Classroom data collection for teachers' data-informed practice

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ABSTRACT

Research indicates that data-informed practice helps teachers change their teaching and promotes teacher professional development (TPD). Although educational data are often collected from digital spaces, in-action evidence from physical spaces is seldom gathered, providing an incomplete view of the classroom reality. Also, most learning analytics tools focus on learners and do not explicitly collect or analyse teaching data. To support teacher-led inquiries in TPD, the authors' Design-Based Research explores the feasibility and effects of teachers actively collecting, with the help of technology, data about their classroom practice and the possible impact of such data on their own teaching. Based on an online survey ($N = 94$), prior research literature and feedback from teachers ($N = 11$), the authors demonstrate the feasibility of such data collection and suggest design principles for classroom data-collection tools as, besides usability and ease of use, they also detected interest in customisation, triggering teacher interest and inclusion of teaching data.

1 Introduction

Despite the fact that data-informed practice has been widely recognised (Feng et al., 2016) and is effectively used in different fields from business to medicine, the use of educational data by teachers to improve teaching in the classroom has not become common or widespread (Kaufman et al., 2014). In their everyday practice, teachers observe students' behaviour, consider assessment data and estimate the effectiveness of their own teaching strategies (Gummer & Mandinach, 2015). However, teachers often adapt their teaching based on their intuition and experience (Schildkamp & Kuiper, 2010), considering what they notice in their classroom and limited observations (Ingram, et al., 2004) rather than purposely collected data.

In this article, we employ the definition of 'data in the context of education' by Lai and Schildkamp (Lai and Schildkamp, 2013) as 'information that is systematically collected and organized to represent some aspect of schools' (p. 10) and focus on individual teacher and classroom-level data and improvements (Mandinach et al., 2006). However, in addition to data, evidence can also be derived from other sources (e.g., teacher observations of student engagement) which inform practice.

Why is data-informed practice still rare among teachers when it is being promoted through different reforms (Datnow & Hubbard, 2016)? One reason might be the nature of the available data. Namely, there is a growing body of research studies about automatic data collection in education (such as educational data mining or learning analytics, which often use data from learning management systems or LMSs). However, such research focuses mainly on students' online learning activities

(Datnow & Hubbard, 2016; Kaufman et al., 2014; Schildkamp et al., 2016; Supovitz, 2013) and aims at informing practitioners about students' learning habits and potential problems. Few research studies have been devoted to the **alignment of the available data with teacher needs and school affordances** (such as teaching in the physical classroom, time constraints, etc.). One overview of actual inquiry questions that teachers take an interest in can be found in a literature review by Dyckhoff et al. (2013), who provide a classification of question categories (which we will compare our findings with) asked by teachers in technology-enhanced learning.

Also, little data are collected and available about **teacher activities**. One line of research is focused on the analysis of the learning designs created by teachers (Hernández-Leo et al., 2019; Rienties & Toetenel, 2016; Sergis et al., 2019). Another is centred around teacher reflection, which is based on either teacher diaries (post-action reflections), resource-bound video-recordings (Supovitz, 2013), outsider observations (Datnow & Hubbard, 2016; Hubers et al., 2016) or eye-tracking (Mangaroska & Giannakos, 2019; Prieto et al., 2015). However, these data-collection methods have not become part of teachers' daily routine, and most of the decisions about classroom practice are still made by teachers using their common sense and pedagogical knowledge.

Dyckhoff et al. (2013) highlighted that learning analytics (LA) tools should address this issue by explicitly **collecting, analysing and presenting teaching data** because neglecting the significant factor of teacher actions during a teaching/learning process hinders holistic inquiry (Sergis & Sampson, 2017) and important questions of teachers remain unanswered by LA tools. Therefore, our study investigates two possibilities for teachers' classroom data collection about their own activities (one helps to collect activity logs from the physical classroom and the other students' feedback on the teaching process).

To gain a more realistic picture of the teaching process, **data from physical spaces** should be collected in addition to automatic online data (from LMSs and quizzes). As teachers in a physical classroom are usually involved in several activities and have multiple aspects to deal with, the means for deliberate in-action data collection are rather limited. Nowadays, several technological possibilities, such as wearable cameras and eye-tracking devices (Estapa & Amador, 2016; Prieto et al., 2015), for classroom observation have been proposed which could help to solve some of the aforementioned issues (e.g., teacher autonomy in data collection, i.e. no need for outside observers). However, as these options have not yet become widely used (either because of lack of dissemination, teacher awareness, complexity for everyday use or other issues), they should be developed further or new data-collection possibilities should be provided, considering teachers' data needs and classroom constraints (Kaufman et al., 2014). One of the aims of this study is to test the feasibility of teacher-led classroom data collection with the help of (mobile) technology.

There is also relatively little research into the ways in which teachers analyse or make sense of data or how they **incorporate data into their teaching practice** (Supovitz, 2013). Teachers regularly analyse, interpret and make decisions based on assessment data and achievement scores (Datnow & Hubbard, 2016; Hubers et al., 2016; Kaufman et al., 2014; Pierce et al., 2013; Reeves & Honig, 2015; Schildkamp et al., 2016; Supovitz, 2013). However, they rarely collect additional data about their teaching (Mandinach, 2012) and, even less, relate such evidence to student success and development (Ingram et al., 2004).

Furthermore, studies often focus on the skills and knowledge that teachers need in order to use data in their work, for example, to regroup students or to offer additional support (Goertz et al., 2009), rather than on **possibilities for changing teaching practice**. Although in recent times researchers cooperate with teachers more often in order to better address their needs (Holstein et al., 2017; Martinez-Maldonado et al., 2020), the scarcity of research into teachers' actual data needs (e.g., from physical spaces and about teaching) might be one of the reasons why data-informed practice in the classroom has not yet become common. Educators find it important to use data in a way that has pragmatic uses in their day-to-day practice (Jimerson & Wayman, 2015). The present study explores how teacher-collected data about their own activities in the classroom could inform their practice.

Table 1. Research gaps explored by this article.

	Currently used data sources vs More data needed about		Questions to explore
Data focus	Students (their activities and behaviour)	Teacher activities (how the teacher acts and how the students perceive these activities)	How could teachers use data to learn about their own teaching?
Data from	Mostly automatically collected data from LMSs	Physical classrooms (improve technologies which have not been adopted into everyday practice or suggest new ways for data collection)	Which technology would cater for teachers' data-collection needs and affordances from physical classrooms?
Data about	Mainly assessment (or automatic LMS logs)	The teaching and learning process (what is happening and how stakeholders perceive it)	How would such data help teachers make decisions about their practice?

The previously described problems (as summarised in Table 1) led us to our main research question for this article: **How can technology support teachers in data collection for data-informed practice?** To answer it, we worked together with a total of 109 Estonian practitioners teaching at different educational levels and focused on three problem areas that triggered our research: (1) teachers' data needs; (2) technology for classroom data collection; (3) possible impact of the collected data on teachers' practice. These problem areas derive from the need for evidence that would demonstrate whether Estonian teachers have adopted the concepts outlined in the Estonian Lifelong Learning Strategy (2020). Namely, when changing towards a student-centred approach to learning, teachers also need evidence that they are moving in the right direction.

The following sections provide an overview of our Design-Based Research methodology and a summary of the results of our iterative studies, followed by a list of the lessons learned (with qualitative and quantitative evidence supporting them). We will also point out some limitations and thoughts for further research.

2 Methods

The research aim of this work is twofold: (a) to test how data collection with technological tools from physical classrooms would enable teachers to make informed decisions about their teaching, and (b) to get practitioner opinions on the feasibility of such data collection and its usefulness, in order to enhance tool design. Therefore, we follow the Design-Based Research (DBR) *methodology* (Wang & Hannafin, 2005), which allows complex problems in real educational contexts to be addressed in collaboration with practitioners (with the aim of working out design principles). In order to answer our main research question (How can technology support teachers in data collection for data-informed practice?), we set out to explore three sub-questions: (1) How could teachers use data to learn about their own teaching? (2) Which technology would cater for teachers' data-collection needs and affordances in a physical classroom? (3) How would such data help teachers make decisions about their practice? (Table 1).

As depicted in Figure 1, our DBR process spans four studies distributed across three iterations using different data-gathering and analysis *methods*. The first iteration is a teacher survey ($N = 94$) into teachers' present data use and preferences for data-collection technology. From the comparison of our survey results with the research literature, we indicate teachers' data needs, which leads to the choice of tools (Prolearning and EduLog, developed for these purposes by our researchers) for our second iteration, where teachers ($N = 15$) collect data in their own classrooms. As the second iteration is mostly concerned with the ease of use and usability of the tools in real classrooms, the third iteration aims at making such data collection more sustainable by asking the teacher to pose his/her own concrete inquiry questions that they need the data for. So, the third iteration is a longer (eight months) action research case with multiple tool usage, where a teacher ($N = 1$) does not just try out data-collection tools but collects data to answer her own inquiry questions.
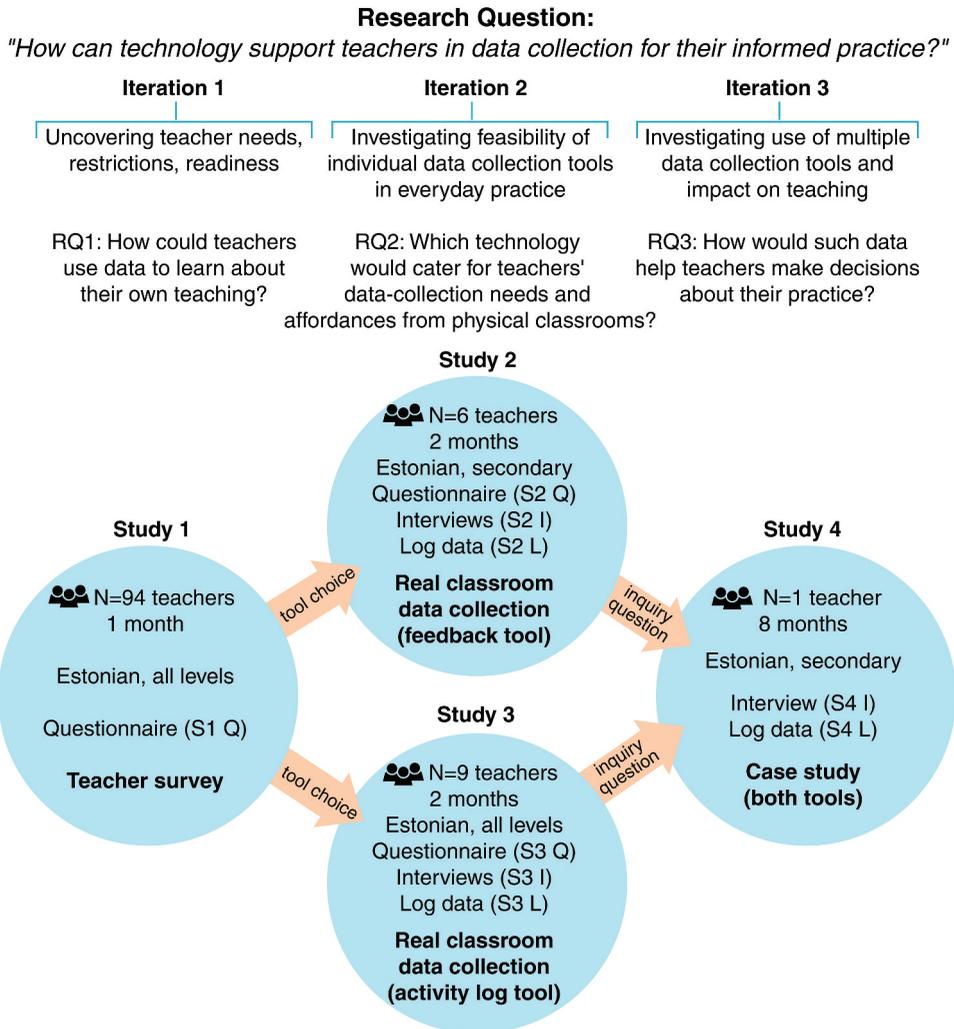
Research Question:

"How can technology support teachers in data collection for their informed practice?"

Iteration 1	Iteration 2	Iteration 3
Uncovering teacher needs, restrictions, readiness	Investigating feasibility of individual data collection tools in everyday practice	Investigating use of multiple data collection tools and impact on teaching
RQ1: How could teachers use data to learn about their own teaching?	RQ2: Which technology would cater for teachers' data-collection needs and affordances from physical classrooms?	RQ3: How would such data help teachers make decisions about their practice?

Figure 1. Our research question, topics and DBR design.

Our main data-collection means are participatory design methods (including questionnaires and interviews) and log data generated by the authentic use of the tools in schools. For data analysis we employ mixed methods, such as descriptive statistics and qualitative (thematic) analysis. First, we established three main themes, corresponding to the three research topics covered in our research (namely, teachers, data needs, classroom data collection and impact on decision making); then the three authors analysed the data on their own, using 'open coding' to classify the qualitative evidence; thereafter, the authors mapped the codes to each of the aforementioned research topics, compared the outcome, and discussed and revisited data to synthesise 'lessons learned' and recommendations for the design of teacher-led data collection tools usable in physical classrooms. The process was repeated for each data set until consensus was reached between the researchers. The different codes correspond to the lessons learnt in the second column of Table 2. Due to the exploratory nature of these studies (as opposed to evaluative, see Andriessen, 2008), the different types of participants and their relatively low sample size, no factor and reliability analyses were performed.

2.1 Iteration 1. Teacher survey and literature (Study 1)

To investigate teachers' data needs from physical classrooms, an online teacher survey (https://forms.gle/jysNN4jfzcQXBudMA) was carried out in spring 2018, and the results were compared with findings from related research literature. The survey items (which constituted only a part of a longer questionnaire about teachers' professional development) used in this study included the following: What would teachers like to improve in their teaching practice? What data would they collect for lesson analysis? How would they prefer to collect such data? What technology (apps, sensors, glasses etc.) would they be ready to use to collect data in their classroom? What are the factors hindering teachers' professional development?

As the aim of the survey was to get an initial understanding of teachers' practice with data and their expectations, a convenience sample ($N = 94$) was used (teachers from primary, secondary and tertiary levels, both formal and informal education, were approached to detect possible differences in their needs, but mainly school teachers responded). The survey data were analysed using descriptive statistics (5-point Likert scale) and thematic analysis (for open-ended questions about teacher professional development [TPD] interests). The aspects that teachers would like to improve in (e.g., time management, organising group-work, motivating students etc.) were organised into data categories by two researchers independently and then discussed together to identify teachers' data needs. Specific needs (learning new methods or digital skills and robotics etc.) were left out as they are not in the scope of the present study. The resulting 'data needs' categories were then compared with the 'question categories' identified by Dyckhoff et al. (2013) to inform the selection of the data-collection tools for our next iterations.

2.2 Iteration 2. Data collection in the classroom (Studies 2–3)

The second iteration included two studies where teachers used a technological tool to collect data from their own classrooms. In Study 2, six ($N = 6$) officially recognised expert teachers (7–41 years of teaching experience, all female, teaching languages or mathematics) from primary to secondary education, volunteered to use a student feedback tool (Prolearning: http://prolearning.realto.ch/) in their classroom for two weeks and participate in the survey. In Study 3, nine teachers ($N = 9$, 1 from kindergarten, 6 from lower and/or upper secondary education and 2 university lecturers), of which five were from the previous sample, volunteered to use a classroom observation tool (EduLog: http://web.htk.tlu.ee/edulog) to collect classroom activity data (the length and sequence of activities).

The Prolearning tool (Prieto et al., 2020) enables teachers to ask for quick student feedback (1–2 minutes) and compare the means of students' responses with the teacher's predictions about them, i.e. compare the students' perceptions about their learning with the teacher's (Figure 2). As the tool is customisable, the teacher can prepare a short questionnaire (yes/no questions and percentage questions) prior to the class and pose the questions that they are genuinely interested in (e.g., student motivation, preparedness for and progress in the lesson, or a predicted test score). The data visualisation shows means of the students' responses (in columns) and the teacher's predictions (a line graph).

Another tool, EduLog (Saar et al., 2018), makes it possible for teachers to log their own teaching process and see the length and pattern of classroom activities. This way, the teacher can compare their lesson plan with the actual lesson situation, explore whether the teacher or students were more active in the class, assess the balance between the activities (e.g., individual vs group work) or variety in activity types (Figure 3). This tool is also customisable (the teacher can alter the button names for the activities and lesson goals) and does not require much preparation from the teacher before the lesson (only to start a session and give it a name). During teaching, the teacher just records the beginning of each new activity (by pressing a button on their phone or computer, depending on

Table 2. Main lessons learned with evidence from the iterations: S1 – Study 1, S2 – Study 2, S3 – Study 3, S4 – Study 4; I – interview, Q – questionnaire, L – tool log data; M – mean score in a 1–5 Likert scale.

Topic 1	Lessons learned	Qualitative and quantitative evidence from our iterations
Teachers' data needs	1. Teachers' data needs vary – by context (student level, privacy etc.) and inquiry questions	• by level of students: 'suitable for lower- and upper secondary students; might be complicated for primary students (technical inability, difficulty understanding the questions, more time-consuming)' [S2 Q]; • by teacher interest: 'helps to see how involved the students are/the teacher is', 'helps to see if different classroom activities are varied enough and last for *an optimal time*' [S3 Q]; • the tool: 'As the logs do not include any identifiable student information, I can use the EduLog tool to monitor the pace and flow of the class and the variety of my teaching methods' [S4 I]; 'I would like to have a possibility to add some more options/buttons for recording my activities' [S3 Q]; • by teacher level: 'especially useful for inexperienced teachers who do not yet have a good understanding of their teaching methods and cannot notice all the different aspects of a lesson' [S3 I]
	2. Teachers' data needs vary – when and how often they would collect data	• teacher need: 'all teachers should analyse their teaching based on some data *every now and then*' [S2 Q]; • tool affordances: 'good for comparison of your teaching *(over a longer period)*', 'gives a clear picture *pretty fast*' [S3 Q]; • the *frequency* of tool use varied: some teachers used the tools every day for two weeks, others once a week for two months [S3 Q], [S2 L]; one teacher used the tool over the period of eight months (a school year) 1–2 times a month (S4 I, S4 L)
	3. Teachers need data about classroom activities	• 72 teachers (77%) mentioned time of students' active involvement in the lesson in an open question 'what would you be interested in investigating?' [S1 Q]; • 69 teachers (73%) would like to see the 'diversity of lesson activities' within the same question [S1 Q]; • 3 teachers (50%) included questions about student initiatives in their classroom feedback tool: 'I asked a question in class', 'I expressed my own idea', 'I asked for help (from the teacher/a peer')' [S2 Q]; • teachers' appreciation of the tools in understanding lesson orchestration: 'do I provide enough feedback to students?', 'do they have enough time for their assignments?' [S2 Q]; 'I wanted to diminish individual work in the classroom and provide more time for group-work and communication in the foreign language, so now I could compare my lessons' [S4 I]
	4. Teachers need data connected with developing self-driven learners/student motivation and participation	• 71 teachers (76%) mentioned topics related to student motivation in an open question 'what would you be interested in investigating?' [S1 Q]; • 6 teachers (100%) included student involvement/engagement questions in their classroom feedback tool usage [S2 Q]; • 1 + 6 teachers (100%) included questions related to self-driven learners in their classroom feedback tool [S4 L] and [S2 L]; • interest in self-driven students: 'I believe that if I keep asking the students about a certain skill or behaviour (e.g., Did you help any of your team members?), it will eventually make them think about the aspect and maybe change their attitude' [S4 I]

(Continued)

Table 2. (Continued).

Topic 2 Classroom data collection	5. Teachers are ready to use some (not all) technologies to collect data	• 71 teachers (76%) would use technology to collect student feedback; 59 teachers (63%) would collect classroom activity logs; 38 would use video-recording of their classes; 48 would use brain-sensors and 56 room-sensors as data-sources [S1 Q]; • some technologies seem not acceptable: 68 teachers (72%) would not use pulse measures, 53 would not use movement sensors and 56 would not use eye-tracking glasses [S1 Q]; • the teacher, who did not have previous experience in Prolearning and Edulog, used both tools for a whole school year to collect student feedback and logs [S4 I, S4 L]
	6. Useful data for teachers: student feedback, classroom logs	• 71 teachers (76%) would collect student feedback; 59 teachers (63%) would collect classroom activity logs [S1 Q]; • 6 teachers (100%) asked student feedback on their self-perception of active participation, 5 teachers inquired about students' learning experience, 4 teachers asked about teacher-student or student-student communication [S2 Q]; • 7 teachers (out of 9) wanted to know 'who (teacher or students) participated in the process more actively' [S3 Q]; • the teacher compared her use of class time (individual vs group work) and used Prolearning feedback for student self-assessment [S4 I]
	7. The tested tools are feasible and easy to use	• teachers' assessment of the Prolearning tool on a 5-point Likert scale: I could ask questions relevant to my interest (M = 4.3); the tool provides a teacher with useful data (M = 4); the tool requires specific technological knowledge (M = 1.2) [S2 Q]; • teachers' assessment of the EduLog tool on a 5-point Likert scale: it helped to analyse my teaching (M = 4), the data were clearly visualised (M = 4.86) and easy to read/understand (M = 4.86); the tool was easy and logical (M = 4.7), did not disturb the flow of the class (M = 4) [S3 Q]; • feedback from users: 'very effective for recording classroom pace' and 'understanding the REAL flow of your class', 'good to have the results as a graph (video would take too long to check', 'really simple to use (even for a technophobe)' [S3 Q]; 'I felt the need to make the tools part of my everyday practice' [S4 I]; • all teachers actually used the tools in their lessons [S2 L, S3 L, S4 L]
	8. Classroom data collection is highly linked to attention/ workload	• although teachers found the tool convenient to use, they hardly ever wrote any reflections or remarks in Prolearning [S2 Q], S2 L]; • teacher perception: 'the trickiest thing was that when you got really excited about the class, you forgot to push the button – however, it might change when you get used to the tool', 'a bit more complicated to use when you have several technological devices in use at the same time' [S3 Q]
	9. Other contextual constraints: beliefs, teacher routines, student routines (age/capabilities)	• anonymity: 'students' answers are more honest and bold as the survey is anonymous' [S2 Q]; • teacher routine: 'at the beginning I was concentrating too much on my phone and students also got curious about my activity', 'I somehow returned to my old system of a paper notebook, which I keep carrying along in the room to take notes' [S3 Q]; • student routine: 'more difficult with younger students (more time)', 'students unable to participate (phones at home or batteries low)' [S2 Q];
	10. Engage stakeholders with the collected data	• 'it was also interesting to "predict" students' answers and compare the prediction with the actual responses', 'my predictions about the lesson did not always match with the students' feedback', 'students liked the fact that their teacher was interested in their feedback' [S2 Q]

(Continued)

Table 2. (Continued).

Topic 3 Impact on decision-making	11. Teachers need an inquiry question or aim (to gather data)	• when teachers collected student feedback without any specific inquiry question in mind, not all were planning to make changes into their teaching (M = 2.8) [S2 Q] and (M = 4.1) [S3 Q]; • 'to make data-collection more meaningful, teachers should first decide what they want to learn about their teaching (set a goal or ask a question)' [S2 & 3 I]; • although they found the tools useful and easy to use, no actual adoption was detected (within a year) [S2 Q, SQ 3, S2 L, S3 L]; • when the teacher had a clear aim, she used the tool throughout a school year: 'I felt the need to make the tools part of my everyday practice' [S4 I, S4 L]
	12. Looking at data triggers awareness, reflection and practice change	• awareness: 'I can update my understanding about classroom orchestration' [S2 Q]; 'helps to check whether you keep to your plan (length of activities)' [S3 Q]; 'I am now much more aware of my teaching as I have been monitoring my classes for a while – not only because of the collected data (logs and feedback), but also because people usually tend to put more focus on the aspects that are monitored' [S4 I]; • reflection: 'it helped to see if the "method works" or if a change in the lesson plan brings along any expected results' [S2 Q]; 'the tools made me really think about my teaching and methods that I use' [S3 I]; 'student anonymous feedback has helped me learn about their motivation and engagement in the process' [S4 I]; • change: teachers planned to make changes into their teaching based on Prolearning data (M = 2.8) [S2 Q] and EduLog data (M = 4.1) [S3 Q]; • change: 'based on the responses I rearranged my next class (contents and pace) and paid more attention to peer communication among students' [S2 Q]; 'I now use more group-work and other active methods' [S3 I]; 'Edulog has helped me significantly change the distribution between individual and group work' [S4 I]
	13. Adoption of classroom data collection is slow	• initially teachers expressed their intention to use the tools in the future (M = 4.2) [S2 Q] and (M = 4.28) [S3 Q]; • however, no adoption was detected within a year [S2 L; S3 L]; • teachers expressed their intention to return to the tool use: 'I have been planning to try the tools again', 'workload has kept my mind busy with other aspects but I will start collecting data again' [S2 I; S3 I]; • one teacher kept using the tools throughout the school year: 'Although it initially took some time to get used to the idea of monitoring your own teaching, now I would like to use the tools even more often' [S4 I];
	14. Usefulness and ease of use is not enough for adoption	• no adoption was detected within a year [S2 L; S3 L] although on a 5-pont Likert scale teachers found the tools convenient to use (M = 3.6) [S2 Q] and (M = 4.1) [S3 Q]; easy and logical (M = 3.3) [S2 Q] and (M = 4.7) [S3 Q]; and the tools were said to provide necessary information (M = 4.0) [S2 Q] and (M = 4.57) [S3 Q];

which device they use). The system records the length of different activities and shows the lesson pattern as a bar chart: the upper bars in the graph show teacher-led activities and the lower rows students' activities (in seconds).

Considering the constraints of physical classrooms (teachers' multiple tasks, time management, possible impact of any outside observers), the tools were used by expert teachers to avoid excessive stress during teaching, since experts are more flexible in their teaching practice (Berliner, 2001). All participants signed an informed consent at the beginning of our collaboration and also provided their tool data for analysis (which complies with the ethical regulations of the university).

Both studies in this iteration were structured similarly: after a short instruction on the tool use, teachers collected data for two weeks in their own classrooms. Online questionnaires (see the Appendix) (https://forms.gle/1xfk6YBGGvcKhH3B8 and https://forms.gle/1jhBy4Vccfufc7o66) were used to collect teachers' opinions about the tools, and to find out how such data collection and analysis would help teachers improve their classroom practice. A 5-point Likert scale, based on the Technology Acceptance Model (Venkatesh & Davis, 2000), was used to explore the Perceived Usefulness and Perceived Ease of Use of the proposed technology as well as the Intent to Use it in the future. We also asked participants' suggestions for the improvement of the tool and asked about the suitability of the tool/analytics for different user groups. Such data collection is consistent with other relevant studies in the field (Ali et al., 2012), which involved teachers as participants evaluating tools for educators.

To triangulate the results and find out about any possible long-term impact of classroom data collection with the tools, as well as to detect any further usage, log data were analysed and post-intervention interviews were conducted 8–10 months afterwards with the teachers who had expressed their willingness to continue using the tools for their informed classroom practice. The interview questions followed the same line as the Likert-scale questionnaire and were posed for more elaborate explanations of the answers. The tool-use questionnaires were analysed using descriptive statistics, and interview data were coded by three authors separately and then discussed together to detect the lessons learned about all the three topics that triggered the study.

2.3 Iteration 3. Multiple tool use for action research

The third iteration was conditioned by the fact that although teachers found the tools easy to use and the data useful, further adoption (based on log data) was not detected. Our assumption was that teachers do not see the benefits of data collection and analysis unless there is a more specific goal that data collection would help to solve. Thus, our third iteration was a case study where a teacher collected data with the two previously tested tools in order to inform her decisions about her teaching, as part of action research. The teacher used the tools with 14-year-old students in her project-type foreign language classes about twice a month, for a whole school year. Her aim was twofold: (1) to limit the time spent on individual tasks in the classroom and promote group-work and communication between students; (2) to direct students towards becoming self-driven learners (setting individual goals and analysing their own development). Our aim was to see if she was able to collect classroom data to make decisions for changing her practice accordingly and if a clear research aim would promote long-term data collection. Her feedback was collected through an interview and compared with the log data from the tools.

The following sections give an overview of the results and evolution of this DBR process over three iterations. The evidence collected through these studies, and the lessons we have synthesised from it (along the three topics outlined above), are summarised in Section 4.
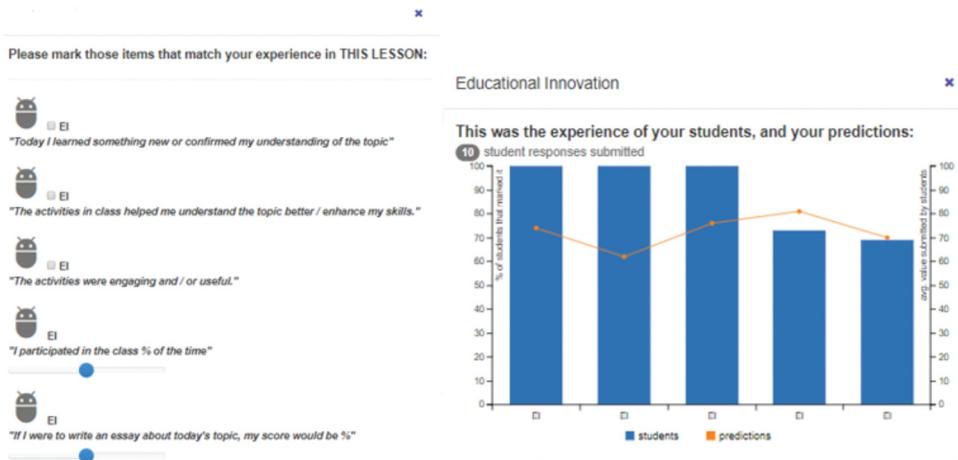
Figure 2. An example of student feedback results with Prolearning (questions posed and the output).

3 Results

Through the three DBR iterations described in the previous sections, we collected evidence to answer our main research question: 'How can technology support teachers in data collection for data-informed practice?' For each research topic (see Figure 1), Table 2 provides the main findings and lessons learned, along with selected qualitative and quantitative evidence. Each piece of evidence is coded according to the study (S1–S4) and the data-gathering technique (interview, questionnaire or log data from the tools used).

Figure 3. An example of classroom activity patterns collected with EduLog.
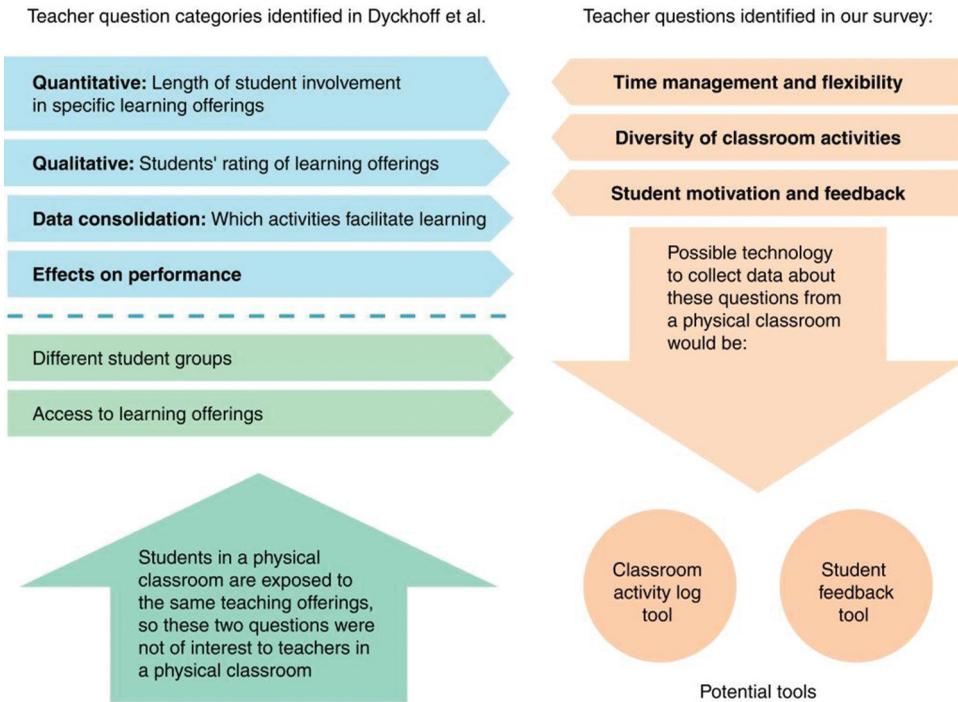
Figure 4. Teacher question categories by Dyckhoff et al. (2013), matched with our survey findings about data needs from physical classrooms, and potential data-collection tools to address them.

3.1 Iteration 1. Focus on teachers' data needs (Study 1)

Our online survey of $N = 94$ teachers aimed at finding out about teachers' data needs when teaching in a physical classroom, and revealed that 76% of the participant teachers ($n = 71$) would like to be better at developing self-driven learners (they would explore student motivation, their involvement in class, providing timely feedback to students, accounting for the needs of different students depending on their level, learning style etc.); and 73% of the teachers ($n = 70$) would monitor the diversity of their classroom activities. Other main aspects indicated by the teachers included: flexibility, better planning, issues related to group-work, triggering interest in students, paying attention to every student etc. Based on these findings, we identified three categories that teachers in a physical classroom would collect data about: time management and flexibility; diversity of classroom activities; and student motivation and feedback.

Out of different data-collection technologies, teachers would use mobile applications (for student feedback, $n = 71$ and classroom activity data, $n = 59$), video-recordings ($n = 38$) and some sensor data ($n = 48$ brain sensors, $n = 56$ room sensors). Also, the teachers pointed out that the main aspects hindering their professional development are time constraints and workload, which is very important to consider when designing tools for classroom data collection.

When we compared our findings with teacher question categories identified by Dyckhoff et al. (2013), who in their literature review analyse research about online learning, we could match four out of their six teacher inquiry categories (quantitative – length of student involvement, qualitative – students' rating of learning offerings, data consolidation – which activities facilitate learning, effects on performance) with our three categories (Figure 4) and assessment data (not in our focus). To collect the necessary data for these categories, it is possible to use classroom **activity logs** (for time management, flexibility and diversity of classroom activities), while **student feedback** (about the learning activities and students' own development) could be used to learn about student motivation

and feedback on their studies. These, in turn, could be compared with student results (effects on performance in Dyckhoff et al., 2013). Therefore, in the following iterations, we focus our efforts on collecting classroom activity logs and student feedback and use two tools that our researchers have developed for these purposes.

3.2 Iteration 2. Testing the feasibility of technological data collection tools meant for the physical classroom (Studies 2–3)

To understand the feasibility and possible impact of collecting classroom activity logs and student feedback, we tested two technological tools, Prolearning and EduLog, which the teacher can use for data collection in a physical classroom. If student test scores were, for example, compared with the data from these two tools, the teacher would get a more holistic view of the teaching process and could make more data-informed decisions about their classroom practice. Results from these studies are grouped according to our research topics and are presented in Table 2.

From the feedback from 10 different teachers who used both tools for in-action data collection, we found out that, despite some limitations, such easy but meaningful data collection is possible and also suitable for informing teachers' practice (see the evidence in Table 2). Almost all teachers ($n = 9$) agreed that the tools helped them reflect on their teaching and made them consider introducing some changes into their teaching. What they all agreed about is the fact that the data-collection process itself made them more aware of their own teaching and really think about their teaching methods and lesson planning. Teachers found the tools feasible, logical and easy to use; the collected data were also easy to understand and promoted teacher reflection (e.g., 'I am now much more aware of my teaching as I have been monitoring my classes for a while', 'it helped to see if the method works') and change in practice (e.g., 'based on the data I paid more attention to peer communication among students', 'I now use more group-work').

Interestingly, teacher feedback questions concentrated only on students' classroom experience and progress, and no questions about the teacher activities or impact were actually asked by teachers themselves in our sample. Also, although teachers reported that the tools had helped them to analyse their teaching and expressed their intention to use the tools in their practice, the log data from the tools did not confirm it. The post-intervention interviews (8–10 months later) provide some insight into the reasons, which are mostly linked to time constraints.

To address the question of discontinued data collection, we wanted to see whether setting an inquiry question by the teacher (in the context of action research within TPD) and using multiple data sources concurrently (with the hope of getting a broader picture of the classroom reality) enhanced or hindered data collection in the classroom and analysis for classroom practice. Therefore, in our following iteration, we set out to explore the feasibility of using different tools by the same teacher in an action research project (as obviously, in addition to useful information, teachers need some other triggers for data collection to become part of their classroom routine).

3.3 Iteration 3. Effects of regular classroom data collection and analysis on teaching (Study 4)

In this iteration, one teacher used both tools (about twice a month) in her eight-month-long action research (Stringer, 2013). We aimed at finding out how the teacher aligns her inquiry questions with data collection and makes sense of the collected data, and how this might impact her classroom practice.

As video recordings in the classroom are often not allowed, the teacher claimed that her self-tracked logs turned out to be a very good source of information about her different teaching activities used in a lesson. The intervention helped her significantly change the distribution of classroom activities (individual vs group work). For her goal to lead the students towards becoming self-driven learners, the teacher customised Prolearning questions to gather feedback following the

SOLO taxonomy (Biggs & Collis, 1982), to make students think about their own learning and development. The teacher considered the tool also good for collecting student anonymous feedback, e.g., to learn about their motivation and engagement in the learning process.

From this small study, we could see that both technological tools proved suitable for the teacher's needs for data collection and helped her in making decisions about her teaching. It also showed that data collection from the physical classroom is feasible if the teacher herself/himself is interested in the data and change in his/her own teaching practice. Despite initial worries about technology use ('took some time to adjust it to the teacher's needs') and strangeness of monitoring one's own teaching ('which eventually became part of the routine'), the tools proved to be helpful for the teacher and could be developed further.

4 Discussion

As in the findings of Dyckhoff et al. (2013), who found that teachers in technology-enhanced learning would use quantitative and qualitative data about student involvement in learning offerings and their ratings of these offerings, our study shows that from physical classrooms teachers would also collect data about student motivation, participation and classroom activity patterns. These data, in our case, were collected with the help of technology by the teacher of the class in the form of regular student feedback and classroom activity logs. This way the teacher was able to determine what data, how and how often to collect, pertaining to their personal needs and interests.

Based on our findings (a list of 14 lessons learned, Table 2), it could be said that technology can support teachers in active data collection about their own classroom teaching if the teacher himself/herself is truly motivated and interested in it (e.g., setting an inquiry question). Otherwise, data use is often neglected (similarly to automatically collected data), even when the data have proven to be meaningful for the teacher and help to make informed decisions. The main constraints hindering
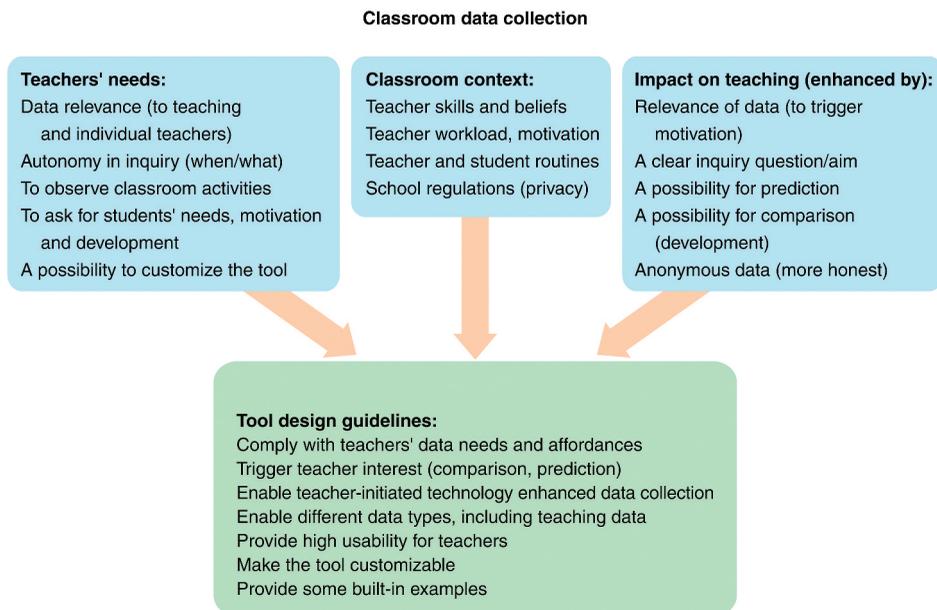
Classroom data collection

Teachers' needs:
Data relevance (to teaching
    and individual teachers)
Autonomy in inquiry (when/what)
To observe classroom activities
To ask for students' needs, motivation
    and development
A possibility to customize the tool

Classroom context:
Teacher skills and beliefs
Teacher workload, motivation
Teacher and student routines
School regulations (privacy)

Impact on teaching (enhanced by):
Relevance of data (to trigger
    motivation)
A clear inquiry question/aim
A possibility for prediction
A possibility for comparison
    (development)
Anonymous data (more honest)

Tool design guidelines:
Comply with teachers' data needs and affordances
Trigger teacher interest (comparison, prediction)
Enable teacher-initiated technology enhanced data collection
Enable different data types, including teaching data
Provide high usability for teachers
Make the tool customizable
Provide some built-in examples

Figure 5. Main findings and design guidelines for classroom data-collection tools.

classroom data collection are still shortage of time and intense workload (also indicated by Dillenbourg & Jermann, 2010; Prieto et al., 2020), therefore the tools have to be easy to set up and use, not require much additional effort (to use or analyse the data) and help to collect data that match the teacher's needs (e.g., classroom activity patterns and student feedback) (similarly voiced by Eradze et al., 2019).

Also, to exploit what humans are good at (e.g., meaning-making, such as deciding what kinds of lesson moments are meaningful to be recorded) and make use of technology (e.g., systematic aggregation and visualisation) to reduce teacher workload, in-classroom data collection should be technology enhanced but teacher initiated (involving the teacher in actively deciding what data to collect and how, but decreasing the workload by automatically analysing and visualising the collected data). As the technology should help teachers be more autonomous in their choices about what data, when and why to collect and/or analyse, the tools should be customisable (Dillenbourg & Jermann, 2010; Saar et al., 2018), yet still easy to use to make the inquiry process simple enough for teachers to implement them (Prieto et al., 2020). The technology should also trigger teachers' interest to collect data (e.g., possibilities for prediction or comparison seem to motivate teachers).

It was also interesting to find out about some constraints (teachers' technology preferences when it comes to pulse, movement and eye-tracking technology, or perceptions about the tool use) as well as changes in teacher awareness, reflection and changed practice (see Table 2). The main changes in classroom practice which teachers brought out were linked to switching to more group-work (as compared to individual student tasks) and empowering students (deciding on their personal goals and reflecting on their achievement using the SOLO taxonomy, and varying classroom activities). Student feedback also provided insight into students' group work habits, initiatives ('I asked a question in class', 'I expressed my own idea'), motivation and engagement. Teachers became more reflective and prone to change: 'I am now more aware of my teaching as I have been monitoring my classes for a while', 'the tools made me really think about my teaching and methods that I use', 'my predictions about the lesson did not always match with the students' feedback' or 'based on the responses I rearranged my next class (contents and pace) and paid more attention to peer communication among students'.

Following the lessons learned from our DBR process, we can also propose certain guidelines (Figure 5) for the design of classroom data-collection tools:

(1) The technology should **comply with teachers' data needs and affordances**, but also **trigger teachers' interest** (e.g., through enabling predictions, comparisons and data download for further analysis (lessons learned 1–4, 10–12, 14).

(2) **In-classroom data collection should be teacher initiated, while automating data aggregation and visualisation** (lessons learned 7, 8, 14) (as automatic online data are often neglected, and paper based or video data are time-consuming to analyse).

(3) **Enable different data types, including teaching data** (lessons learned 1, 3–6). In our experience, teachers want to collect the length and pattern of classroom activities and (anonymous) student feedback. These, in turn, can be compared with assessment data.

(4) The technology should **provide high usability for teachers/be easy to use** despite teacher overload in the classroom (lessons learned 5, 7, 9, 12, 13) and offer **easy-to-understand visualisations** of the data for analysis (lessons learned 7, 10).

(5) **Make the tool customisable** (lessons learned 1–2, 11) – as teachers have different contexts and needs, the technology should allow for some customisation (still bearing in mind that the data should enable comparisons (especially within multimodal LA) and the tool should be simple to use).

(6) **Provide some built-in examples** (to imply possible inquiry aspects and trigger interest, lessons learned 7, 10, 14), as a clear inquiry aim is also crucial for meaningful data collection and analysis.

The main limitation of our research is the small number of teachers who have used such data-collection means so far and the fact that those teachers had a very specific profile (expert teachers, as opposed to the wider variety of teachers in Study 1). Also, the reliability of the scales was not tested as the Likert scale questions in the first iteration were used to probe teachers' preferences for data-collection technology and their current data-use habits, with no intention for generalisations. For the second iteration, the questions were based on the Technology Acceptance Model (Venkatesh & Davis, 2000), but due to such a small sample, no generalisations were intended and only descriptive analysis was used. However, to strengthen the research design, the questionnaire and interview data about the use of the tools were triangulated with log data from the tools used in the classrooms. Nevertheless, further data and participant triangulation (e.g., through student feedback or classroom observations) could have been used to further enhance the reliability of our findings.

While some research shows that teachers' skills in using digital tools might lead to difficulties in classroom data collection, in the specific case of this study (the Estonian educational context) teachers were enthusiastic to use technology. This might be due to the small sample of volunteer expert teachers who are interested in innovation and their general disposition towards technology use (in fact, by 2019 100% of Estonian schools were already using e-school solutions). Therefore, studies with a different sample or in a different country might reveal different teacher preferences for data collection.

5 Conclusions and future research

Through a three-iteration DBR process, this research study attempted to provide an insight into teachers' data needs for informed classroom practice, suggest ways for collecting such data with the help of technology and explore possible effects of the collected data on teachers' practice. Therefore, the article introduced two teacher-led data-collection possibilities for a physical classroom bearing in mind teachers' needs and classroom contextual constraints, and tested the suitability of such data-collection options in actual classroom settings. Although the feedback from users was positive, actual adoption into everyday practice after the researchers leave the scene seems insufficient. However, our third iteration shows that long-term usage of the tools is feasible if a teacher is genuinely interested in his/her classroom practice and wants to analyse and keep a record of the processes. To foster usage, the tools have to be easy to use and the data easy to understand; the data collection should be as automatic as possible (not many notes were written down by the teachers) and possibly integrated into the lesson and with other classroom technologies already in use. Most importantly, the data-collection technology should cater for teachers' specific needs for classroom data, e.g., include varied data and be customisable.

The next step in our research would be the implementation of an in-action technology-enhanced teacher-led inquiry with multiple tools (e.g., to support different phases of the inquiry process, not only the data gathering) for a longer period of time, to track their actual adoption and find out about the impact of such data collection on teachers' classroom practice and student success. We will also continue with further development of the tools themselves, to provide a richer picture of the classroom (e.g., its activities and atmosphere) in order to detect the possible changes in teachers' practice due to their data use.

Future research could focus on studies with a wider variety of teacher profiles, longitudinal studies that follow teachers and their practice of inquiry for longer periods of time, and studies that use a wider variety of data sources and participants for triangulation. Implementing similar data-collection studies with a wider variety of teacher profiles could also unearth different adoption challenges (e.g., the technology issues, since in other countries teachers' needs and tool preferences could play a different role).

Also, frameworks/models and materials to support teacher implementation of these practices are needed and new technologies to support teacher data collection based on their needs should be developed. Indeed, a whole new set of research directions can spring up from our present research,

on the topic of novel teacher tools for in-classroom data collection. To help teachers inquire into their practice and triangulate the evidence they gather from their classrooms, these new tools could provide data about student motivation and involvement (e.g., sensor data) and teacher talk (clarity of explanations, tone) and would help collate different data into a meaningful overview of a class taught, connecting it to student success (progress and satisfaction).

Disclosure statement

Funding

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References

Ali, L., Hatala, M., Gašević, D., & Jovanović, J. (2012). A qualitative evaluation of evolution of a learning analytics tool. *Computers & Education*, *58*(1), 470–489. https://doi.org/10.1016/j.compedu.2011.08.030

Andriessen, D. (2008). Combining design-based research and action research to test management solutions. In B. Boog, M. Slager, J. Preece, & J. Zeelen (Eds.), *Towards quality improvement of action research: Developing ethics and standards* (pp. 125–134). Brill Sense.

Berliner, D. C. (2001). Learning about and learning from expert teachers. *International Journal of Educational Research*, *35*(5), 463–482. https://doi.org/10.1016/S0883-0355(02)00004-6

Biggs, J. B., & Collis, K. F. (1982). *Evaluating the quality of learning: The SOLO taxonomy (structure of the observed learning outcome)*. Academic Press.

Datnow, A., & Hubbard, L. (2016). Teacher capacity for and beliefs about data-driven decision making: A literature review of international research. *Journal of Educational Change*, *17*(1), 7–28. https://doi.org/10.1007/s10833-015-9264-2

Dillenbourg, P., & Jermann, P. (2010). Technology for classroom orchestration. In M. Khine & I. Saleh (Eds.), *New science of learning* (pp. 525–552). Springer. https://doi-org.ezproxy.tlu.ee/10.1007/978-1-4419-5716-0_26

Dyckhoff, A. L., Lukarov, V., Muslim, A., Chatti, M. A., & Schroeder, U. (2013, April). Supporting action research with learning analytics. In *Proceedings of the third international conference on learning analytics and knowledge – LAK. (Vol. 13)* (pp. 220–229). ACM. https://doi.org/10.1145/2460296.2460340 .

Eradze, M., Rodríguez-Triana, M. J., & Laanpere, M. (2019). A conversation between learning design and classroom observations: A systematic literature review. *Education Sciences*, *9*(2), 91. https://doi.org/10.3390/educsci9020091

Estapa, A., & Amador, J. (2016). Wearable cameras as a tool to capture preservice teachers' marked and recorded noticing. *Journal of Technology and Teacher Education*, *24*(3), 281–307. https://www.learntechlib.org/primary/p/171269/

Estonian Lifelong Learning Strategy. (2020). https://www.hm.ee/en/estonian-lifelong-learning-strategy-2020

Feng, M., Krumm, A. E., Bowers, A. J., & Podkul, T. (2016, April). Elaborating data intensive research methods through researcher-practitioner partnerships. In *Proceedings of the sixth international conference on learning analytics & knowledge – LAK.* (pp. 540–541). ACM. https://doi.org/10.1145/2883851.2883908

Goertz, M. E., Olah, L. N., & Riggan, M. (2009). From testing to teaching: The use of interim assessments in classroom instruction. CPRE Research Report# RR-65, *253*. https://doi.org/10.12698/CPRE.2009.RR65

Gummer, E., & Mandinach, E. (2015). Building a conceptual framework for data literacy. *Teachers College Record*, *117*(4). https://www.tcrecord.org/Content.asp?ContentId=17856

Hernández-Leo, D., Martinez-Maldonado, R., Pardo, A., Muñoz-Cristóbal, J. A., & Rodríguez-Triana, M. J. (2019). Analytics for learning design: A layered framework and tools. *British Journal of Educational Technology*, *50*(1), 139–152. https://doi.org/10.1111/bjet.12645

Holstein, K., McLaren, B. M., & Aleven, V. (2017, March). Intelligent tutors as teachers' aides: Exploring teacher needs for real-time analytics in blended classrooms. In *Proceedings of the seventh international learning analytics & knowledge conference* – LAK. (pp. 257–266). ACM. https://doi.org/10.1145/3027385.3027451

Hubers, M. D., Poortman, C. L., Schildkamp, K., Pieters, J. M., & Handelzalts, A. (2016). Opening the black box: Knowledge creation in data teams. *Journal of Professional Capital and Community*, *1*(1), 41–68. https://doi.org/10.1108/JPCC-07-2015-0003

Ingram , D., Louis, K. S., and Schroeder, R. G. (2004). Accountability policies and teacher decision making: Barriers to the use of data to improve practice. Teachers College Record,*106*(6), 1258–1287. https://www.tcrecord.org/Content.asp?ContentId=11573

Jimerson, J. B., & Wayman, J. C. (2015). Professional learning for using data: Examining teacher needs and supports. *Teachers College Record*, *117*(4), n4. https://www.tcrecord.org/content.asp?contentid=17855

Kaufman, T., Graham, C. R., Picciano, A. G., Wiley, D., & Popham, J. A. (2014). Data-driven decision making in the K12 classroom. In J. M. Spector, M. D. Merrill, J. Elen, and M. J. Bishop (Eds.), *Handbook of research on educational communications and technology* (4th ed., pp. 337–346). Springer. https://doi.org/10.1007/978-1-4614-3185-5_27

Lai, M. K., & Schildkamp, K. (2013). Data-based decision making: An overview. In K. Schildkamp, M. K. Lai, and L. Earl (Eds.), *Data-based decision making in education. Studies in educational leadership* (Vol. 17). Springer. (pp. 9–21) . https://doi.org/10.1007/978-94-007-4816-3_2

Mandinach, E. B., Honey, M., & Light, D. (2006, April). *A theoretical framework for data-driven decision making* [Paper presentation]. Annual meeting of the American Educational Research Association, San Francisco, CA. https://www.academia.edu/1080315/A_theoretical_framework_for_data_driven_decision_making

Mandinach, E. B. (2012). A perfect time for data use: Using data-driven decision making to inform practice. *Educational Psychologist*, *47*(2), 71–85. https://doi.org/10.1080/00461520.2012.667064

Mangaroska, K., & Giannakos, M. (2019). Learning analytics for learning design: A systematic literature review of analytics-driven design to enhance learning. *IEEE Transactions on Learning Technologies*, *12*(4), 516–534. https://doi.org/10.1109/TLT.2018.2868673

Martinez-Maldonado, R., Elliott, D., Axisa, C., Power, T., Echeverria, V., & Buckingham Shum, S. (2020). Designing translucent learning analytics with teachers: An elicitation process. *Interactive Learning Environments*, 1–15. https://doi.org/10.1080/10494820.2019.1710541

Pierce, R., Chick, H., & Gordon, I. (2013). Teachers' perceptions of the factors influencing their engagement with statistical reports on student achievement data. *Australian Journal of Education*, *57*(3), 237–255. https://doi.org/10.1177/0004944113496176

Prieto, L. P., Magnuson, P., Dillenbourg, P., & Saar, M. (2020). Reflection for action: Designing tools to support teacher reflection on everyday evidence. *Technology, Pedagogy and Education*, *29*(3), 279–295. https://doi.org/10.1080/1475939X.2020.1762721

Prieto, L. P., Sharma, K., Wen, Y., & Dillenbourg, P. (2015). The burden of facilitating collaboration: Towards estimation of teacher orchestration load using eye-tracking measures. In O. Lindwall, P. Häkkinen, T. Koschman, P. Tchounikine, and S. Ludvigsen (Eds.), *Exploring the material conditions of learning: The Computer Supported Collaborative Learning (CSCL) Conference 2015, Volume 1* . The International Society of the Learning Sciences. (pp. 212–219) . https://repository.isls.org/handle/1/410

Reeves, T. D., & Honig, S. L. (2015). A classroom data literacy intervention for pre-service teachers. *Teaching and Teacher Education*, *50*(1), 90–101. https://doi.org/10.1016/j.tate.2015.05.007

Rienties, B., & Toetenel, L. (2016). The impact of learning design on student behaviour, satisfaction and performance: A cross-institutional comparison across 151 modules. *Computers in Human Behavior*, *60* (C) , 333–341. https://doi.org/10.1016/j.chb.2016.02.074

Saar, M., Prieto, L. P., Rodríguez-Triana, M. J., & Kusmin, M. (2018, July). Personalized, teacher-driven in-action data collection: Technology design principles. In *2018 IEEE 18th International Conference on Advanced Learning Technologies (ICALT)* (pp. 58–62). IEEE Computer Society. https://doi.org/10.1109/ICALT.2018.00020 .

Schildkamp, K., & Kuiper, W. (2010). Data-informed curriculum reform: Which data, what purposes, and promoting and hindering factors. *Teaching and Teacher Education*, *26*(3), 482–496. https://doi.org/10.1016/j.tate.2009.06.007

Schildkamp, K., Poortman, C. L., & Handelzalts, A. (2016). Data teams for school improvement. *School Effectiveness and School Improvement*, *27*(2), 228–254. https://doi.org/10.1080/09243453.2015.1056192

Sergis, S., Sampson, D. G., Rodríguez-Triana, M. J., Gillet, D., Pelliccione, L., & de Jong, T. (2019, March). Using educational data from teaching and learning to inform teachers' reflective educational design in inquiry-based STEM education. *Computers in Human Behavior*, *92*, 724–738. https://doi.org/10.1016/j.chb.2017.12.014

Sergis, S., & Sampson, D. G. (2017). Teaching and learning analytics to support teacher inquiry: A systematic literature review. Peña-Ayala , A. (Ed.) . In *Learning analytics: Fundaments, applications, and trends* (pp. 25–63). Springer. https://doi.org/10.1007/978-3-319-52977-6_2

Stringer, E. T. (2013). *Action research*. Sage Publications.

Supovitz, J. A. (2013, April). *The linking study: An experiment to strengthen teachers' engagement with data on teaching and learning*. Consortium for Policy Research in Education [Paper presentation]. Annual Meeting of the American Educational Research Association, San Francisco, CA. https://eric.ed.gov/?id=ED547667

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science*, *46*(2), 186–204. https://doi.org/10.1287/mnsc.46.2.186.11926

Wang, F., & Hannafin, M. J. (2005, December). Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development*, *53*(4), 5–23. https://doi.org/10.1007/BF02504682