Towards a teacher dashboard design for interactive simulations

To cite this article: D López Tavares et al 2019 J. Phys.: Conf. Ser. 1287 012055

View the article online for updates and enhancements.
Towards a teacher dashboard design for interactive simulations

D López Tavares¹, K Perkins², M Kauzmann² and C Aguirre Velez¹
¹CICATA-Legaria, Instituto Politécnico Nacional, 1150 CDMX, México
²Department of Physics, University of Colorado Boulder, 80309 Colorado, USA

Abstract. The use of interactive simulations (sims) in physics education is increasing. Aside from direct observation, teachers currently lack options for gaining useful insights into how their students are using these sims. A teacher dashboard to analyze and visualize student interaction with sims holds promise for responding to teacher needs and providing opportunities for improved classroom implementation of such sims. In this work we present progress in the design and development of a teacher dashboard that analyzes and visualizes student interaction with sims. A survey of over 800 teachers was conducted to identify the types of information teachers’ perceive as useful and how they would use that information to guide instruction. Teacher report valuing information that helps them to review student performance, to improve the design of sim-centered activities, and to plan lessons. A prototype dashboard design informed by this survey is also presented, including data collected from student sim use during a college homework activity. Finally, we describe how this dashboard design can address teacher needs related to insights around sim-based activities. Future work will evaluate teacher opinions regarding their interpretation of the data visualizations and the dashboard design in general.

1. Introduction

The use of interactive simulations (sims) is increasing in physics education [1–3]. Research shows that how students interact with a sim is influenced by the level and type of guidance used in the activity worksheet and/or facilitation coupled with the sim [4–9]. Guidance can help center the attention of students on sim elements that are important for achieving specific learning goals; however, excessive guidance can lead students to follow directions without engaging students in the deep exploration [4] and the rich science practices – asking questions, designing experiments, collecting and interpreting data, reasoning from evidence – associated with inquiry-based learning and aligned with modern science standards (e.g. the Next Generation Science Standards [10]. At the same time, other research has associated of the type and level of guidance used with sims to students’ frustration and motivation [9].

Optimizing the learning potential of sims within physics, and refining instructional design and teacher facilitation techniques for implementing these technologies, remains a critical challenge and active area of research [3,11]. A dashboard that can effectively communicate students’ interaction patterns with sims can help address this challenge, providing new insight and feedback to teachers and researchers as they implement sims in instruction.

Significant recent research by the learning analytics community has focused on dashboards for a range of educational tools, including Learning Management Systems (LMS), Massive Open Online Courses (MOOCs), and Intelligent Tutor Systems (ITS) [12–17], but no prior research on dashboard design and use with interactive simulations was found in our literature review. In the context of these other tools, dashboards have been shown to support teachers in decision-making processes, classroom
problem solving, and instructional design [12,14,17], and to improve online personalized learning experiences [18].

Sims pose unique challenges for characterizing and communicating information about student interactions that is useful and actionable for teachers. Unlike many educational tools, sim environments are highly interactive and open; there is no linear progression of problems and no right or wrong answers. In these environments, individual students can manipulate and explore the sim in many complicated and unique ways. In addition, sims do not include conventional measures of achievement. The student data produced by such interactions is thus quite different from other educational technology services, and requires new research to characterize the needs of teachers using sims and to develop an effective dashboard design with data sources, analysis, and visualizations effective for these open-ended, exploratory environments.

Identifying the kinds of data that can generate useful information for teachers and how to present that information in an easily digestible way is the focus of our research. This paper presents the in-progress design and a developmental prototype of a sim dashboard. The dashboard is designed as a post-use analysis tool following a sim activity. This research remains in progress, and the design and results are preliminary.

2. Research question
Our central research question is: What data about student use of highly interactive educational tools – specifically interactive simulations – are useful and actionable for science teachers, and how can these data be effectively visualized and presented to teachers?

The goals of this research are to: 1) Identify teachers’ instructional challenges and questions that can be informed by collection of student interaction data during sim use; and 2) Design and develop a teacher dashboard that analyzes, organizes, and presents information on student interaction with sims that teachers can use to inform their sim-based instruction, using accessible and interpretable visualizations.

It is important to emphasize that this research focuses on characterizing aspects of student interaction and engagement with a sim that are interpretable and actionable by teachers. The data collected and presented in the dashboard has limitations, in that it cannot provide direct insight about student learning or understanding. Rather, this teacher dashboard aims to impact student learning by improving teacher pedagogical actions with simulations, similar to other teacher dashboard efforts [19].

3. Theoretical Framework
Learning Analytics (LA) uses learner-produced data together with analysis models to create useful information for motivating actions, such as reflecting on previous teaching or learning activities, in order to improve teaching and learning [15]. Teacher dashboards are used to represent data in a visual way and convey the results of a LA analysis.

In a recent literature review on learning dashboards, Schwendimann et al. concluded that, while progress has occurred, making dashboards useful as decision-making and learning support tools and identifying what and how information should be displayed in a timely and accurate manner remains a challenge [20]. Recent research studies about educational dashboards can, however, provide guidance and serve to inform the current work [12–17].

Prior research has demonstrated the importance of aligning the goals of the dashboard and the types of information displayed. Some information in previously developed dashboards proved not helpful or efficient [12]. In other cases, dashboards provided more information than teachers needed or could process, or included unsurprising information about their students [21]. For instance, the display of unnecessary personal information or information with potential data privacy issues [15].

Some research studies provide insight into how teachers use data in dashboards to drive instruction and remediate issues both in class and at the individual student level [12,14,15]. Through direct teacher observations, these studies showed that teachers use data to plan what to cover in each period,
to evaluate student progress and performance, and to determine if an intervention is needed and, if so, the focus of such an intervention.

Other researchers directly asked teachers “If you could have any superpowers you wanted, to help you do your job, what would they be?” and evaluated their responses to help elucidate teachers needs and which of those needs could be addressed with students’ data [21]. They found that teachers wanted: 1) information on when and where to perform an intervention; 2) indicators of activity and student success; 3) information that helps with class orchestration; and 4) insights into students’ motivation and the affective state in the classroom. Data to guide lesson planning and intervention looks to be a constant priority across prior research studies, but interestingly this study also includes student’s motivation as a quality that teachers wish to evaluate.

Several design frameworks have been used in designing educational dashboards. Griller et al. [16] consider the following dimensions in their design: stakeholders (those who will receive and interpret the information); education data itself (what is going to be collected); visualizations; and limitations. The research of Bakharia et al. [22] considered an alternative framing, examining these dimensions: temporal (the interval of time used for the presentation of the results); the possibility to compare results (multiple graphics in a single user view); dynamic graphics that change with the use of filters; specifying elements for obtaining finer-grained details; and tools for intervention and assessment.

Prior efforts have demonstrated the importance of including teachers as part of a user-driven design process that includes interviews, prototypes, and empirical evaluations of dashboard design [12,21,23]. Holstein et al. [23] present dashboard design and redesign as an iterative process involving constant communication with teachers. This approach ensures that the final product has the characteristics that teachers need, and is critical to effectiveness. While dashboards are normally designed for power and flexibility, they can sometimes neglect simplicity, making it too complex or too time consuming for educators [15]. Dashboards should be easy for teachers to read, manipulate, and interpret.

In their review of the literature, Schwendimann et al [20] found that the main data sources used by educational dashboards include: 1) logs to track computer-mediated user activity; 2) learning artifacts used or produced by the student; 3) personal information and background; 4) content; and 5) the results of activities. However, on the case of sims, which are open-ended environments and do not often include traditional concrete measures of achievement, identifying what data to use and how to synthesize this data remains an active research question.

Prior research studies about student experiences and engagement with sims have made use of student interaction data [4,7], and can help inform the current work. These studies were able to characterize student interaction with a sim, and differentiate between groups of students, using a variety of metrics, including the time of interaction, mouse clicks per minute, sim elements used, and the evolution of mouse clicks in time. Other research with sims analyzed the interaction patterns of students to predict student learning [24], demonstrating that student behaviors while try to solve a challenge correlated with improved learning.

Finally, data analysis and visualization approaches commonly used in web usability testing and analytics – such as mouse tracking, click maps [25,26], and visualizations provided by Google Analytics [27] – also serve as useful models and can be adapted to help represent the interaction of students with educational virtual environments, like simulations.

4. Methods
The research described here focuses on 1) understanding the needs of teachers using interactive sims and their perspectives what student data around sim use would be useful and actionable, and 2) designing a dashboard prototype that is informed by the prior research and addresses the teachers’ needs.

For this research, we use sims from the PhET Interactive Simulations project of the University of Colorado Boulder (https://phet.colorado.edu). These sims are used highly popular among physics and other STEM teachers – used over 100 million times per year – and thus provide a useful context for exploring these research questions. In addition, we solicit input from the broad base of teachers using PhET sims.
4.1 Survey of Teacher Needs

As an initial step in the dashboard design process, an online survey was administered to collect information about teachers’ needs and interest in student interaction data with sims. The survey was sent to US-based math and science teachers working in diverse K-12 and college settings who had previously registered for a PhET user account. Of the 71,049 teachers emailed, 892 responses were collected; not every teacher responded to each all questions, but all questions received over 800 responses. The survey first asks if the teacher would like access to data about their students’ interaction with sims.

The survey included two main section: 1) a series of open-ended questions constructed to elicit initial ideas from teachers, and 2) a Likert-scale response section to a broad list of options for individual student and group data that could be collected and presented following student sim use. The open-ended questions included: 1) what information would you like to know about your students’ interaction with the sim? and why? 2) how would you make use of that information? 3) what kinds of questions do you have when you design and assign an activity that requires the use of sims that could be informed by having this type of student interaction information? The list of options for individual student and group data included a range of suggestions for teachers to consider – from duration of sim use to elements used and so forth. Teachers rated each data option on a 5-point scale from “Not important” to “Critical”, or selected N/A if they had no opinion about the item. These list options were derived from references [1,3] and suggestions from the research team.

The open survey answers were analyzed using qualitative analysis methods and MAXQDA2018 software to identify emergent themes [24]. The first 100 surveys analysed, with common codes emerging directly from the teacher’s written responses. The codes were grouped by the three major questions – what data is needed, how would the data be used, and what kinds of questions do teachers have in their use of sims – with a set of sub-codes for each section. One question answer may contain several sub-codes and, in a few cases, pertain to more than one of the major questions (for example, in the question regarding data, some teachers mentioned how they could use that data as well). An additional 100 survey answers were coded and compared with the initial 100; the codes and their frequency were very similar, indicating that analyzing more survey responses was unlikely to provide any new insights.

4.2 Simulations and Sample Data

An adaptation of the PhET simulation, Capacitor Lab: Basics, was used for this research study [25]. In this sim, students can explore the physics of a parallel plate capacitor. Students can change the plate area and the separation distance, and the capacitor can be connected and disconnected from a battery. In addition, students can change battery voltage, display numeric data, and use a voltmeter.

The version of the sim used was instrumented with the PhET-iO extension – an extension that allows all student-sim interaction and changes in the sim’s model to be captured in a data stream file. The following data was recorded and used in the initial prototype dashboard design: student and group IDs; time and screen position of each student’s events (clicks, mouse-down and mouse-up); and use of specific sim elements. Additional data – e.g. the record of sim element values during sim use – is also recorded and being considered for inclusion in the dashboard.

A sample of student sim interaction data was collected from students in an introductory college physics course as they completed a homework activity. The homework asked students “Explain how changing each factor changes the amount of stored energy. Use data from the simulation to support your claim”. This data was used in the dashboard design and development process, to guide and evaluate the dashboard’s ability to describe student interaction and to tailor the visualizations and graphs to teacher concerns.

4.3 Design and Development

An iterative design process was used to arrive at the prototype dashboard design presented here. First, indicators and visualizations were adapted from references about engagement with sims [1,3] and website usability [21–23]. To refine the design, dashboard mock-ups were presented to expert
designers and developers from the PhET team, physics education researchers from the University of Colorado, and learning analytics experts from the University of British Columbia and Stanford University. Once the design was solidified, the prototype dashboard was developed using the sample data collected. The prototype dashboard is available here [26].

5. Results and Discussions
In this section, we first present the results of the teacher survey. With that information and the references, the design of the prototype dashboard is introduced with a description of each of its visualisations and the student data collected.

5.1 Teacher Survey Analysis
Of the teacher responses received from PhET simulation users, 82.7% mentioned that they definitely or probably would use data from student interactions with sims. Teachers who responded that they would not use this data had several explanations, including: using simple classroom observations or follow-up questions with students; using worksheets to record student’s results from an activity with the sim; not wanting to lose time in class with logins (requirement to follow the student’s interaction); lacking time to review such data; issues with student privacy; and the potential that such interaction tracking may limit student exploration. The majority of teachers reported that they would use data on student sim use, suggesting that a teacher dashboard would be a valuable instructional tool for teachers.

Qualitative analysis of the question probing information teachers would like to know about their students’ interaction (N=156 responses) identified 16 different codes and helps reveal the data teachers perceive as valuable to their instruction. The most popular responses included:

- Duration (60%): how long students use the sim. For example, the answer: “Time using the sim”
- Track different students’ configurations with the sim (30%). For example, the answer: “I would like to know if students completed certain steps of the sim”
- Duration in specific level/question/sim’s area (18%). For example, the answers: “What parts of the sim they are using and for how long” and “where did the students spend the most time”
- List of the sim’s elements used (14%). For example, the answer: “which parts of the sim students were interacting with”
- Level of interaction (12%): this requests means a measurement to determine if the student was actively using the sim. For example, the following answer: “Duration is only useful if it is active use, for example, at least one click every 40-60 seconds, or something along those lines”.
- Level of completion/success (10%): some teachers want to know the progress of an activity reached by students. For example, the following teachers’ answers: “how advanced did the students get using the sims” and “their success rate”.

The Likert-scale responses by teachers further illuminates these open-ended responses, and what data teachers perceive as useful. Table 1 shows each type of data item presented and the percentage of teachers rating it as critical/important, when considering it in the context of aggregated data for groups of students and data from individual students. Teachers responding N/A were not included in the analysis.

| Type of Data                                                                 | Individual student | Aggregated for group |
|----------------------------------------------------------------------------|--------------------|----------------------|
| Achievement of a specific state (e.g. did they saturate the solution)      | 72.8%              | 77.3%                |
| Duration and time of sim use                                              | 54.0%              | 45.7%                |
| How the students’ interaction changes over time                           | 47.7%              | 45.1%                |
Information about the elements of the sim used 46.3% 47%
Option to compare information of different students/groups 45.3% 42.2%
Information about draggable objects (e.g. locations, paths of movement) 35.1% 32.4%
Option to divide the information by sim “screen/tabs” 31.4% 33%
Information about students’ mouse clicks 30.0% 21%

The teacher survey positioned the open-ended questions before the Likert scale questions as to minimize impacting teachers’ first thoughts with researcher-suggested types of data. Thus, the lower percentages for some types of data in the open-ended questions is expected because teachers were unlikely to consider all these options during the open-ended portion.

The results show that some of the data considered previously by the research team was also mentioned by teachers in the open-ended questions, such as duration of the interaction. Teachers desire to track configurations in the sim relates to knowing if students achieved a specific state, the path followed to achieve this state, and the level of completion. During instructional use, teachers often assign sim-based activities where students have to solve certain tasks which specify a state in the sim (generate a saturated a solution, reach the maximum amount of stored energy, etc.). If teachers can see information that reveals whether these states were achieved, they can evaluate the level of completion of an activity.

Duration in specific level/question/area in the sim is the third most popular teacher answer in the open-ended questions. Combining information about the elements of the sim used, information about achievement of a specific state, and parsing the information by a sim’s “screen”, it is possible to approach this goal with the student interaction data available. However, this teacher request cannot be realized in a single visualization. The dashboard should be designed in a way that the visualizations needed to provide this information work well together for easy interpretation.

The open-ended question about how teachers may use this data (N=190) revealed information about teacher’s goals for use of this dashboard. Of the analyzed responses, 86% of teachers reported that they would use it to review student performance (assessment, identify struggling students and how to support them, student compliance, common errors, identify students copying/cheating). Teachers (46%) also reported that they would use the data for planning lessons (focus of the next lesson, differential lessons plans for students struggling or more advanced, plan student and group discussions). Reviewing and improving the lesson activity design was mentioned by 43% of teachers. These answers were related with the third open-ended question in the survey – which prompted teachers about the questions they have when planning instructional use of sims (N=126). For this prompt, the responses fell into 3 main categories: 72% of teachers described having questions about how to structure the activity (how and what to ask in the activity, time needed for each question, if the sim is better for introduction or summary, how to center the attention to a specific control in the sim, prior knowledge needed, not only about the topic, also about how to use the sim); 41% of teachers discussed having questions about how much instruction about how to use the sim is needed; and finally, 22% of teachers desired students’ opinions about the activity (if they find it useful, interesting, engaging, hard or easy).

The information prioritized by teachers in the survey is consistent with the information described in the theoretical framework for other researches [8,17]. The survey results also suggest that the issues important to teachers regarding interactive sims can be addressed with the types of data produced by students during their sim use. The survey designing a dashboard for interactive sims is as complex and as for other learning environments.

Additionally, in the introduction of this paper we highlighted prior research around how the interaction of the student is affected by the instructions of the activity (guidance) [1,3–7]. The survey answers show that teachers share these same concerns and questions about the guidance they provide in their activities. A high percentage of the teachers (72%) would like to have information to help them structure activities with the sim to generate productive exploration and interaction; finding the balance between inquiry questions vs specific instructions. Furthermore, 16% of these teachers went deeper in
their answers and expressed that this balance between inquiry and specific instruction depends on a student’s ability, interest and knowledge, as well as how intuitive or difficult the sim is to use. These teachers need a tool that gives them specific information about their students, to help them refine the type of instruction in their activities.

Defining *productive exploration and interaction* with sims forms another challenge of this project. We think that, from the teacher’s perspective, *productive exploration and interaction* with the sim is when students generally do what the teacher expects. For example, if the teacher assigns a question having in mind that students will interact with specific sim elements and spend some time exploring, it is considered productive if student interactions align with these assumptions. Even though in this research we plan to identify general patterns of productive exploration and interaction, this idea can depend on the teacher perspective. Thus, we also recognize the need for a tool that allows each teacher to identify and interpret the data that they consider important.

5.2 Dashboard design and development

The dashboard design separates the visualizations into three screens. The data shown in the figures in this section are from collect physics students, using the simulation and activity described in the section 4.2, but the names of the students were modified. Some features of the dashboard design are available to interact with in the linked prototype, where as other features – marked with an “*” – as well as user INTERFACE improvements are awaiting further software development.

The first screen has all the information related to events (clicks, mouse-up and mouse-down) and time (Fig 1). In this screen users can select the group they want to analyze and get some median values for the group, like total time of interaction, and events (Fig. 1-A). One student can be selected by name (or ID) to be compared with the rest of the group (Fig. 1-B). The main visualization is the “Events map” (Fig. 1-C); here red dots overlaid on a screenshot of the sim represent all the recorded events. If one student is selected, his/her events are going to appear on top of the red dots in different color. This visualization helps to identify the settings of some elements, for example to identify the range of values students explored in a slider. The time interval of interest can also be selected using a double slider (Fig. 1-D). Users can also modify the opacity of the red dots in the events map with a slide bar (Fig.1-E). This adjustment helps to identify the areas in the sim with more interaction when analyzing groups with different numbers of students, or to hide the red dots if only the events of a selected student are needed.

**Figure 1. Events and time screen in the dashboard**

In graph Fig.1-F, each dot represents one student, the coordinates of the dots are the total time of interaction and total number of events. The red lines in the graph are the median of these values for the group. Users can select one student by clicking dots in this graph (equivalent to Fig. 1-B, but in this
case is for selecting students with specific performance, for example identifying which students finish the activity in a longer or shorter time). In addition, the line representing the chosen student in the graph Fig. 1-G displays the time evolution of interaction. This graph helps to visualize the moments with more and less interaction with the sim. For example, comparing the students Mike and Sam, we can see that Sam has a long time with no interaction with the sim represented by the horizontal section of the line, and Mike was interacting actively with the sim the whole time.

When the radio button “% Student graphs” (Fig. 1-H) is selected, the Events map is hidden and, in its place, two other graphs appear. Graph Fig. 1-I shows the percentage of students that are running the sim vs time. This graph helps to display the duration of the activity, showing when most of the students finish using the sim. It also shows the time that students were dragging elements in the sim. A student could take the battery voltage control and move it up and down before releasing it, but the dashboard will not show all this movement. However, with the drag time, we can have an idea of this kind of interactions.

Graph Fig. 1-J shows how the rate of events/min changes over time. The median value of the group’s data can be seen in green, and the data of the selected student can be seen in orange. We can observe, for example, that in the beginning students have a high mouse interaction with the sim, and have another small peak around 10 to 15 minutes. This information can help teachers to identify when students are answering different questions. In general, students interact with the sim to answer one question, then they stop interacting to write or comment their findings, and then interact again to answer the next question. This graph addresses the teacher desire to know the duration students spend on specific questions of their activities. Combined with the events map (Fig. 1-C) and selecting time intervals (Fig. 1-D), teachers can observe what was the part of the sim used in that time.

The dashboard’s second screen (Fig. 2) has all the information related to the sim’s elements used. The header for select group and student is the same that the first screen (Fig. 2-A). The elements used map (Fig. 2-B) is a screenshot of the sim with colored boxes displaying the percentage of students that used each interactive element. The color of the boxes corresponds to a color gradient indicating usage level. To the right of each box is a square with a black number indicating the median value of the times that the element was used by the students, and a pink number indicates the number of times that the element was used by the selected student.

![Figure 2. Elements used screen](image)

Fig. 2-C is the same “Total Time and Events” graph as in the first screen (Fig.1-F), but now each dot has a color that represents the percentage of elements used by each student. The user can also select students by clicking dots in this graph. Fig. 2-D is visible when the user selects the “Common Elements’ values” radio button. This graph shows in a pie chart the percentage of time that a two-option element was active in green, and the slider positions used most by the group and the selected student.
The third screen of the dashboard (Fig. 3) includes a version of the sim in which a user can set the sim in a specific configuration (Fig.3-B), check the sim’s elements that have to be in that specific state/position (Fig.3-A), and then search for students that achieved that specific configuration (Fig.3-D). The user can save several configurations, and then move from one configuration to another with the arrows on the bottom (Fig.3-C). This screen is not yet implemented.

6. Conclusions and future work
In the currently designed version of the dashboard, most of the interests expressed by teachers in the survey have already been addressed. Teachers can review student performance and see the interaction that questions in the activity generate. If more or different interaction with the sim is desired, the guidance in the activity should be modified. In this manner, the dashboard can help improve activities and give specific information about what activity questions and what sim elements can improve guidance. Also, knowing the elements that students used can generate a classroom discussion in the following class, giving information to teachers that can help to plan lessons. A deeper analysis of students’ performance using the dashboard developed so far has been accepted for publication in the proceedings of the Physics Education Research Conference 2018 [27].

The question now is if the visualisations and structure of the dashboard are understandable and easy to read for teachers. Dashboards are usually evaluated for usability, usefulness, and user satisfaction, often with the intention of gathering formative feedback to improve the dashboard itself [16,17,19]. Teacher interviews to answer these open questions and evaluate usefulness are already in progress.

The visualizations work well in the sim used thus far for studies, but we need to evaluate if they work well for other sims with more complex potential manipulations. The data of three groups of students, using two different simulations have been already collected and the development of the dashboard is in progress.

7. Acknowledgments
The authors would like to thank the teachers for taking the time to respond to our survey and the PhET team for their support. Funding for this project was provided by CONACYT and CICATA-IPN (Mexico), as well as the Gordon and Betty Moore Foundation.

8. References
[1] Moore E B, Herzog T A and Perkins K K 2013 Interactive simulations as implicit support for guided-inquiry *Chem. Educ. Res. Pr.* 14 257–68
[2] Velasco J and Buteler L 2017 Simulaciones computacionales en la enseñanza de la física: una revisión crítica de los últimos años Enseñanza las Ciencias 35 161–78
[3] Chamberlain J M, Lancaster K, Parson R and Perkins K K 2014 How guidance affects student engagement with an interactive simulation Chem. Educ. Res. Pr. Chem. Educ. Res. Pr. 15 628–38
[4] Adams W K, Paulson A and Wieman C E 2008 What levels of guidance promote engaged exploration with interactive simulations? AIP Conference Proceedings vol 1064 pp 59–62
[5] Podolefsky N S, Perkins K K and Adams W K 2010 Factors promoting engaged exploration with computer simulations Phys. Rev. Spec. Top. - Phys. Educ. Res. 6
[6] Salehi S, Keil M, Kuo E and Wieman C E 2015 How to structure an unstructured activity: Generating physics rules from simulation or contrasting cases 2015 Physics Education Research Conference Proceedings (American Association of Physics Teachers) pp 291–4
[7] Borek A, Mclaren B M, Karabinos M and Yaron D 2009 How Much Assistance is Helpful to Students in Discovery Learning? Proceedings of the Fourth European Conference on Technology Enhanced Learning. Learning in the Synergy of Multiple Disciplines (EC-TEL 2009) vol LNCS 5794, ed U Cress, V Dimitrova and M Specht (Nice, France: Springer-Verlag) pp 391–404
[8] Xhakaj F, Alevan V and McLaren B M 2016 How Teachers Use Data to Help Students Learn: Contextual Inquiry for the Design of a Dashboard (Springer, Cham) pp 340–54
[9] Corrin Linda de B P 2014 Exploring students’ interpretation of feedback delivered through learning analytics dashboards Rhetoric and Reality: Critical perspectives on educational technology ed & S-K L B. Hegarty, J. McDonald (Proceedings ascilite Dunedin 2014) pp 629–33
[10] Klerkx J, Verbert K and Duval E 2017 Learning Analytics Dashboards Handbook of Learning Analytics (Belguim) pp 143–50
[11] Dyckhoff A L, Zielke D, Büttmann M, Chatti M A and Schroeder U 2012 Design and Implementation of a Learning Analytics Toolkit for Teachers Educ. Technol. Soc. 15 58–76
[12] Greller W and Drachsler H 2012 Translating Learning into Numbers: A Generic Framework for Learning Analytics Educ. Technol. Soc. 15 42–57
[13] Verbert K, Govaerts S, Duval E, Santos J, Assche F, Parra G and Klerkx J 2013 Learning dashboards: an overview and future research opportunities Pers. Ubiquitous Comput. 1–16
[14] Observatory of Educational Innovation 2014 EduTrends Adaptable Learning and Testing
[15] Holstein K, Mclaren B M and Alevan V 2018 Student Learning Benefits of a Mixed-reality Teacher Awareness Tool in AI-enhanced Classrooms Aied 1–14
[16] Schwendimann B A, Rodríguez-Triana M J, Vozniuk A, Prieto L P, Shirvani Boroujeni M, Holzer A, Gillet D and Dillenbourg P 2017 Understanding learning at a glance: A systematic literature review of learning dashboards IEEE Trans. Learn. Technol. 10 148–57
[17] Holstein K, McLaren B M and Alevan V 2017 Intelligent tutors as teachers’ aides Proceedings of the Seventh International Learning Analytics & Knowledge Conference on - LAK ’17 pp 257–66
[18] Bakharia A, Corrin L, de Barba P, Kennedy G, Gašević D, Mulder R, Williams D, Dawson S and Lockyer L 2016 A conceptual framework linking learning design with learning analytics Proceedings of the Sixth International Conference on Learning Analytics & Knowledge - LAK ’16 (New York, New York, USA: ACM Press) pp 329–38
[19] Holstein K, Hong G, Tegene M, McLaren B M and Alevan V 2018 The classroom as a dashboard: Co-designing wearable cognitive augmentation for K-12 teachers ACM International Conference Proceeding Series vol Part F1354 pp 79–88
[20] Käser T, Hallinen N R and Schwartz D L 2017 Modeling exploration strategies to predict student performance within a learning environment and beyond Proceedings of the Seventh International Learning Analytics & Knowledge Conference on - LAK ’17 pp 31–40
[21] Atterer R, Wnuk M and Schmidt A 2006 Knowing the user’s every move: user activity tracking for website usability evaluation and implicit interaction Proceedings of the 15th Int. Conf. on World Wide Web pp 203–212
[22] Navalpakkam V and Churchill E 2012 Mouse tracking: measuring and predicting users’ experience of web-based content *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI ’12* pp 2963–72

[23] Google Google Analytics

[24] Milles M, Huberman M and Saldaña J 1994 Fundamentals of Qualitative Data Analysis *Qualitative Data Analysis* (Arizona: SAGE) pp 69–104

[25] PhET Interactive Simulations [Capacitor Lab: Basics](https://phet.colorado.edu/sims/html/capacitors/eng/index.html)

[26] PhET Interactive Simulations 2018 [Interaction Dashboard](https://phet.colorado.edu/sims/html/interaction-dashboard/eng/index.html)

[27] López-Tavares D, Perkins K, Reid S, Kauzmann M and Aguirre-Vélez C 2018 Dashboard to evaluate student engagement with interactive simulations *Physics Education Research Conference* p 4