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Teacher-Centered Dashboards Design Process

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ABSTRACT: Interest in dashboards in schools has been growing in recent years as they have great potential in fostering data transparency and informing teachers' practices. However, research surrounding them is not unified and even less transparent, because of a lack of guidance in grounding their design as a process tailored to end-users needs. We present a process model for teacher-centered dashboards as a design and validation process with four mutually informed stages: (1) situate the domain space by framing teachers' routines, practices, and needs, (2) ideate the domain into multiple alternatives and prototypes, (3) develop, and (4) evaluate the dashboard. We drive recommendations within each stage to inform the process. We borrowed the foundations of the model from research in the HCI and InfoVis fields. We apply our model to five case studies from literature. We find that this model can provide a framework to scaffold dashboards' design process, mutually inform the underlying stages, and guide consolidating artifacts. We reflect on our work to provide design implications to point towards explainable dashboards design to best support teachers.

Keywords: Teacher-centered design, Dashboards, Explainable dashboards, Design process

1. INTRODUCTION

Mainstream technology is becoming ubiquitous in todays classrooms (Technavio, 2016; Buabeng-Andoh, 2012; Millar, 2013). and, it has the potential to provide insightful information about the state of learning. Recently, out of 762 polled teachers, 86% think that data is important for being an effective teacher, and 81% think that students will benefit when data informs teaching (Campaign, 2018). Likewise, dashboards are becoming important assets to facilitate data transparency, sense-making, reflection, as well as sophisticated portals for teachers to inform their work, decisions, and practices (Verbert et al., 2013; Sedrakyan et al., 2019). Prior work has shown the potential of dashboards to assist teachers, for instance, in monitoring students' performance to mediate the classroom (Molenaar and van Campen, 2017), to allocate time to students of lower abilities (Holstein, McLaren, and Aleven, 2018), to plan lessons and debriefs (Xhakaj et al., 2017), and to provide personalized in-time support to students (Aslan et al., 2019).

Although the great potential and interdisciplinary opportunities for research, current literature on dashboards designed for teachers is, less unified, and less tailored towards end-users needs, which hampers the trust and adoption of such tools. For instance, a development that is gaining momentum in human-centered design, e.g., "participatory design", "design thinking", is still "under-presented" in technology-enhanced learning (McKenney and Kali, 2017). Moreover, information visualization (Infovis) techniques are not embraced well yet by visual learning analytics (Vieira et al., 2018). Additionally, there is still a lack of specific visualizations and visual metaphors addressing teachers' and students' unique needs in learning analytics dashboards (Schwendimann et al., 2017). Furthermore, as pointed out by two recent systematic reviews (Schwendimann et al., 2017; Bodily et al., 2018), there is still a weakness in the process of design and evaluation of dashboards in learning

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contexts. We argue that this is primarily due to a lack of guidance in grounding the design as a transparent design process with a deep consideration of both technical and social aspects surrounding the design and evaluation of dashboards. Also, a lack of articulation in reporting not only on the end-artifacts but on the underlying design rationales and validations. This inspired the main motivation of our work: *Designers for teachers need models as systematic guiding principles to help scaffold the process of design and validation of dashboards to help foster trust and adoption.*

To inform the design of such interfaces, to foster transparency – through input from teachers, we present a process model for teacher-centered dashboards design with four mutually informed stages: (1) situate the domain space by framing teachers' routines, practices, and needs, (2) ideate the framed domain into design goals, tasks, data, visual abstractions, design alternatives, and prototypes, (3) develop a dashboard, and (4) evaluate its significance by assessing teachers' data-informed practices. We provide recommendations within each stage to inform design activities: exploring ideas, refining solutions, and consolidating artifacts.

By reflecting on our personal experience on the design and evaluation of dashboards for teachers, we turned to pertinent research in HCI and InfoVis to borrow the foundations of the model. HCI provides a wide range of methods that help empathize with teachers to understand their routines and needs (Wright and McCarthy, 2008), and to onboard them in a space of shared trust and knowledge while designing and validating interfaces (Muller and Kuhn, 1993). InfoVis, on the other hand, provides a tool-set to abstract a domain space into design goals (Lam et al., 2018), tasks (Brehmer and Munzner, 2013), and data semantics (Munzner, 2014) which are mapped into visual forms (Cleveland and McGill, 1984) to shape the interface of a dashboard. Together, HCI and InfoVis ensure a good fit between dashboards' designs and the ways teachers are aiming to perform their everyday activities. We argue that designers not only need to be familiar with such approaches from both fields but they also need to appropriating (Dourish, 2003; Louridas, 1999) such approaches to scaffold a design process. To demonstrate this model, we apply it to concrete examples from literature through five case studies. We find that this model can provide a framework to structure dashboards' design process, mutually inform underlying stages, help consolidate, and report on artifacts along the way.

2. BACKGROUND AND RELATED WORK

2.1. Informing Dashboard Design From HCI

The field of HCI provides a rich and varied range of methods to guide the design of dashboards. Roughly designerly practices fall into three main approaches: implicit, explicit, and process. Early work in design was more informed through implicit or primitive approaches. Bricolage is one primitive approach where designers try to blend different elements available in their immediate environment in making a new design (Louridas, 1999). Similar to bricolage, appropriation is another primitive approach that can be associated with customization in the sense that designers try to adapt, adopt, and reuse different elements into a new working design (Dourish, 2003). In both bricolage and appropriation, designers do not create new elements, but instead make use of existing ones (e.g., ideas, artifacts) to serve new purposes different than the ones for which the original design was intended.

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Follow-up work informed the raise of explicit methods to provide formal guidelines as designers start developing professional ways of working with related formal education and qualification. One of the most current dominant explicit approaches is human-centered design (Bannon, 2011). That is, designers, before engaging in any design activity at their own, for instance, using bricolage or appropriation (Louridas, 1999; Dourish, 2003), first onduct a research design by engaging with end-users of the design, to develop a deep knowledge of their issues, needs, tasks, activities, and abilities. Based on the knowledge gained they design a solution, which they then evaluate with end-users, and iterate on the design as needed. It would be unsound and misleading to propose a valid dashboard solution based on inferring "end-users". Although this approach helps overcome poor design, it might be challenging for designers to tailor the design for individual (or group of) people without making it less appropriate or even overwhelming for others. Other methods emerged with different add-ons to address this shortcoming. For instance, activity-centered design (Norman, 2006) aims at addressing this by not focusing on the interface as simply a means to perform some tasks but instead on the activities that the interface enables end-users in their everyday routines and practices. For instance, a dashboard for teachers may integrate several tasks such as tracking students' idle moments, responses, rapid attempts, etc. but the main activity of teachers might be to mediate (or orchestrate) the classroom. Value sensitive design (Friedman, 1996) pushes this approach even further by focusing on human core values in designing the interface rather than tasks or activities. Returning to our example, in the context of value-sensitive design, we might devise the design of a dashboard as an "equalizer force" in a way to help a teacher ensuring equal progress to all students of the classroom.

Recently, design processes emerged to provide systematic heuristics to guide the activity of design. Design thinking (Brown, 2008) is gaining momentum in HCI research and industry, which is a set of hands-on methods to guide - iteratively, framing a problem (to solve) from wildly and diverse perspectives, critic and refine ideas to uncover an innovative solution that meets users' needs. To this end, design thinking wraps three fundamental skills, namely, empathy, rapid prototyping, and empirical justifications. The first step is empathy (Wright and McCarthy, 2008; Beyer and Holtzblatt, 1999), advocating designers to immerse themselves in end-users' lives to experience, first hand, their problems, contexts, and needs. Once designers frame a deep understanding of needs from end-users' perspectives, the second step is to prototype by rapidly generating multiple approximations of design ideas to try and test with actual users as quickly as possible (Dow et al., 2011; B. Hartmann et al., 2006). The third step is to evaluate prototypes using empirical evidence to justify choices. Prototypes are not end-artifacts in themselves. Instead, they are used as concrete communicative proxies to seek both positive and negative feedback about how they impact certain users' behaviors, reflect on design ideas, and learn insights to inform subsequent iterations. Another popular process is participatory design, rather than designing for people, advocates fundamentally designing with people by situating with them, to articulate their problems, identify their needs, and co-design solutions in cooperation (Muller and Kuhn, 1993). By doing so, the new design will directly support users' skills, activities, and fit within their workplace. Participatory design and design thinking both build upon rapid prototyping and active collaboration with end-users. Each method either implicit, explicit or process has its strengths and weakness, and each will lead to different solutions and designs. As designers, we need to appropriate them (Dourish, 2003; Louridas, 1999) to scaffold a design process to best support teachers' needs.

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2.2. Informing Dashboard Design From InfoVis

InfoVis provides a wide range of methods to map domain problems and questions into visual forms and dashboards by capturing four fundamental elements: rationales, tasks, data, and visual encoding. Significant research has been devoted to guiding capturing, bridging between these abstractions, and explicitly describing them in formal ways (Munzner, 2014; Amar et al., 2005; Lam et al., 2018; Brehmer and Munzner, 2013; Carroll and Rosson, 2003). Articulating on the aforementioned HCI methods of knowing end-users' contexts, activities, and identifying their needs (Wright and McCarthy, 2008), designers need to produce an explicit representation of design goals (or rationales) in terms of claims about the aspects that the new design must address, and how every aspect impacts (enable/limit) specific end-users' behaviors (Carroll and Rosson, 2003). Next, designers need to translate domain-specific questions into task abstractions, such as identify extremes, analyze outliers, compare or retrieve values, etc. (Amar et al., 2005; Brehmer and Munzner, 2013). However, bridging between high-level questions and low-level tasks is a challenging endeavor. Goals analysis aims at addressing this by decomposing domain questions into immediate design goals (explore, describe, explain, confirm) before mapping them to concrete tasks (Lam et al., 2018). Formal tasks can be used then to facilitate data abstraction by describing properties of (related) data, namely real semantics (temporal, spatial, continuous, discrete, keys, values, dates), types (quantitative, ordinal, categorical), and datasets (table, graph, text, field, stream, static), as first-class objects that can be visualized (Munzner, 2014) by mapping such properties into visual forms (or visual encoding). Data abstraction is actually the method of effectively mapping data properties to both graphical elements and properties (Cleveland and McGill, 1984). Point, line, surface, and volume are the basic graphical elements that can be used and combined to create visual forms. Position, size, color, orientation, texture, and shape are graphical properties that can be used to decorate visual forms.

The essence of dashboards is to emphasize insightful indicators by compacting the needed (all related and relevant) information in a small amount of visual space to inform the audience in a meaningful, efficient, and actionable way (Few, 2006). Dashboards capitalize on human perceptual and cognitive abilities of processing visual information. As a result, they lay on visual design techniques for monitoring, exploration, presentation, communication, and storytelling to better address the needs of a target audience (Segel and Heer, 2010; Echeverria et al., 2018; Skau et al., 2015; Parsons, 2018; Kosara, 2016).

Informed by business data analytics, prior literature provides three roles for dashboards mainly, strategic, analytic and operational (Few, 2006; Smith, 2013; Sarikaya et al., 2018). We instead think that it is more beneficial and practical for dashboard design to directly build on techniques that have already developed and validated in InfoVis regarding interfaces design specifically, role of visualizations (e.g., exploratory, confirmatory, presentation) (Schulz et al., 2013), design goals (e.g., explore, describe, explain, confirm) (Lam et al., 2018), and analytical tasks (e.g., retrieve values, compare items, find extremum, filter, sort) (Amar et al., 2005; Brehmer and Munzner, 2013). Explicitly describing rationales, tasks, data, and visual encoding in "abstract" rather than domain-specific form, translates into three key benefits. First, it avoids oversimplifications and converging into local-optimum solutions without exploring the design space of possibilities and alternatives. Second, it structures the validation of the newly designed artifact. And finally, it fosters transparency, trust, and adoption of the new design.

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2.3. Engaging Teachers in the Design Loop

There is little research, mostly related to curricula (TEL) design, that has examined teachers as designers through different design processes. For instance, Roschelle and Penuel (2006), using a co-design approach, reported on dynamics and tensions between researchers, teachers, and developers in the following three phases (collecting requirements, rapid prototyping, software solidification) design process for (TEL) curriculum. Along the same line, Cober et al. (2015) highlight the vital role of teachers in participatory design. Some, on the other hand, are skeptical Kirschner (2015) about the approach of the teacher as a designer because they believe teachers - as professional - can adapt/ adopt any TEL. They are not convinced by the benefit of engaging teachers in the design over the cost (time, resources, and energy) put in. We instead subscribe to the first call. That is, effective teachers are experts in the classroom's everyday routines (Hattie, 2012) thus having an essential role in bridging research, design, and practice.

2.4. Teachers' Dashboards Design Research

Unfortunately, the literature on design-based research and practices of design, analysis, and evaluation of teachers' dashboards is very scarce, with only very few exceptions. In two recent systematic reviews of more than 150 learning dashboards, almost half of the surveyed papers do not conduct any evaluation nor report on conducting a specific or using an existing design process (Schwendimann et al., 2017; Bodily et al., 2018). The first welcome exception is the framework proposed by Verbert et al. (2013) to guide the analysis of learning analytics dashboards. Although the framework is an excellent thinking tool, to evaluate the impact of a dashboard (e.g., see (Molenaar and van Campen, 2017), it mainly captures the evaluation part, and it does not provide a full model of how to design dashboards guiding the whole process from domain characterization to evaluation. Another welcome exception is the four stages workflow (problem identification, low-fidelity prototyping, high-fidelity prototyping, pilot studies) by Martinez-Maldonaldo et al. (2015) to guide the design and deployment of awareness tools for instructors and students. However, the workflow does not capture the principles of visualizations nor the challenges to tackle while designing dashboards. Our model aims at extending this latter by providing a process model built upon pertinent research from HCI and InfoVis.

3. APPROACH

This work is formed by reflecting on our experience in designing dashboards for teachers. In a process of introspection and analysis we generated, questioned, and interpreted practices surrounding dashboards' design, extensively reviewed literature from LAK, TEL, HCI, and InfoVis fields; we projected that understanding to articulate the conceptual model and, refined the reporting omitting evidence specific to our context. The process model that we describe in this paper is informed by previous models and methods aimed at applying visualization research to domain-specific problems. Namely, the model proposed by Munzner (2009) to guide and unify the analysis and validation of visualization tools through four nested levels, each with different threats of validity; for instance, in the characterization level –of the domain space, the threat is "wrong problem" and validation is "observe and interview target users". Although we find the nested model an excellent analysis tool, it does not provide a process approach of how to design nor offers practical advice to scaffold a design process. In fact, other models that build upon the nested model, have been proposed with the aim to provide a more holistic process. For example, a design study approach to

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conducting visualization research projects to solve a real-world problem through iterative stages (Sedlmair et al., 2012; McKenney and Kali, 2017). However, one main strand of these models is a lack of actionability. There persists a need for practicable models that do not compromise clarity and depth in the portrayal of the theoretical applicability. Our work is instead a process model offering a practical approach to devise design and validation of teachers' dashboards by providing specific design knowledge within each stage guiding designer to explore, assess, and refine design alternatives and consolidate artifacts along the way. We refer to validation as an ongoing practice of justification of steps of the design and evaluation as the deployment of a dashboard for teachers in real-world settings. Finally, we aimed at applying the model to concrete examples from literature. This has the advantage to capitalize on previous thinking and research about dashboards' design from multiple researchers and across different domains in the field which provide an initial, yet reliable validity of the model.

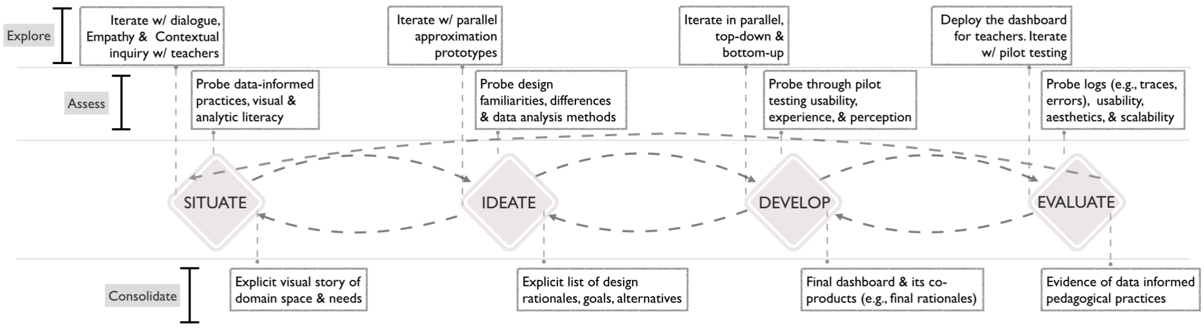

Figure 1: Four Stages of the model centered around three activities: explore, refine, consolidate.

4. PROCESS MODEL

Dashboard design is a process of solving a problem (Jonassen, 2000) to uncover a solution that meets users' needs and giving it a form and shape. The process model assumes that we have already a problem, question, or idea to address through the design of a dashboard. Therefore, our model starts by situating the problem, exploring possible ideas of solutions, acting on those solutions by generating design approximations prototypes, assessing prototypes by seeking feedback and refining them before evaluating how they impact teachers' practices and what behaviors they enable and limit in real-world settings (see Figure 1.).

4.1. Situate

Situate the domain space. Although the aim is to produce artifacts (e.g., dashboard), designers face phenomena whether facts (e.g., students' progression), tasks (e.g., identify outliers), activities (e.g., class orchestration) or values (e.g., equal progress to students). These phenomena are situated and dynamic. They develop and change over time in specific places (e.g., classroom, school, home). When designing, we need to understand the interplay between a teacher and a dashboard through those phenomena, and other related entities (e.g., students, parents, staff members). Situating the domain space is (1) capturing those phenomena and entities, (2) understanding their impact on teachers, and (3) explicitly describing their roles as parts and considerations of the design. Domain space reflects the possible range of motivations, needs, and constraints under which teachers are able and want to do their work in real-world settings.

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Recommendations: The aim of this stage is to understand teachers' problems, tasks, activities, values, and needs in context. One way to achieve this is by conducting empirical research in real-word settings using to gather valuable insights. HCI provides a wide range of approaches to tackle this (see related work). Wright and McCarthy (2008) report the most commonly used methods in HCI to "know users" through dialogue and empathy (e.g., role play-based, scenario-based, interviews, observations). The contextual-inquiry methodology is another way to learn about how users perform tasks in context (Beyer and Holtzblatt, 1999). This method advocates immersing where users perform their activities to observe, ask questions, participate, empathize, and learn about users' practices, decisions, workflows, pain-points, constraints to gain insights and inspirations. At the end of this stage, as designers, we will be able to create an explicit description (visual story) of all the dimensions, phenomena, stakeholders that impact teachers in using the dashboard. This will help to form an explicit list of teachers' needs, i.e., all the claims that the design needs to accomplish.

4.2. Ideate

Ideate by generating multiple design ideas to address teachers' needs. Prior work, appropriation (Dourish, 2003), bricolage (Louridas, 1999) are common sources of inspiration and creativity. The goal is to explore multiple and wild design alternatives and to use various sources of evidence to learn insights, validate and refine solutions. Then act on those solutions by generating multiple design approximations prototypes (B. Hartmann et al., 2006). Parallel prototyping is an effective method to generate alternatives in parallel, which helps discover unseen constraints, local optimum, and new opportunities (Dow et al., 2011).

Recommendations: The goal of this stage is to iterate by creating multiple design prototypes to approximate solutions (Dow et al., 2011). Then to make prototypes tangible, e.g., paper frame, sketch, PowerPoint, wireframe so that we can externalize them early and often to seek feedback, and to validate design choices. While doing so, we need to create an explicit data abstraction to capture the types and attributes of data at hand, which will help consider all constraints early in the ideation phase. At some point in the ideation, prototyping needs to converge to "data sketching" by incorporating real data into digital prototypes. This will help discover unseen limitations, and gather practical insights. At the end of this stage, as designers, we will be able: to create an explicit description design rationale of the dashboard all the claims to accomplish with the design, to select main design alternatives prototypes (for development phase) with associated validations, and to create an explicit data abstraction and transformations (e.g., algorithm) to compute the needed indicators of the dashboard.

4.3. Develop

Within this stage, designers ***develop*** the validated design alternative prototypes to build a dashboard system. By the end of this stage, the dashboard needs to work using real data. To this end, designers need to address different design challenges to shape and put together all the required information on the dashboard (see design challenges in related work). The key is to iterate in parallel using both top-down (user interface) and bottom-up (data, algorithm) to discover unseen constraints and/or and new opportunities early during the development. Javascript frameworks (e.g., React, Angular, Vue) and visualization libraries (e.g., D3js, Vega) can be useful to design interactive dashboards.

Recommendations: At this stage, it may be useful to iterate in parallel from both top-down by abstracting design goals, rationales, and needs into interactive visual encoding, views, pages,

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navigation, and layout to shape the dashboard, also from bottom-up by connecting dashboard with underlying data sources, and implementing the queries, algorithms, and transformations to expose indicators' data to the views of the dashboard. Adding traces loggers can be useful to gather insights into teachers' use of the dashboard (e.g., time spent, clicks). Adding audit loggers can also be useful to gather evidence on bugs and issues that may happen. Then, we need to conduct pilot testing to inspect if visual encodings meet teachers' needs, data, and visual literacy and whether there are other important details to consider. At the end of this stage, as designers, we will be able: to create an explicit description of the evolution of the interface of the dashboard through different iterations made – including iterations caused by constraints and/or and new emerged opportunities, to deploy the final concrete dashboard in real-world settings, and to create the final design rationales and needs as co-products of the dashboard.

4.4. Evaluate

At this stage, the goal is to ***evaluate*** the dashboard in teachers' context so that they can use it to inform their pedagogical practices. Evaluation often concerns larger-scale deployment and issues, and new needs will emerge. It may be useful to have a protocol of how to iterate on the dashboard during the period of the field deployment. Interestingly, at this stage, we loop back to the ***situate*** stage with the aim to understand the interplay between teachers and the newly designed dashboard considering all the phenomena (e.g., activities, tasks, motivations, pain-points) and entities (e.g., students, parents, home) to collect different source of evidence and learn insights about teachers' data-informed practices using the dashboard.

Recommendations: At this stage, we need to deploy the dashboard for teachers in real-world settings. We iterate first with pilot testings to inspect that the dashboard is working as expected and that the logs provide the needed insights into teachers' use of the dashboard. As this stage involves more teachers with diverse data, visual, and analytic literacy, it may be useful to inspect usability, aesthetics, and scalability issues as well as new needs that may emerge. At the end of this stage, we need be able to build an explicit description of teachers' overall use, experience, perception, pain-points, and suggestions as well as an explicit description of how the dashboard informed teachers' pedagogical practice (e.g. monitoring students, planning instructions, conducting lessons, providing debriefs, making sense of data, self-reflection).

5. ILLUSTRATIVE CASE STUDIES

5.1. Case Study 1

Ez-zaouia and Lavoué (2017) presented a teacher dashboard for the visualization of multi-modal students' emotions (Ez-zaouia and Lavoué, 2017). They propose an approach to use cloud APIs for emotion recognition to infer students' emotions in online learning environments. They demonstrated their approach using a videoconferencing tool for foreign language training. Using audio and video streams they infered automated emotions along with students' self-reported emotions. The dashboard presents a set of visualizations of students' discrete, dimensional and self-reported emotions.

The authors stated an interesting research question: "How can learners' inferred emotions be visualized by tutors to facilitate actionable feedback?". Using "how," we think that some qualitative work will be made to situate the problem and drive teachers' needs, before iterating, on ideas to

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uncover a solution. Instead, the authors select three data sources to infer emotions from, and they set four design principles for the dashboard. That is, the paper did not tackle the first two stages, situate and ideate, to motivate design rationales and goals concerning teachers' needs. However, the paper shines very well in the third stage (develop). The paper reports on the underlying architecture of the dashboard, an explicit description of data abstraction, and an extensive data analysis and transformations to drive the indicators of the dashboard. The paper also reports well on the visual abstraction (or encoding) for all the visualizations of the dashboard. For example, describing that they used a bubble and star as markers for discrete and dimensional emotion, and the size of both bubbles and stars is mapped to a derived score of emotions. However, task abstraction is not addressed. The authors conducted a pilot study using a questionnaire with two teachers. Finally, the dashboard was not deployed in real-world settings for evaluation.

5.2. Case Study 2

Ruiz et al. (2016) presented both students and teacher dashboard for the visualization of students' emotions (Ruiz et al., 2016). They propose an approach to use self-reported emotions to infer students' emotions in online learning environments. They first used google docs to validate both a questionnaire and prototypes of visualizations. Then they integrated the questionnaire and visualizations in a tool used by students. Students are then asked to fill the questionnaire before and after the class by reflecting on their emotions. Students' responses to the questionnaire are used to feed the visualizations, which students and teacher have access to.

The authors stated an interesting research question: "How can students' emotions be visualized to promote self-reflection?". Here also we find no qualitative work made to situate the problem and drive students and teachers needs in terms of what are the appropriate ways to enable students to express their emotions (e.g., questions, emojis, text, drawings, photos), and the appropriate ways to reflect back such information to students and teachers to enable self-reflection. In the develop stage, the paper reports very well on the visual abstraction, stating for instance that stacked bars are mapped to the average rating of every student's emotion for all sessions versus the average ratings of the group. However, data and task abstractions are not addressed in the paper. The authors conducted different iterations on the design of the dashboard before being integrated into a learning application called PresenceClick, but without end-user-driven justifications. The paper excels in the evaluation stage; the authors deployed the dashboard for students and teachers in real-world settings evaluating the usability, usefulness, and impact of the dashboard on mainly, students' motivation using logs and satisfaction questionnaires.

5.3. Case Study 3

Fu et al. (2017) presented both students and teacher a dashboard for the visualization of students' difficulties and differences while learning the C programming language in the classroom. They propose an approach to collect students' learning logs from a learning tool called BookLooper to feed the dashboard, which was integrated (as a plugin) into Moodle.

The paper reports on the develop stage describing in great detail the data abstraction, but not tasks nor the transformations to drive the indicators of nine sophisticated visualizations that shape the dashboard. The authors reported on the visual abstraction, for example, regarding a heatmap, they stated that the color of the cells encodes the number of times students try to compile C programs. However, justification of the choices made regarding all the visualizations are subjective to authors

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themselves (e.g., "With this heat-map chart, we can easily detect the activity and inactivity of students"). That is, the three other stages, situate to understand teachers' and students' problems and gather evidence about their needs, ideate to uncover the solution that meets the needs, then evaluate are not tackled by the paper.

5.4. Case Study 4

Gruzd and Conroy (2018) presented a dashboard for the visualization of students' interactions with learning materials resources and their fellow students in the class. They propose an approach to collect logs about students' discussions on Twitter, which is used by instructors for both formal and informal teaching.

The authors stated a research question to address by the design: "What analytical techniques would instructors like to see in a LA dashboard to support their assessment of Twitter facilitated discussions?". In fact, in the situate stage, they used both qualitative and qualitative evidence to understand instructors' needs using a survey administrated to 54 higher education instructors. Then, the authors analyzed instructors' responses to extract needs, which they then used to inform the design of the visualizations of a prototype dashboard. The authors reported on the visual encoding and few rationales behind their choice based on both related work and evidence from the questionnaire. However, there was no ideation to explore the space of possibilities and alternatives. Similarly, the authors did not report on the data and tasks abstractions nor tackled the develop and the evaluate stages.

5.5. Case Study 5

Holstein, Hong, et al. (2018) presented a virtual reality glasses dashboard for the visualization of real-time student performance indicators using an intelligent tutoring system in the classroom. In the situate stage, the authors based their work design findings from a previous work they have conducted to gather teachers' needs where teachers converged towards the idea of using eyeglasses giving them access to different indicators about students' performance indicators. During the ideation stage, they first conducted an in-lab storyboarding, brainstorming, and lo-fi prototyping with three teachers using papers-sketches, photoshop, and a combination of plastic eyeglasses and images on a computer to simulate the classroom. The first lo-fi prototyping session revealed that it was difficult for the teacher to embrace an actual class using mixed-reality glasses. In the next sessions, the authors used real smart glasses. After, the authors moved to mid-fi prototyping. Next, the authors used contextual design and affinity diagramming by analyzing interviews and think-aloud sessions data to extract an explicit list of design rationales. The authors did not report on the data and task abstractions nor the visual encoding or design alternatives of the views of the dashboard. In the develop stage, the authors designed a hi-fi prototype that was used to conduct 10 sessions with teachers in simulated classrooms where the authors iterated on the design based on teachers' feedback. The tool was deployed during a single session for a pilot evaluation.

6. DISCUSSION AND DESIGN IMPLICATIONS

6.1. Reflecting on the Process Model

Our model does not attempt to be a full teacher inclusive design process. Several steps can be assessed thought pilot testing before validation with teachers. However, we believe that the situate

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stage is crucial to engage with teachers to understand their problems, contexts, needs, goals, values, and suggestions. Our work by no means attempts to propose a unique design process model for teachers' dashboards. Instead, we aim to articulate a process model to help inform and structure the design for teachers as a design process. Given the impact that a dashboard might have, not only on teachers, but also on students, parents, and other stakeholders, we argue that models that are more specific need to be proposed, implemented and tested.

Current literature of learning analytics dashboards (Bodily et al., 2018; Schwendimann et al., 2017) conveys the results of proceeding directly to the develop stage without much characterization of the interplay between a teacher and a dashboard in real-world settings. We echo that this field will benefit as much as from experiences in characterizing teachers' routines, practices, and particular types of problems they face and how data and dashboards can address them. Our case studies show that dashboards do not build upon explicit tasks nor design goal abstractions. Lack of such abstractions makes it difficult to conduct systematic performance evaluations among different dashboards (Schwendimann et al., 2017). This highlights a need for more focused design-based models and principles to guide dashboards' design, analysis, and validation.

Our process model sits between an analysis model and a systematic design process. We describe four stages of designing teachers' dashboards with steps and recommendations within each stage. We do not aim at providing fully structured (holistic) directives to design a dashboard. Instead, we aim at a flexible model of how to explore, refine, make and report on artifacts in design and use of teachers' dashboards, thus supporting designers to appropriate (Dourish, 2003) the four stages of our model as building design-blocks to devise and scaffold their process regarding their own needs, contexts, and constraints.

6.2. Designing for and with Teachers

Reflecting on our personal experience, we echo four implications of our model in designing for teachers. Although there is a similarity between these four challenges, they are neither completely independent nor equivalent. Their main distinction lays in the stage where they unfold, so we must consider them separately.

Design for Diverse and Situated Needs. Designers for professionals count on a consensus in users' needs when framing domain space, and abstracting it into an interface. However, teachers have a complex and changing context, different workflows and practices. They have different interests in using a dashboard to achieve different outcomes, which may be challenging to address through a fixed design (Sarikaya et al., 2018; Schwendimann et al., 2017).

Design for Different Data, Visual and Analytic Literacy. Designers for professionals build upon a homogeneity among users' visual literacy. However, such homogeneity is scarce among teachers, and they have different visual and analytic literacy, which need to be addressed using tailored representations (Sarikaya et al., 2018). We have been amazed to know that some teachers rely on their colleagues to manage tools to inform their practices. Others recommended sophisticated interactions such as sort, hide, resize from tools like a spreadsheet (Barbara Wasson, 2015).

Design for Robustness. Professionals can adjust to perform the task with the interface at hand. However, Teachers have very limited resilience to new interfaces, especially if they find it incomplete for their own needs, their way of doing things, and their familiarity with other interfaces.

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Design for Attractiveness. Professionals are intrinsically motivated to use dashboards to perform their work. Teachers attempt to prefer instruction over formative assessment. Some might think that spending an hour on a dashboard to formally inform their practices is an hour wasted where they could be instructing students. Addressing both usability and aesthetic (J. Hartmann et al., 2007) will support teachers' adoption of the dashboard.

6.3. Towards Transparent Teachers' Dashboards

Although dashboards may have a beneficial story to positively empower teachers, they entail different challenges distinguishing between: social, cognitive, and technical. First, dashboards by their nature aim at capturing, summarizing, and presenting a set of measurable indicators. However, other important metrics are often omitted during both the design and evaluation of dashboards, which can be done on purpose, as such metrics are hard to quantify, e.g., teachers' experience, perception, pain-points, and frustrations using dashboards. We suggest that dashboards for teachers are deeply embodied in rich and diverse socio-cultural practices that although hard to observe, quantify and integrate, might provide valuable insights to inform the design and evaluation of dashboards, to best support teachers.

Similarly, teachers' reliance on and trust in dashboards are important factors to quantify. This is important as (black-box) AI or machine learning now powers several learning dashboards, where uncertain or even inaccurate inferences can be made, which may lead to inappropriate interpretations. Besides, teachers are often confronted with the black box and sophisticated nature of dashboards, and the associated learning platforms, which may hamper their trust in dashboards. Although, how to best design dashboards to assist teachers in developing informed strategies so that such systems empower their judgment in context and in a way to hinder over-reliance, and foster trust in the long term is still to be explored. Additionally, dashboards build upon the notion of data collection, processing, sampling, and selection of a subset of metrics to visualize to inform the audience. Even when this process is properly conducted to compute accurate information, metrics on dashboards can be misinterpreted by teachers (Barbara Wasson, 2015), for instance, depending on their data, visual, and analytic literacy. Besides, the process itself might lead to losing the variation of data through summarization, or even reducing the quality of data, in both cases the interpretation of a dashboard may lead to inappropriate decisions and biases. Finally, dashboards rely on collecting, storing, and processing data. Surprisingly, ethics and privacy was not a major concern of many dashboards papers that we surveyed, except two papers that explicitly highlighted ethical concerns regarding learners' tracking (Ruiz et al., 2016) and transparency of the underlying technology of learning analytics (Aslan et al., 2019), and both papers were dealing with emotional information tracking. Ethics and privacy concerns should be addressed to provide enough information, to different stakeholders, regarding the collection, use, and design of data in dashboards.

6.4. Towards Explainable Roles of Teachers' Dashboards

We articulate five roles of dashboards with some underlying design considerations (DC). We aim therefore at abstracting dashboards' ill-defined (complex) goals (e.g., "monitoring", "exploration"), into low-level tasks (e.g., "validate indicators", "discover insights"), then into explicit considerations (DC), to guide designers in leveraging the desired information (e.g., indicators), while considering the task and purpose of each view on the dashboard.

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Monitoring – Validate Indicators. Monitoring dashboards require close attention from the target audience to validate indicators related to data. Thus, their design needs to (DC1) allow a user to keep an eye on events that are in constant change, using (DC2) a reasonable data refresh rate, and (DC3) providing formative, quality, and safety ensuring metrics. Additionally, the design need to (DC4) grab users' attention immediately if any monitored indicators become invalidated, and (DC5) allow users to take immediate action.

Exploration – Discover Insights. Exploratory dashboards require direct manipulation and sense-making from the target audience to discover insights about data. Thus, their design needs to (DC1) provide different perspectives of data often using different views, (DC2) allows a user to manipulate and change different parameters related to data and (DC3) switch between different views. Finally, the design need to (DC4) allows a user to generate, ask, and interpret different questions about the data.

Presentation – Confirm Facts. Presentative dashboards require a glance view from the target audience to confirm (specific) facts about data. Their design needs to (DC1) be explanatory to educate and/or inform a user, (DC2) be augmented through annotations to create a long-lasting impression, and (DC3) enable memorability, engagement, and learnability. Further, the design is (DC4) often specific and compact rather than general and scalable (Kosara, 2016).

Communication – Convey Messages. Communicative dashboards require a glance view from a target audience, but in contrast to presentation techniques, the aim is to convey (multifaceted) messages rather than presenting a set of information. Thus, their design needs to (DC1) often address to a wide range audience with different (or even low) visual literacy and hence (DC2) build upon an ill characterization of the audience. Additionally, the design needs to (DC3) uses different embellishments in charts using domain-specific knowledge and metaphor to communicate the message while (DC4) avoiding distraction from the pure visual representations of data (Skau et al., 2015; Parsons, 2018).

Storytelling – Persuade Users. Storytelling dashboards require a glance view from the target audience, but in contrast to both presentation and communication techniques, the aim is to persuade users of some facts through data. Thus, their design needs to (DC1) help the user reason about those facts by providing arguments, (DC2) use specific interactions to sequence those arguments. Additionally, the design need to (DC3) combines data-driven indicators with textual contexts in a narrative way to create and tell a story (Segel and Heer, 2010; Echeverria et al., 2018).

These techniques, however, are neither completely independent nor equivalent nor mutually exclusive. Designers need to appropriate all of them to address different needs and visual literacy. Thus, understanding the strengths and weaknesses of each technique will help choose, combine and augment these techniques to craft a dashboard. For instance, connected scatter plot, cloud-words, sankey, stream graph, treemap, bubble-chart are some graphics that are known to work well for presentation (Kosara, 2016). Similarly, isotype, domain-specific graphics, glyphs, and more general metaphors are known to work well for communication (Skau et al., 2015). However, techniques such as presentation or communication might not be appropriate for exploration where the purpose is to support sense-making.

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7. LIMITATIONS AND FUTURE WORK

The main limitation of the current work is the lack of "active" empirical evidence by applying the model to a concrete dashboard design to illustrate and support its validity. While applying the model to research from literature provides an initial validity of the model, we hope to take it to implementation and research to design, analyze, and validate dashboards in future work.

8. CONCLUSION

In this paper, we presented a process model for teacher-centered dashboards design. We articulated our model by reflecting on our personal experiences along with an expanded literature review from LAK, TEL, InfoVis, and HCI research. Our model articulates four mutually informed stages: situate, ideate, develop, and evaluate. We demonstrated our model through five case studies from the literature. We found that our model can provide a framework to structure dashboards' design process, mutually inform underlying stages, guide consolidate, and report on artifacts along the way. We provide design implications to support teachers' dashboards design. We hope our work provides a new perspective on teachers' design, highlights its value and research.

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