questions were asked about the four phases of differentiation (e.g., how did you prepare for this school term; how did you prepare this specific lesson and do you evaluate the lesson at the end of the day).

Six of the 10 observed and interviewed teachers were able to attend the expert meeting. This whole-day meeting was aimed at deepening our understanding of the skills and knowledge teachers need to differentiate in an ALS context, and at comparing these skills and knowledge with their insights related to the more traditional context. In small groups, teachers were asked to map out the subsequent steps they take in each phase in a so-called “roadmap”. These steps were the basis for an in-depth discussion in order to identify the skills and knowledge necessary for each step teachers perform in the differentiation process. After that, in each small group, teachers compared their roadmaps with the skills hierarchy from the traditional context. Similarities and differences were discussed by the whole group.

After an initial inventory of the results from the observations, interviews, and expert meeting with teachers, the first results were presented to the panel of subject-matter experts during another whole-day expert meeting. Experts could comment on the results, and performance objectives for “high quality differentiation in technology-enhanced classrooms” were formulated.

### D. Data Analysis

Interviews with the teachers and group discussions during the expert meetings were audio-recorded and transcribed. Additional materials such as the “roadmaps” and sticky notes were collected. Deductive coding was applied: interview content was divided into the four phases of differentiated instruction and within each of those phases, what teachers said about the different skills from the skills hierarchy in the regular context was checked. If applicable, new codes for knowledge and skills were added. The findings from the interviews were taken as a starting point and were supplemented with the expert meetings data. This resulted in a skills hierarchy and overview of knowledge needed for differentiated instruction with an ALS and teacher dashboard, which will be presented in the results section.

## III. Results

### A. Skills

The skills hierarchy for differentiated instruction in the context of using an ALS with teacher dashboards is presented in Fig. 3. This skills hierarchy is very similar to the skills hierarchy from the CTA in the more traditional context [4], since there are strong resemblances between the skills required for providing differentiated instruction with and without using an ALS with teacher dashboard. In the following sections, for each phase the required skills for differentiated instruction using ALSs and teacher dashboards are described Light gray blocks indicate this skill is present in both the skills hierarchy with, as well as without using ALSs, dashed blocks are only present in the more traditional context, dark gray blocks are only present in the ALSs context.

*1) Preparing for a school term*

All teachers in the sample reported they analyze student results prior to the start of a school term, where “school term” can refer to several timeframes. In the Netherlands, teachers give standardized student monitoring tests twice a year. These tests cover the learning content for half a school year and provide information about the progress of the student and the class as a whole compared to the national average. Furthermore, the majority of teachers (7 out of 10) give a curriculum-based test approximately every six weeks to determine students' progress. Two of these teachers deliberately give these tests on paper, in order to measure transfer from digital to paper. Three teachers mentioned that they do not use additional tests, since students’ progress with regard to learning goals is monitored by the ALS. Overall, the teachers explained that they combine the information from the student monitoring tests, the curriculum-based tests (if applicable), and student work in the ALSs to determine students’ progress and identify possible gaps that students still have to work on.

In preparing for the school term, teachers set two types of goals: “new group goals” and “individual goals” (i.e., remedial goals or additional challenging goals). To gain insight in the learning goals that will be addressed in the upcoming school term, teachers check the overview of goals that will be addressed in the ALS. Furthermore, in case (either curriculum based or standardized) tests are used in their school, teachers determine which learning goals will be addressed in these tests as well. The external experts emphasized the importance of this

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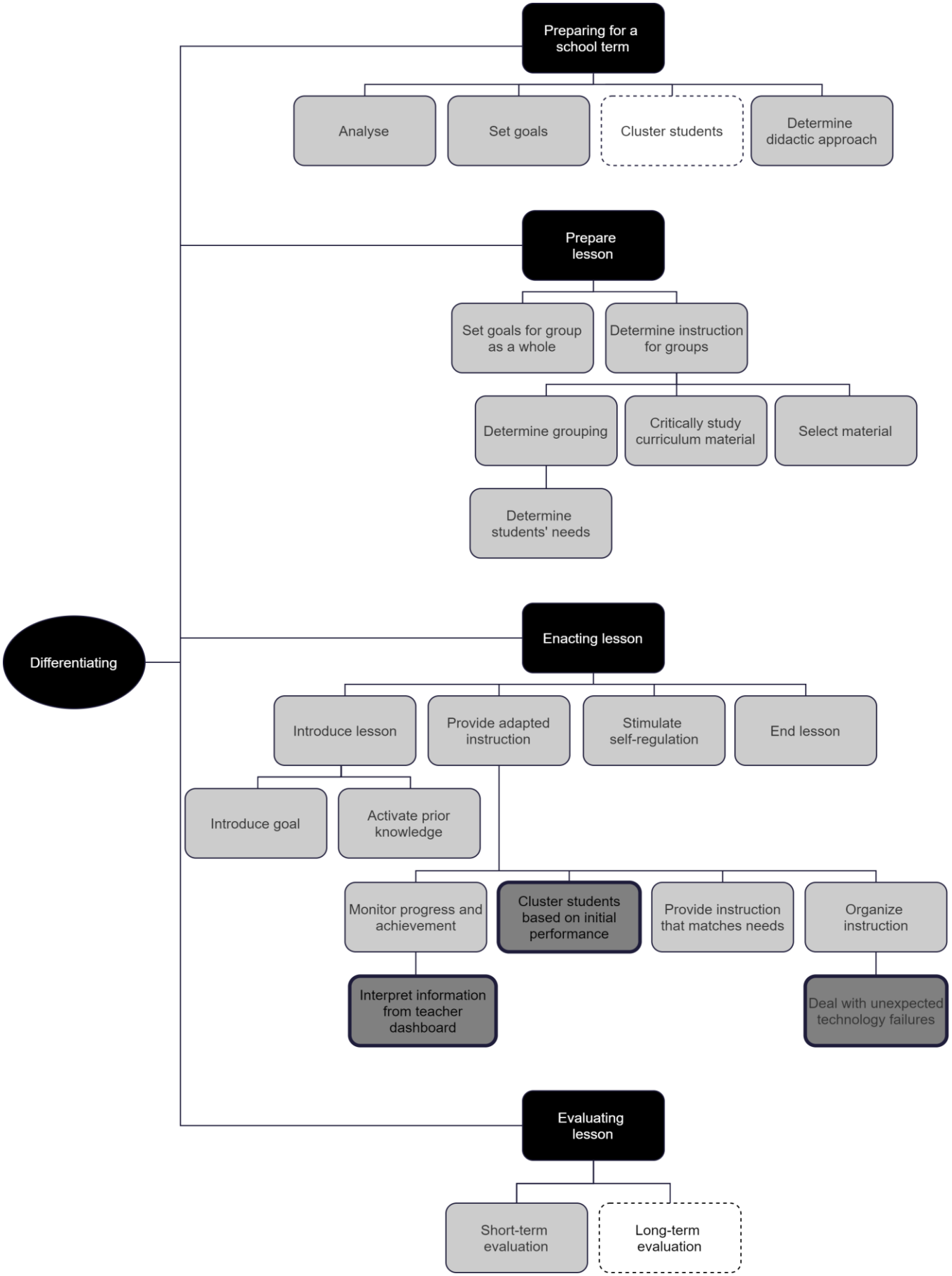


Fig. 3. Skills hierarchy for differentiated instruction with an ALS and teacher dashboard.

phase, especially to keep track of the long term (i.e., what do students need to learn this school year and how do the goals for this school term relate to the long-term goals).

Next, the teacher compiles "work packages" for each student, in which they add individual goals students have not yet mastered. Usually these are learning goals that have already mastered. Usually these are learning goals that have already been addressed, but for which the student has not yet reached the desired level. For students who have reached all of the goals already, more challenging new goals can be added. Two to six goals per student are selected, which they have to work on along with the regular learning goals in the upcoming school term. Four teachers do not select these goals by themselves but discuss them with the students. For example, Wendy explained: "These [high-achieving] students get more responsibility: they should compose their own work packages."

Finally, teachers determine a didactic approach for the upcoming lessons. Similar to the more traditional context, teachers make a rough plan, determine what lessons they will teach and how they will teach the strategies. In addition, teachers in the ALS context decide whether and how they will (not) use the ALS; for example, they choose in which lessons they will not use the tablets, but will instead go outside to measure square meters.

In the context of teaching with ALSs, as opposed to the traditional context, teachers do not cluster students prior to a school term. Wendy said, "Before we used an ALS, I divided students into semi-fixed ability groups. Now, I check whether there are children who need extra instruction per goal, mostly per lesson." Dennis explained, "In the past we used to cluster students, but nowadays with Snappet you see more and more that a student who usually scores high can sometimes go completely wrong with, for example, 'kilos'."

*2) Preparing a lesson*

The second phase is "preparing a lesson." Most teachers usually start preparing a lesson by determining the lesson goal. The software provides suggestions about the upcoming lesson goal(s) and content and most of the teachers stick to the(se) suggested lesson goal(s). Wendy said, "I usually use the goal the software indicates. I sometimes rephrase it, so the children also understand what they will be learning." Three teachers in the one-goal-per-lesson context do not stick to the suggested goals, but select for themselves the topic they will be teaching; for example, based on their evaluation of the previous lesson, they determine whether it is necessary to work on the same lesson goal for another lesson, or whether they will continue to a subsequent goal. Anthony said, "At the beginning of the week I select the goals for the upcoming four lessons: I check the overview of all learning goals, and then I choose a goal that matches the previous learning goal, or if most students reached a specific goal, I select a new goal. I make sure we do not work on the same subject for a whole week. And I try to find a balance in the difficulty. If we work on a generally difficult goal at the beginning of the week, I select an easier goal for the end of the week, or the other way around."

Teachers analyze how students scored with regard to the lesson goal to determine the expected need for instruction: which students can probably work on the exercises independently and which students will need teacher-led instruction. The software provides an overview of those students who presumably need extra instruction and those students who have already reached the goal. However, the external experts in particular emphasized the importance of a critical attitude towards these suggestions from the software. It is important that teachers stay in charge of decisions related to who will follow what instruction. The software dashboard gives suggestions as to which students should follow what instruction, but an expert teacher supplements this information with other insights such as their daily observations and knowledge about the students. Furthermore, the software suggestions do not take the class composition into account. Teachers must evaluate the suggestions in relation to the practical possibilities. For example, six out of the 10 expert teachers were teaching in multi-grade groups. These teachers analyze the software suggestions, taking instructional time limitations into account.

The same critical attitude is necessary towards curriculum materials. Teachers determine how they will shape their instruction, based on the suggestions from the software combined with additional materials. This skill includes asking questions such as: Is this the best way to introduce X to my students? How will I introduce this strategy? Can we work on the tablets immediately, or should I let my students work first with materials or on paper? In this phase, teachers also select additional materials (i.e., manipulatives such as base 10 blocks, or paper worksheets in addition to the tablets). Charles explained, "The software gives suggestions of steps to take to reach the lesson goal, just like previously in the teacher manual. I always check if these steps are really necessary. Sometimes a step is rather confusing and then I skip that step. I do that based on my experience gained in my years as a teacher: I know what steps I can skip."

The phase of "preparing a lesson" results in an overview of the lesson; teachers have thought about the grouping, instruction, organization, and materials. Note that goals were already set for individual students in the preparation for the school term. Besides planning for time to work on these individual goals, teachers cannot prepare this further, since teachers do not know what types of (adaptive) exercises students will work on, as the software selects the exercises on the fly.

As can be seen in Fig. 3, in the phase "preparing a lesson" all skills are light gray, indicating that the skills teachers need for preparing a lesson are the same in the context with and without the use of an ALS. Although the software offers support (i.e., with determining group-level instruction), the teacher needs to adopt a critical attitude to determine whether the suggestions from the software are appropriate.

*3) Enacting lesson*

During a lesson in the context of using an ALS with a teacher dashboard, a teacher needs four constituent skills (see Fig. 3). Note that the first (introducing a lesson) and last (ending a

lesson) skills are time-bound, but the skills and subskills below "'providing adapted instruction" and "stimulating self-regulation" are needed throughout the entire lesson. Similar to what teachers in the more traditional context do at the beginning of the lesson, the teacher introduces the goal and relevance or meaning of this goal to the students. Teachers also activate prior knowledge related to this goal, and (by applying various monitoring strategies) make an inventory of this prior knowledge. All students are involved in this lesson introduction. Most teachers (nine out of 10) choose not to use tablets at the start of the lesson, but instead let students complete some exercises in their notebooks or on "wipe boards" (i.e., mini whiteboards) or they start the lesson with playing a (board) game. The external experts also emphasized the importance of hybrid lessons in which teachers deliberately choose when to work with tablets and when not.

The skill of "providing adapted instruction" is the most comprehensive and, according to the external experts, the most crucial skill in the hierarchy. To do so, teachers need to monitor students' progress towards the lesson goal, cluster students in instructional groups, and provide and organize instruction.

The teachers who were observed continually monitored students' progress towards the lesson goal during the entire lesson. These teachers used the teacher dashboard to monitor, but combined this with various other means. For example, teachers said they often use wipe boards while providing instruction. According to Isabel, "With those wipe boards all students are actively involved so everyone is completing the exercise, plus if they show their boards I immediately see, 'oh, [he] doesn't understand it yet,' and so it is information for me and everyone is involved." Other means of monitoring are: asking questions, observing student behavior, walking around, and checking students' work. Most teachers plan a number of moments during the lesson in which to check the dashboard. What they check differs. On the one hand, teachers look at the number of assignments completed. Isabel explained, "I mainly look at how far they are, who needs some encouragement." On the other hand, teachers look at the incorrect answers. Wendy said, "I use the dashboard to keep track of how the children are performing. If I see that they get stuck, I can call them up to see what is going wrong. You will not find out what is exactly going wrong if you only look at the dashboard. When I see that several children get stuck with the same exercises, I call them all up at the same time for extra instruction."

All teachers agreed that the teacher dashboard provides them with a quick informative overview of the students' progress. They acknowledged that the information they receive is limited; you need to check students' calculations or talk to a student to understand what is going wrong in students' thought processes. As such, the teacher dashboard in itself does not provide enough information. Nonetheless, teachers felt that the dashboard signals signal students' misunderstanding faster, and as a result they can respond more quickly to students' needs. To do so, teachers need to be able to interpret and prioritize the information provided by the dashboard in order to make deliberate decisions regarding clustering students and providing adapted instruction. Dennis said, "During the lesson I check students' progress; in this lesson, I saw a student who made multiple errors in a row, so I decided to check on her, asking: what is the matter? What do you find difficult? Let's check it together."

In the lesson preparation teachers determined instruction groups. During the lesson, teachers revise these instruction groups based on the exercises made in the learning software—they decide who needs extra instruction and who can work independently. This skill is additional to the traditional context where it is less common to review instruction groups during the math lesson.

Teachers provide multiple types of instruction during a lesson. Commonly they start with whole-class instruction and then give small-group or individual instruction to students. To make sure that this instruction matches the needs of students, teachers need to teach in the zone of proximal development [19], for example, by using additional math materials or adapting the level of abstraction of the instruction. In particular, the individual instruction teachers provide is not all easy to prepare, because at a certain point in the lesson all students are working on different learning goals. A teacher then needs to be able to respond ad hoc to students' questions and to improvise.

In addition to being able to present sound mathematics instruction, providing instruction also requires an organizational component. This includes dealing flexibly with unexpected events during the lesson (e.g., a group of students who do not understand the content at all, or the opposite—all students somehow already reached the lesson goal). Moreover, it is important for the teacher to arrange time during the lesson so that the balance between instruction and processing is optimal for all students, with a view to achieving the lesson goal. Organizing instruction in the ALS context also includes dealing with unexpected technology failures, such as loss of internet connection, uncharged tablets, or software bugs. Eric remarked, "I always have a pile of paper worksheets on my desk anyway. Because the internet may drop out. That has never happened, and we will keep it that way, but it can happen."

The third constituent skill needed for enacting a lesson is stimulating self-regulation. Similar to the traditional context, the teachers who were observed all found it important to involve students in differentiated instruction, and regularly challenge them to take responsibility for their own learning.

The software shows students' progress not only to the teacher, but also to students. Students have an overview of the goals they need to reach and can see their progress towards reaching these goals. As a result, students in the observed classrooms were all very aware of the lesson goals and their individual goals. Moreover, once a student gives an answer, the student receives immediate feedback (correct/incorrect). Most teachers have a classroom agreement that students will ask for help after more than two incorrect answers.

Finally, teachers use the teacher dashboard to show students their progress and stimulate them to work hard or to ask for help

if necessary. Some teachers do this individually and plan learning conversations (prior to or during the lesson enactment). For example, Eric explained, "Yesterday I asked N to have a look at his progress with me, he did 2 exercises in 20 minutes. That does not make sense at all. Then I know that he has been sleeping. So I showed him his progress on the dashboard and talked about how it could be better. This works to get them back to work in a focused way." Other teachers show the students' progress on the classroom screen. Eric said, "I also do it occasionally so that they can check their own progress. Many children like that."

Contrary to the more traditional context, most teachers did not end the lesson with the students. When the interviewer asked about this, the teacher indicated that they would like to do this more, but do not always get to it, since students all work at their own level at the end of the lesson. Nonetheless, they indicated that it is important to end the lesson collectively. The external experts emphasized this, for example, one of the inspectors said "Since teachers still start their lesson with a joint lesson goal, it is important to evaluate this lesson goal and the process towards this lesson goal together." The "ending lesson" skill is therefore included in the skills hierarchy.

The two teachers who did end the lesson showed the teacher dashboard to students to show what their progress was and used this to discuss what students learned (product) and how they worked (process).

*4) Evaluating lesson*

All observed teachers considered it an advantage that they no longer have to grade students' work at the end of the school day. Their workload is reduced since they do not have to grade all exercises for all students. After school, teachers check on the dashboard how the lesson went. They evaluate whether the groups as a whole reached the lesson goal and whether there were students having difficulties achieving the goal. The teacher takes notes, for example, writes down the names of the students who dropped out for the next lesson (either for themselves or for the colleague who is teaching the class the next day). Eric commented, "I check the dashboard always, every day. I then check how they did, which children dropped out, how often did they need to correct an answer? I scan and then I pick one or two students out and check: What strikes me? What exercises did they find difficult? I also check: Do I have to do this lesson again? Because sometimes it strikes me that they find something very difficult, then I say: Well, we will do it again. Or a day later, that we don't do it two days in a row. But then I know, that has to be done again. I also think of the next lesson: What will I do next? And I write that in my daily schedule: Today went well, but tomorrow we have to do this again."

Six teachers mentioned that they also discuss student progress with students. As an example, in the evaluation phase teacher Eric saw on his dashboard the results of a higher achieving student who worked on his additional exercises. The results (presented in Fig. 4) show that the student's last five exercises were incorrect and the student did not correct them. Eric noted, "And then I see that he made a lot of mistakes with

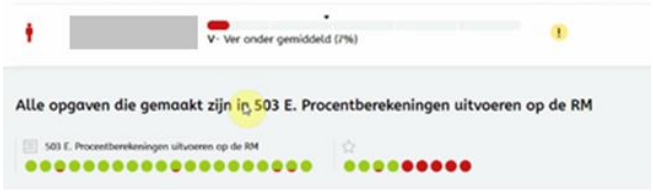


Fig. 4. Eric's teacher dashboard.

his plus work. He didn't correct them. So then I can say next time I see him: Hey, why are you doing this wrong, and how can you tackle it, so then we look at it together. That's how I actually do my lesson planning."

The emphasis of lesson evaluation is on evaluating the process and product in the short term. Contrary to the more traditional context, teachers rarely evaluate for the long term (i.e., makes notes about how this lesson could be better next year). On the one hand, the lack of a paper teacher manual in which they can make notes is one of the reasons teachers do not evaluate for the long term; on the other hand, teachers do not feel the urge to do so, since the software is constantly changing and improving. When an exercise is not appropriate or suggestions for instruction are not suitable, the teachers can immediately pass this on to the software makers and this will be adjusted if necessary.

### *B. Knowledge*

To be able to differentiate, teachers require three types of underlying knowledge. Similar to the traditional context, teachers need knowledge about the students (e.g., level of achievement, pedagogical and instructional educational needs, their interests, motivations, etc.) and subject-matter knowledge (e.g., knowledge about the mathematics curriculum and didactic models). For the context in which teachers use ALSs and a teacher dashboard, one specific aspect of subject-matter-related knowledge is crucial: knowing when to deliberately choose not to use the software, but to let students work with physical material or on paper.

In addition, teachers need to know their software. They need to know what the options are and how to manage the settings, but also how "the back end" of the system works. Teachers need to understand the data representations on their teacher dashboards. They not only need to know the meaning of graphs, symbols or color usage, but also need to know what these representations are based on and what kind of information is lacking. When teachers do not know or understand the underlying algorithms, they cannot weigh the information presented, and therefore cannot make informed decisions with regard to instructional actions. For example, Charles commented, "This student always scores high, so as soon as he makes one or two mistakes, he scores 'below expectations' and the software gives me a signal, but I know that I do not have to respond immediately."

## IV. Discussion and Conclusion

This study was aimed at identifying knowledge and skills teachers need to be able to provide differentiated instruction, when working with ALSs and teacher dashboards, by means of

conducting a cognitive task analysis. The findings were compared to the outcomes of a CTA into differentiation in a more traditional context. Findings suggest that most underlying skills teachers need to differentiate are comparable across contexts. Small differences between the skill hierarchies are related to organizational aspects (e.g., dealing with unexpected technology failures during lessons, or no long-term evaluation since the software is updated throughout the year). A more substantive difference between the skill hierarchies is the fact that teachers in the ALS context feel they have up-to-date information about students' progress available faster and can deal with this information during the lesson. As a result, teachers do not cluster students during preparation for a school term, but during the lesson. This might imply that teachers tailor their instruction to students' needs more quickly and accurately, but on the other hand, the conclusion by Deunk *et al.* [2] also applies here: "it is still the teacher who implements the differentiation practices" (p. 44). The actions a teacher takes based on the information they receive on the dashboard are crucial. In that sense, knowledge is crucial: knowledge about the students and the subject matter, but also deep knowledge about, and insights into the systems teachers work with, in order to make accurate decisions.

In conclusion, there are some slight differences between the two contexts, and it seems that software such as a teacher dashboard and ALS can support teachers in differentiating their instruction. However, in the end, the quality of differentiated instruction lies in the teachers' deliberate decisions. The findings of this study support the findings in previous work that the five principles of differentiated instruction are solid. The principles underlying expert differentiated instruction in the traditional context also applied for the experts in the ALS context. This suggests that the essence of providing tailored instruction lies in a strong goal orientation, continual monitoring, adapting instruction and exercises, ambitiousness, and stimulation of students' self-regulation.

The findings of this study suggest that teacher dashboards can support teachers in differentiated instruction, but we must not forget that this task analysis revealed that knowledge of and insight into the software are essential for being able to differentiate properly when working with this technology. Less experienced teachers or teachers without sufficient training in working with the technology may not benefit from the advantages of the software. The biggest risk of introducing such technology lies in having teachers who trust the software completely and do not question the suggestions by the system. Another risk might be that teachers are aware of the advantages of using the system for differentiation during the lesson, but that they neglect the phases prior to and after the lesson, which are just as crucial. As described, the current study was based on a sample of experts; these risks were described by these experts as "common pitfalls" they have encountered themselves during their learning process and problems they see their colleagues struggling with. The composition of the sample and scope of this study did not allow us to study this issue further, but in further research we recommend digging into these risks and how to address them. Due to our focus on experts, we were only able to include teachers working with one specific type of ALS, since this is the most mature software version on the market. Although this system was used in various ways by the experts included in the study, it is not guaranteed that all knowledge and skills identified in this CTA would also emerge when teachers working with various software systems would have participated.

Furthermore, this study was conducted in the context of primary mathematics education. The question remains whether the insights from this study could be generalized to other educational level such as secondary or higher education. To our knowledge, curriculum covering ALSs and teacher dashboards up until now are often implemented in primary education, but not yet widespread in secondary or higher education. Based on our analysis in primary education, we would strongly recommend future users, at all levels of education, to gain sufficient knowledge and insight in these systems, in order to be able to make optimal use of the possibilities the systems provide.

This study focused on the additional knowledge and skills a teacher needs when working with dashboards and ALSs. Similarly, it could be argued that using an ALS also requires new skills from students, such as knowing how to deal with feedback, deliberately choosing exercises to work on individual goals and—as often mentioned by the teachers in this study—being able to determine when to use paper and pencil to calculate answers. These are skills students must develop, and the teacher needs to support students in doing so. A CTA addressing the skills and knowledge students need could provide more insight into this.

To conclude, this thorough comparison of the thoughts and actions of expert teachers in their practice provides rich insights into the knowledge and constituent skills needed to be able to adapt education to student differences. Up until now, teacher educators have paid little attention to teaching with ALSs and teacher dashboards [15]. Since the number of schools using ALSs is quickly increasing [10], we can no longer ignore the need to prepare teachers to work with these systems. These insights can be useful for initial as well as in-service teacher training for using an ALS to differentiate.

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