

Design and CoDesign of Learning Analytics Dashboards

...

1. Introduction

Learning analytics dashboards are designed to use learners' traces to present the computed indicators and other visual elements in a clear and intuitive way [11]. They have emerged as applications for visualizing and interacting with data collected in a learning environment in various forms [43]. Steiner et al. [54] referred to them as "visualizations of learning traces". For Yoo et al. [64], a learning dashboard is "a display which visualizes the results of educational data mining in a useful way". Schwendimann et al. [50] identified a lack of an agreed and shared definition and thus proposed the following:

"A learning dashboard is a single display that aggregates different indicators about learner(s), learning process(es) and/or learning context(s) into one or multiple visualizations. " [50]

Learning dashboards provide interactive, historical, customized and analytical displays that are based on the results of analyzing learning data [41, 32]. By implementing visual and interactive analytics, they amplify human natural abilities to detect patterns, establish connections and make inferences. The produced visual outputs can significantly highlight aspects of interest from the mined and discovered knowledge [20].

Learning dashboards are suitable for online, face-to-face, and blended learning [57]. They can target different stakeholders: administrators, instructors, learners or all of them. Within a single display, indicators and visualizations about learners, learning processes and contexts are rendered using different shapes, from plain text to visual elements (e.g., tables, spreadsheet charts, scatterplot, 3D representations) to complex

artifacts such as alerts and notifications that prompt interventions [23, 42, 50]. Currently, they are increasingly deployed as a meaningful component in learning analysis systems. For instance, they are currently used in studying progression through courses [39], learners level of attainment [27], and learners’ engagement from the cognitive and behavioral perspectives [13]. Despite being fairly recent educational tools, the research found many benefits of using learning dashboards to improve learning performance [3] and to increase learners’ motivation [57, 61].

...

According to Bennett and Folley [7], we can distinguish three types of learner dashboards: predictive, modeler and descriptive.

- Predictive types use machine learning based on computer algorithms that rely on a series of trace data to predict the likelihood that the students outcomes. Many works in this category (i.e, [4]) use these algorithms to produce at risk rating for individual students.
- For example, aspects of a student’s online behaviors such as communication, initiative, presence that have been derived from the number of messages, the number of comments in response to others’ messages, time spent online, etc., are not included in this section.
- The third type of dashboard is descriptive and displays past learning behaviors

2. Issues in current LA design approaches

The design and evaluation of learning dashboards is a major area of inquiry in learning analytics research. There is a growing body of literature on learner dashboard design. A comprehensive literature review by Bodily and Verbert [9] involved identifying and analyzing 93 papers with respect to functionality, data sources, design analysis, student perceptions, and measured effects. They found that the clear majority of the papers focused on technical features such as data sources, functional aspects (e.g., visualization data, what the dashboard was intended to do) while only two papers

reported on how students' behaviors were changed as a result of using the Learner Dashboards and only one-third (34 of 93) focused on students' perceptions of the design.

2.1. General design principles

Due to the recent emergence of learning analytics dashboards, there is still a scarcity of studies on their design principles [21]. Yoo et al. [64] argued that, since dashboards are an instrument of communication, effective design is tied to several theoretical foundations, such as human cognition and perception, situational awareness and visualization technologies. In other words, their conceptualization must be based on an understanding of how humans see and think.

Based on a number of theoretical principles in addition to his practical experience, Few [24] outlined some good and bad examples of dashboard design. He claimed that the essential characteristics of a dashboard are: 1) to be visual displays; 2) to display the information needed to achieve specific objectives, 3) to fit on a single computer screen, and 4) to be used to monitor information at a glance. In terms of human perception, due to the limited working memory of humans, only three or four pieces of visual information can be stored at a time. Therefore, for more effective memory perception and retention, it is essential to incorporate graphic patterns such as graphs rather than individual numbers. In addition, there must be a proper and reasoned use of pre-attentive attributes such as colour, shape, spatial position and movement. From Few's principles, Yoo et al. [64] drew three main implications:

1. the most important information should stand out from the rest in a dashboard, which usually has limited space to fit into a single screen;
2. the information in a dashboard should support one's situated awareness and help rapid perception using diverse visualization technologies; and
3. the information should be deployed in a way that makes sense, and elements of information should support viewers' immediate goal and end goal for decision making.

Situational awareness deals with disclosing the type of information that is important

for a particular purpose or task [22], and thus constitutes another design principle related to dashboards. Three levels can be distinguished:

1. perception of the elements in the environment;
2. comprehension of the current situation; and
3. projection of future status.

Situational awareness is commonly understood in terms of people being consistently aware of what is going on, in order to predict what will be happening as well as to prepare what must be done.

2.2. Limitation of the existing dashboards design approaches

2.2.1. Lack of theoretically informed design

One obstacle to the adoption of dashboards is the often existing gap between visual analyses and the objectives of the study [46]. Sometimes, to represent the analyzed data from different angles, designers use complex representations and visualizations that are rather difficult for end users to interpret, especially "at a glance" [20]. According to the survey reported in [44], the existing dashboards generally have poor interface design and lack of usability testing. The selection of data to be visualized is generally not what the stakeholders in the analysis want or really need because they have not regularly been involved in the design process [29]. Bodily and Verbert [8] also noted the absence of design choice justifications in the conception of several learning dashboards.

A primary concern of dashboard designers must be the identification of what type of visual representations to implement, and what kind of interaction to offer. Gašević et al. [26] argue that, without careful considerations, the design of dashboards can result in the implementation of fragile and undesirable instructional practices by promoting ineffective feedback types and methods. In order to encourage adoption of learning dashboards, the design needs to be further informed by theories related to learning sciences and educational psychology. Holstein et al. [29] argued that the success of the dashboards depends on the degree to which its stakeholders have been involved in co-designing them.

2.2.2. Selection of the input data and the computed indicators

A rich variety of measured data and indicators are used and computed in existing dashboards. Dashboard solutions are heavily based on trace analysis, and little attention has been paid to use other data sources such as direct feedback or the quality of the produced artifacts. Moreover, as noted by Schwendimann et al. [50], there is little work on comparing which indicators and which visualizations are most suitable for the different user data literacy levels. In most cases, the chosen visualizations are rather similar to those in other areas of dashboard applications (e.g., web analytics), which highlights the lack of specific visualizations and visual metaphors that address the activities of learning and teaching (another potential area for future research) [50].

2.2.3. Learners' aptitudes are not considered

The review of Schwendimann et al. [50] revealed that current focus hugely falls on the information that can be extracted from the log data rather than how individual differences might affect the interpretation of the information presented to the learner in terms of reflection and taking actions [26].

Studies undertaken by Bodily and Verbert [9] and Viberg, Hatakka, Bälter, and Mavroudi [58] also point to the need to understand users' views of dashboards qualitatively and in use rather than as technical artefacts. This conception foregrounds the purpose of the tool in that it considers how students make use of information presented via the dashboard and how it might change their behavior as a result. Dashboard conception needs also to focus attention on the perspective of the user, the learner, and on the purpose of dashboards as tools that provide feedback to students to encourage them to make more informed decisions about their study behaviors Howell, Roberts, and Mancini [31], Bennett and Folley [7].

2.3. Need to involve dashboard stakeholder in the design process

While the primary purpose of AL tools is to promote learning, there is a risk that these tools impose a number of assumptions that do not necessarily meet the students' or educators' needs [16]. One main reason identified by many authors (e.g. [12]) is the lack of active stakeholder collaboration in the process of design of these tools.

According to Beattie et al. [6], failure to involve learners and educators in the decision-making process can hinder the adoption and acceptance of LA innovations. For instance, many authors point out that monitoring and analysis tools may be considered a risk by learners who may perceive that they no longer have the freedom to influence their learning environment and follow their own learning strategies.

3. CoDesign of learning analytics dashboard

3.1. *Designing with stakeholders*

The goal of designing data visualizations is to empower users to better understand the data presented by the visualization, so the user must be kept in mind when designing data visualizations. Two concepts are relevant in this context: human-centered design and user-centered design :

- *Human-centered design* focuses on creating systems that are easier to use by taking human factors into account.
- *User-centered design* involves users in the design process where design development is influenced by end-users. Model-based, story-based and scenario-based design are examples of user-centered design methodologies.

For Vilpola [59], user-centered design is an an imperative part of creating products that ensures usefulness to users, and that allows creation of systems that fulfill users requirements. The authors highlight four principles of user-centered design: (1) user is actively involved; (2) user’s tasks and technological function must be distinguished; (3) the design should be iterative; and (4) the design should be multidisciplinary. Vredenberg et al. [60], while recognizing that user-centered design improves product usefulness and usability, pointed out a lack of effectiveness measures to evaluate the success of a user-centered design effort.

3.1.1. *Participatory design*

The emergence of participatory design, according to Bannon et al. [5], was motivated by the need to involve users in the process of design, and to help mitigate

situations of divergent ideas through democratic decision-making processes. Participatory design allows the involvement of the users of the system in the design process and gives stakeholders the opportunity to learn more about other stakeholders' views [56]. Often participatory design is referred to in discussions of user-centered design, so the difference between user-centered design and participatory design has become quite unclear [5]. Yet, participatory design is sometimes discussed alongside user-centered design, as a user-centered approach [34].

Dearnley and Mayhew [17] identified two main reasons why participation in design emerged: firstly, as a means of mitigating the problem of conventional approaches that do not work; and secondly, because of ethical issues, claiming that end-users should have some influence over the environment in which they work.

Arguing that the design paradigm of participatory design is constructivism, Spinuzzi [53] assumes that knowledge exists in a certain context, not just in a person's mind. The author identified three stages of participatory design research: initial exploration of work, discovery processes and prototyping.

- *Initial exploration of work*: this is the stage where users and designers meet to become familiar with how users work with each other. The used research methods are ethnographics and include observations, interviews and visits to the organization.
- *Discovery processes*: during this stage, the design stakeholders use different techniques to improve their understanding, prioritize the organization of work, and construct a future vision for the workplace. The used methods include organizational games, role-play games, organizational toolkits, future workshops, storyboarding, and workflow models and interpretation sessions.
- *Prototyping*: Here, users and designers form technological artifacts in an iterative manner, to fit into the future vision created in the second stage. This is achieved using different methods including mock-ups, paper prototyping, and cooperative prototyping.

3.1.2. Co-design

Co-design derived from user-centered design as a particular case of co-creation where designers who are trained in creativity work together with non-designers during the design process. [47] define it as a process where designers and non-designers work together creatively ideally in all stages of design. A main claim of codesign is that it remedies design’s conventional exclusion of people from design outcomes that affect them [55].

[52] describes the co-design process as a facilitator that directs the level of end-user awareness of design choices, providing professional advice and guidance on the consequences of alternative choices while end-users provide advice and contribute to the contextual experience. Research suggests that including end-users in the design process ensures appropriate design responses that are aligned with end-user requirements [55].

To glean as much information as possible about the context and needs of users, a common strategy is to use participatory design techniques where end-users are directly invited to participate in the design process. Participatory Design for Learning is a growing field with its own history, philosophies, and body of techniques and methods [18]. In practical terms, the LA researchers used a subset of techniques such as pre-interviewing end-users about their needs to derive design ideas [62], employing practitioner-partners as informant designers who give feedback on designs [25], and engaging teachers throughout the prototyping process itself to create classroom analytics [30].

Different methods and techniques are being used to apply participatory design. The most popular include brainstorming exercises, card sorting, group affinity diagramming, rapid paper prototyping, wireframe walkthroughs, preferences testing [1].

3.2. Human-centered design approach in LAD

3.2.1. Emergence of HCD for LAD

Within the learning analytics community, designers and researchers are increasingly turning to human-centered design methods to adopt practical design techniques and knowledge to explore the design cycle of a learning analysis project. In the cur-

rent literature on learning analysis, there are calls for theory-based and participatory approaches. Alhadad [2] noted that data visualization design should be grounded in theories of cognitive learning. For example, attention to issues of cognitive loading, attention, human perception and data literacy has direct design implications, such as avoiding visual clutter and breaking down data into segments that can be interpreted on the screen. This perspective is consistent with what data visualization researchers understand to be visual coding and interaction design decisions [38], where choices regarding graphic types, interface components such as text and placement of visual markers, and interactive elements align with what is known about cognition and perception. However, as noted by Dollinger and Lodge [19], learning analytics researchers often work in applied contexts with real educators and educational settings, where it quickly becomes apparent that interface-level design decisions alone are not sufficient to productively promote effective use of visual dashboards.

3.2.2. *CoDesign approaches of LADs*

In educational settings, designers and developers commonly rely on teams of visual designers, business specialists and educational theorists who produce educational innovations (Herold, 2015). I McColl-Kennedy, Vargo, Dagger, Sweeney, and Kasteren [37] define cocreation, or codesign, as *the benefits realized from the integration of resources through activities and interactions with collaborators*. historical, it is thus originally a marketing and management strategy, incorporating stakeholder and user resources into the design, process and analysis of services, breaking down the traditional boundaries between producers and users. Co-creation can benefit the current design of learning analytics in several key ways.

The benefits of co-designing a dashboard with the collaboration of multiple stakeholders with diverse perspectives are numerous. A dashboard design team should include education administrators, technology experts, data managers and, most importantly, learners. A co-design approach encourages alignment among multiple stakeholders with the purpose and main goal of the dashboard, and ensures consistent implementation by anticipating obstacles or potential difficulties in adopting the system,

and increases innovation capacity and efficiency Boscardin et al. [10]. A participatory approach also facilitates opportunities for consensus building and the creation of shared mental models for key learner outcomes, as well as the appropriate interpretation and use of evaluation data by multiple stakeholders. As pointed out by Schuler and Namioka [49], a co-design approach reflects a participatory design movement that emphasizes mutual learning, with users learning about the opportunities and constraints of the technology while designers learn about user practices and perspectives.

3.3. Recent related work

4. Paddle: Participatory Design of Learning Analytics Dashboards

4.1. Rationale and requirements

4.1.1. An iterative refinement process

We have conducted an iterative process to develop our needs-capture method. First we carried out a study to assess needs based on questionnaires and semi-directive interviews, and then, after evaluating the findings of this first study, we organized a participatory workshop with the stakeholders.

Phase 1: Questionnaires and interviews. We carried out a study to assess the capture needs based on questionnaires and semi-directive interviews with stakeholders from 8 case studies out of the 13 identified by the Hubble project [15]. The objective was to develop an explicit understanding of the users' context, tasks, needs and environments in order to enable the dynamic generation of dashboards. This study included a survey and semi-structured interviews.

We adopt the framework proposed by Chatti et al. [14], which identifies four questions around the analysis of learning data. We supplement these questions with a fifth one, "When", which we felt was important for participants to better understand their interactions with learning dashboards. We thus list five questions where each refers to a contextual dimension "Who, why, what, how, when".

"Who" dimension dimension makes it possible to specify the users and their roles.

”Why” dimension concerns the identification of users’ objectives. In other words, it is used to identify why it is important for the user to use a learning dashboard.

”What” dimension is devoted to identifying the context of the observation objective and the indicators that users wish to visualize in order to improve their learning process.

”How” dimension concerns the description of the most appropriate way (i.e. the most comprehensible by the user) to visualize the indicators. This dimension highlights the notion of user preferences in terms of visualization to facilitate the interpretation of these indicators.

”When” dimension makes it possible to specify how the dashboard should be used.

After this initial study, we realized that users find it difficult to clearly express their needs through simple questioning. Potential users have significant difficulty projecting themselves into use (when interviewing designers of indicators) or picturing what is possible (when interviewing teachers who often have little culture regarding the use of digital data). Therefore, as a second step, we decided to conduct a participatory workshop.

Phase 2: Participatory workshop. We conducted this second study with 8 primary and secondary school teachers who share the same objective of monitoring their students’ activities. Teachers use the Tactileo Map [13] application available on the tablet that was created to guide students during a field trip. This tablet provides various tools for students such as a notepad, a camera, an audio recorder and allows to collect traces of their use. This workshop was delivered in an open manner, without tools other than paper and whiteboards. It was followed by a wireframe stage and the development of a model.

During this workshop, the wide range of needs, contexts of use and preferences led to a diversity of proposals that were difficult to formalize. To go further, an adapted tool was therefore necessary.

4.1.2. A Design Thinking approach

Design Thinking is a way of embedding the notion of iterative design into the design process. Coming up with ideas, building and testing in a short period of time is what Design Thinking brings to the table in comparison to other iterative processes (Ellingsen, 2016). In terms of innovation through iterations, Design Thinking specifies three main stages (Koh, Chai, Wong, Hong, 2015): understanding, creation and delivery (see inner square in Figure 1). The iterative process starts with creating empathy and defining goals/expectations from stakeholders. This first part of the process can be exploratory and in some cases may set the tone of the project for the next stages (IDEO, 2016).

4.1.3. Participatory design approach

In order to be able to collect user needs in terms of dashboard usage, we have to overcome several difficulties:

1. Because users are not familiar with the use of dashboards, they have difficulty expressing their visualization needs. As in Xhakaj et al. [63], we consider that the decisional expression linked to the dashboard is structuring for its design.
2. Users have little knowledge of the existing opportunities provided either directly by certain tools or through the indicators proposed by the research. In other words, it is difficult to link user demand with research supply. We consider that an initial step is to build on current practices and therefore to allow users to express themselves.
3. The context in which the dashboard is used impacts its organizational structure. Therefore, it is necessary to be able to explicitly explain this context, both to help users think about it and to capitalize on these usages for the purposes of reuse.

Participatory design methods are still not widely used in the field of learning analysis [1]. Yet they allow for a better expression of user needs and the exploration of design alternatives. Mackay and Fayard [36] qualify the use of technologies in this context as "co-adaptive" in the sense that design and use are transformed simultaneously. Knibbe

[33] also emphasizes the learning dimension for participants in this type of design, and consequently its impact as a process of appropriation of digital tools by teachers.

To be effective, a participatory design method needs to be properly instrumented [48]. We have therefore selected a series of tools to help dashboard users to better express their expectations and needs.

According to Lucero et al. [35], the use of maps can strengthen collaboration, reinforce combinatorial design, and facilitate the exploration of possible linkages between users' decision needs and the numerous proposals for indicators and displays available in design workshops. This feature allows us to address the first two challenges identified.

The use of a board to explore and share the options selected at the design stage allows us to meet our need to express the context and capitalize on it [40]. To design their design support tool Hallifax et al. [28] use the notion of design space [51] to identify the different alternatives and the structuring decisions of their design.

As in [45], we seek to combine efficient needs capture tools with a progressive collection of these needs to build and enrich design models. The first phase of the project is to collect requirements and interfaces via paper wireframes to facilitate the production of relevant displays, followed by a proposal of mockups in the form of executable interface mock-ups. We focus here on the collection phase, knowing that the automatic generation of dashboards from a model resulting from the requirements remains our main objective.

4.2. Support for the participatory design of learning analytics dashboard

In this section, we present details of the design space for a learning dashboard. This design space allows us to identify the tools that support the capture of these needs. It also serves as a basis for harnessing the expression of requirements and reference dashboards. The second part of this section is devoted to the actual translation of this framework into an adapted framework.

4.2.1. Design space for learning analytics dashboard

The primary benefit of making a dashboard available to the intended users stems from the need to provide them with data and a representation of this data that is

Dimensions	Elements
Who?	User
Why?	Objective / Decision
	Level of analysis
	Point of interest
	Horizon
What?	Learning Context
	Data
	Data Collection
	Observed tools
How?	Visualization
	Organization
	Shared
When?	Usage
	Observation time

useful and most importantly, meaningful to them. These dashboards must therefore best meet the desired decision-making objectives of the learning process. We conceived our design space around the five dimensions described in 4.1.1. After the preliminary stages of our needs capture process, we have identified several elements that allow us to further characterize these dimensions, listed in 4.2.1.

"Who?" dimension. Answering the question "Who" may not be so straightforward because, depending on the perspective, dashboards can involve several people. However, setting the learning dashboard in relation to a specific user is essential in order to qualify how the proposed observations will be exploited. The different possible roles are known: Teacher, Learner, Tutor, but also administrator, politician, researcher, etc. The definition of this role is obviously fundamental for the exploration of solutions, as in any interface design process.

"Why?" dimension. The aim here is to explain the usefulness of the dashboard and to clarify the purpose of its design. As we stated previously, we finally chose to focus on the decision rather than the need for observation. Following the exchanges gathered

during the interviews, it seemed preferable for users to indicate their intention to use the dashboard rather than directly express what they want to see on it. Within our design space, participants are asked to choose a decision type from those provided by us or define a new type. This choice is pivotal to the entire dashboard design. We have identified 6 decision types related to the field of pedagogy:

Adaptation Adaptation refers to changing a pedagogical sequence or a complete teaching program in response to an observation (factual, following an evaluation, an observation). The teacher remains within the framework of his teaching.

Evaluation Evaluation consists of using the traces and the learning session to assign a mark, to validate skills or to make an assessment.

Evolution Evolution concerns amendments made to a sequence or teaching as part of a reinvestment or renewal for the following session.

Planification Observation is used at this point to reorganize the activities of the current learning situation.

Remediation Remediation is a phase that immediately follows a formative assessment and is designed to help a learner address his or her shortcomings. It is often instantiated by support and personalized assistance in addition to instruction.

Monitoring (tracking) Monitoring refers here to observing actors during their learning session without intervention. These are typically active pedagogy sessions, or projects. Afterwards, the idea is to make a synthesis and/or a feedback to the actors.

"What?" dimension. This dimension specifies the context in which decisions are made, and defines exactly what the decision is being made about. It includes seven elements to qualify what the observation focuses on: the learning context, the level of analysis, the point of interest, the horizon (or term), the data required, the way it is collected and the tools from which it is derived:

Analysis level/scope/peremiter A decision can be made for an individual student, the entire class, or at the school, department (in the geographical sense), academy, or intermediate level.

Point of interest The point of interest qualifies what the observations focus on: the people, their activity, their results, the context, the content, the exchanges.

Horizon The horizon makes it possible to specify in which term the decision action is situated in relation to the observations: short, medium or long term. This information allows us to categorize the dashboards according to strategic, tactical or operational levels [11].

Learning context Observation and decision making can occur in a classroom, online, or outside the classroom. It can also be mixed, combining different contexts: use of online tools in face-to-face teaching, exploration outside the classroom, and in-class use . . . Participants can also specify how learning is organized (individual, group, . . .).

Data Participants clarify the data users need to make their decision. Since each specific dashboard is tied to a specific situation, the participants are free to express their own opinions on the dashboard. These data are expressed in the form of indicators, i.e. resulting from possibly complex processes.

Data collection Depending on the decision-making time and the capacity of the tools, data collection must/can be done synchronously for immediate availability, or on the contrary asynchronously, i.e. the data are available after the learning process. This is identified as a source of discrepancy between the expressed need and the technical possibilities, so it is important to highlight it. The resolution of the discrepancy can then be dealt with as soon as possible.

Observed tools It is necessary to specify which tools are used, either hardware (tablet, smartphone, camera, etc.) or software (Digital Work Environment, MOOC plat-

form, social network, etc.).) during the learning process. These tools typically put constraints on data collection.

"How?" dimension. The "How" corresponds to the most visual part of the space of design, here we are asking participants to consider the two following points view. Firstly, it is important that they specify the most appropriate graphical representation to depict the data they need, they can select from a predefined list of representations or draw their own personal vision of the most suitable graphical representation. Then, they are invited to think about the spatial organization of the dashboard according to the support used (tablet, smartphone, computer, ect.).

"When?" dimension. This dimension aims to capture different aspects of the decision-making process, mainly three aspects: the sharing with other users, the time of use, and the observation time on which the decision is based.

- *Sharing:* The dashboard can be either used personally by a user, or shared between different users for a collective use, for example between a teacher and his students.
- *Usage:* A dashboard may be necessary in real time with respect to the learning situation or a posteriori, depending on the type of decision.
- *Time of observation:* At this point, we want to know over which period of time the observation takes place, is it a day, a semester, a session, a sequence, ... This allows to orient the type of dashboard and to filter the indicators.

4.3. Support for the exploration of the design space

The analysis of the different elements identified to qualify the different domains of the design space, can be broken down into four major types.

1. The decision to be made, which needs to be made explicit and then characterized, and which can be chosen from a set of options from the field of education. Lucero et al. propose the concept of domain inspiration cards to represent these options [35].

2. Elements of characterization around this decision making, which should be made explicit and captured to better characterize the framework of the dashboard. We have therefore chosen to propose a plateau, called a characterization plateau, which allows participants to discuss these elements and then annotate them. The different fields of these elements are recalled in 4.3.
3. Free elements (data) that participants will propose at their discretion and that can be collected by means of small papers. We propose blank colored cards, called measuring cards, so that they can be identified, handled, and combined with the visualization cards.
4. The elements of visualization, i.e. the different data visualization options, are technological choices that participants will be asked to make during the workshop. Lucero et al. propose the concept of technology maps in their "inspiration workshops" [35].
5. The organization element of the different selected visualizations corresponds to a paper prototyping step. We therefore propose a plateau, said prototyping plateau, corresponding to a display screen of a piece of equipment. This template effectively corresponds to the outline defined for a learning dashboard.

Each of these elements provides space for participants to annotate, complete and clarify their intent, with a view to providing maximum openness to participants while focusing them on designing a learning dashboard. First of all, as already mentioned, the central point of the dashboard from the users' point of view is the decision that is easier for them to express than the objective of observation. We have therefore developed several so-called domain maps to identify the decision category (Remediation, Adaptation, Evolution, Evaluation, Monitoring, Planning), but also blank decision maps to let participants suggest other possibilities. These decision cards summarize on the back what the category means and on the front they provide space for participants to elaborate on their decision: Why do they need to make this decision? What actions do they intend to implement? How does it fit into their pedagogy? These are the blue cards visible in the upper left corner of the characterization plateau in 1.

Element	Value	Description
User	free field	Allows to identify the role of the user
Analysis level	Student, Class, School, Department, Academy	Allows to indicate the perimeter of the decision
Point of interest	Person, Activity, Context, Outcome, Content, Social	Allows to indicate on which element the decision should be centered, and thus the dashboard
Horizon	Short, Medium, Long	Specifies when a decision is to be made
Learning context	In class, online, outside	Specifies the organizational context of the observed situation, the choices can be multiple
Data collection	Synchronous, Asynchronous, Tools used in learning	Details the origin of the various data to be taken into account
Observed tools	free field	Characterizes the tools used during the learning process
Shared	Yes, no	Indicates whether the dashboard will be shared and with whom
Usage	Real time, a posteriori	Indicates when the dashboard will be used in relation to the observed situation
Observation time	Free space	Specifies over what duration the situation is observed, it can be a time in hours/minutes or day/month/year, sessions, modules ...

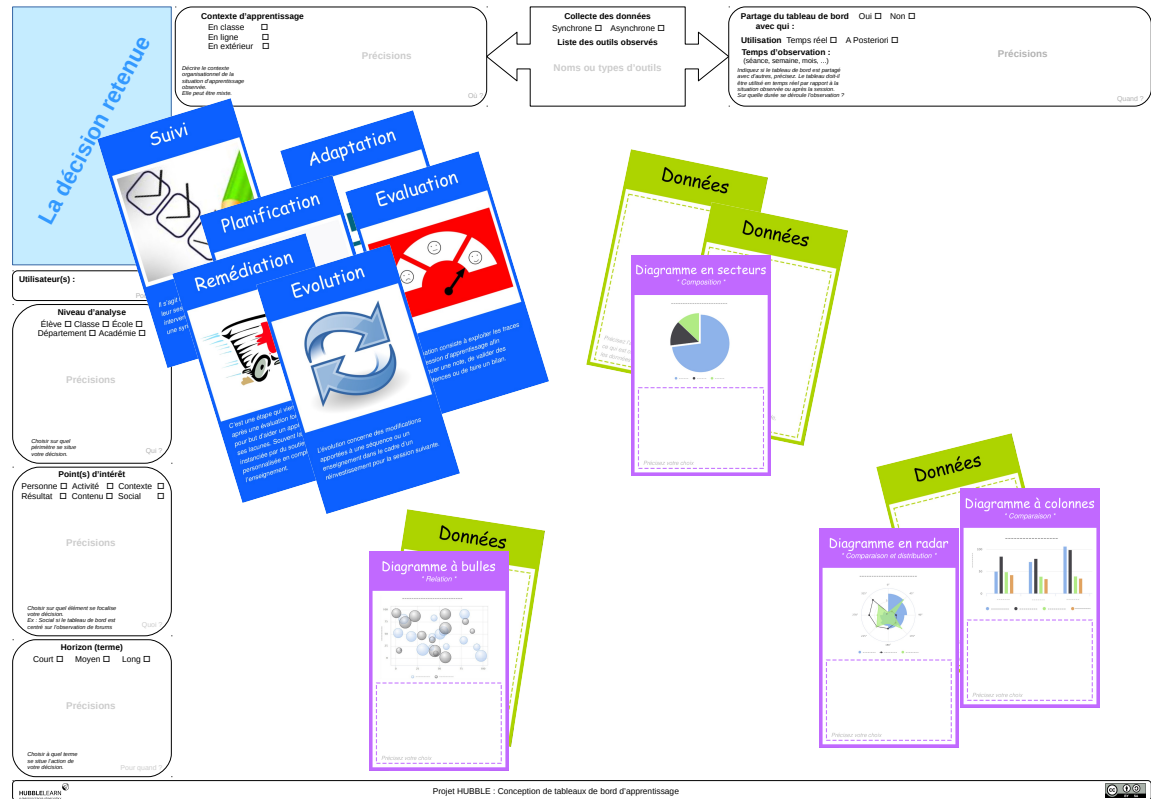


Figure 1: Learning Dashboard Characterization Plateau

On the characterization plateau, the location of the decision map is in the upper left corner so that participants collaborating on the plateau maintain a permanent view of this objective. This position was chosen to highlight the pivotal nature of this dimension. The plateau is then divided into different areas to specify the general context of the dashboard. A place is provided to precise the target user(s) of the dashboard. For each of the zones, the participants have the opportunity to provide details explaining their choices. The lists on the board are not fixed, participants can propose new values.

The purpose of this first plateau is to clarify what the dashboard is, its usefulness and its content. This is why we have left an important place on the plateau for the participants to design their content. They can use two types of cards: the measurement cards and the visualization cards (respe. green and purple cards on figure 1).

- Measurement cards are blank cards in which it is necessary to describe the data that participants want to see in order to make their decision. They are asked to be accurate and to explain the data. For example, "I want to visualize learner engagement in the forum, so I need the number of messages posted and read per learner and per session". These measurement cards will then be associated with one or more visualization cards.
- Visualization cards depict different possibilities for graphically representing the data. For this purpose, participants are given a visual example of the representation, and are asked to indicate the title of their graph, the location of the data to be represented (for example, learners on the x-axis and the number of messages on the y-axis). They also have a space on the map to specify if needed their expectations from this visualization. To stimulate their creativity, we have designed blank visualization cards so that participants can propose their own graphical representation that they can easily understand.

Combining these two types of cards allows to associate elements of the "How" dimension with elements of the "What" dimension in a very flexible way.

For the prototyping, we invite the participants to think about to the formatting of their dashboards. For this, we offer several prototyping plateaus representing different

equipment (web browser, smartphone, tablet). Participants are then asked to place the visualization cards from Step 1 in the locations they feel are most appropriate. They can also add artefacts describing the dashboard functionalities (button, refresh, title, scroll bar, menu, functions: filter, zoom, hide, print, save as image, etc.).

4.4. User workshops

In this section, we describe how to use our tool in a participatory workshop and then provide some initial feedback on its use.

4.4.1. workshop setup

A user workshop consists of 5 steps: introduction, dashboard characterization, dashboard prototyping, presentation, and summary. We adopt the basic process proposed by Lucero, Dalsgaard, Halskov, and Buur [35] and introduce a specific step for the layout of the dashboard.

Introduction. The workshop starts with a presentation of the plateaux and maps (decision, measurement, visualization). Presentations are typically made by a facilitator whose task it is to lead the discussion. The maps can be presented either by the facilitator or by specialists in the field and/or in dashboard design. Participants are divided into teams of 2 to 6 people.

Dashboard characterization. This step refers to the phase of co-creating and combining ideas. Participants are encouraged to specify their need through the first stage (see Figure 1) and the decision map. The discussion can be organized as they wish, but the goal is to fill in the different sections of the plateau. In addition, the participants can define the different measures they wish to have and associate visualization modes to these measures. This combination step represents the crucial part of moving from the expression of the intended decision to the visualization objective. Having cards allows participants to associate several measures with a visualization and to combine several visualizations to make interaction with the measures tangible. In this phase, the facilitator plays an important role in encouraging participants to explore other combinations and to formalize their ideas to the best of their ability. Participants can

write on the plateau their explanations or the justification of their choices, which will help in the creation of the dashboard. The result of this step is twofold : (i) a shared and clear understanding of the needs (ii) a collection of the needs of the dashboard.

Dashboard prototyping. This step is intended for the visual representation of the dashboard, both at the organization and visualization level as well as at the interaction level, using the trays representing a selected piece of equipment. The support provided by a dashboard designer can motivate the participants to develop their projection in this future tool intended for them. This step concludes the phase of convergence towards the expressed need. The result of this step is a first hardcopy prototype established by the participants.

Representation. After the two creation steps, the participants are asked to take the time to consolidate their results and the concepts they have chosen. If several groups are present, the different groups can do a cross-referenced restitution. This step allows a pooling of proposals.

Summary. After the workshop, the proposed new maps and dashboards are collected with three complementary objectives: production, capitalization and evaluation.

- *Production.* This collection allows, through the dashboard generation process, to produce a dashboard matching the expressed needs.
- *Capitalization.* Capitalization covers all the elements proposed during the workshop, to feed the Hubble project's study base in general and the base used to generate learning dashboards in particular. New maps may be produced to complete the tool presented here.
- *Evaluation.* Evaluation of the tool and the workshop process are ensured for improvement.

4.4.2. Initial user feedback

This participatory design tool has been tested in two different contexts. A first test workshop was set up with teachers in computer science OTCs; a presentation and test workshop was proposed during national meetings between researchers and national education supervisory staff. During each of these tests, the conduct of the workshop was observed and filmed, with the agreement of the participants. A satisfaction questionnaire was also used to gather participants' opinions.

4.4.3. Workshop with computer scientists

This first test in an educational context was carried out with two test groups of 4 and 2 teachers in the DUT Informatique. The first group (G1) consisted of a teacher in charge of the pedagogical situation to be observed and 3 colleagues wishing to collaborate on the design of his dashboard. The second group (G2) has a different profile as it consists of 2 teachers involved in the same learning situation with the same students.

Both groups started in the same way to analyze the decision cards in order to select the most appropriate one. The first group came up with several possible decisions and focused on the evaluation as it seemed like a map with a wider scope. The second group went directly to the decision related to monitoring as they were in a tutored project situation with a necessary follow-up for supervision.

Secondly, the two groups took different paths in the conception phase. Group G1 exploited the maps and annotated them. They made numerous hypotheses and produced many data maps, not knowing if all of them would be useful in the end. Group G2 started by thinking about the tool needed for the students to express their progress through the different phases of the project, which is the same as describing the data they need, but they did not use any maps. In the end, they constructed a data grid.

Also, in terms of graphical representation, the G1 group made good use of the maps (see Figure 2). They filtered their dataset to keep only the main points and realized that there were clearly two sets of information corresponding to two types of decisions: remediation and evolution. They therefore reconsidered their first choice of decision. Group G2 took inspiration from the visualization maps to develop a new type

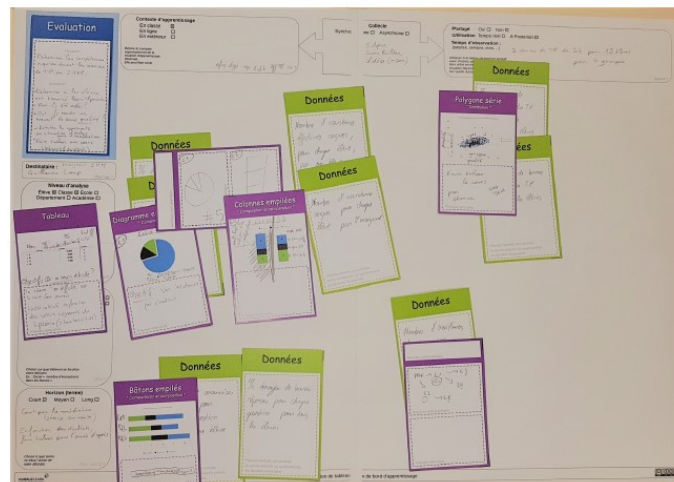


Figure 2: A characterization plateau at the end of the first user workshop

of graphical representation corresponding to a composition of several maps. They then drew the graphic representation they needed.

Finally, on the section related to the design of the dashboard interface, the G2 group was satisfied with its summary graph for monitoring, while the G1 group imagined 2 different and disconnected interfaces, which reflects the fact that decision is a central point and that clarifying it allows participants to organize the dashboard in a different way.

Both groups agree that the proposed materials are pleasant to use, encourage and energize the exchange. The two groups had very different experiences with lively debates, which confirms the quality of the support for creativity. The choice to highlight the decision objective of the dashboard as a pivotal element of the design was effective in allowing participants to focus on an explicit need.

Comparing with the workshops held previously, especially the workshop with Tactileo Map teachers, we notice a saving of time, a better productivity and an intensification of exchanges. Indeed, during our first study, we had grouped the teachers in teams of two and we had to play an important role as facilitators. We had to question the teachers and push them to think. This took them out of their comfort zone and produced interesting results, but the full-day session was challenging. Thanks to our design spaces, this new session was reduced to two and a half hours, the exchanges were more natural and our role was reduced to observation as well as answering a few comprehension questions. Moreover, during the first session, we had only obtained a description of the learning situation, a list of data and some means of representation. In this workshop, we also obtained the information related to the decision as well as the dashboard interface mock-ups corresponding to what teachers needed (see Figure 3).

4.4.4. Presentation workshop for national education inspectors

This workshop made it possible to constitute two groups of four and three participants respectively. In both groups, a great dynamic of exchanges was set up, and the participants were able to test and discuss many options on the different dimensions of

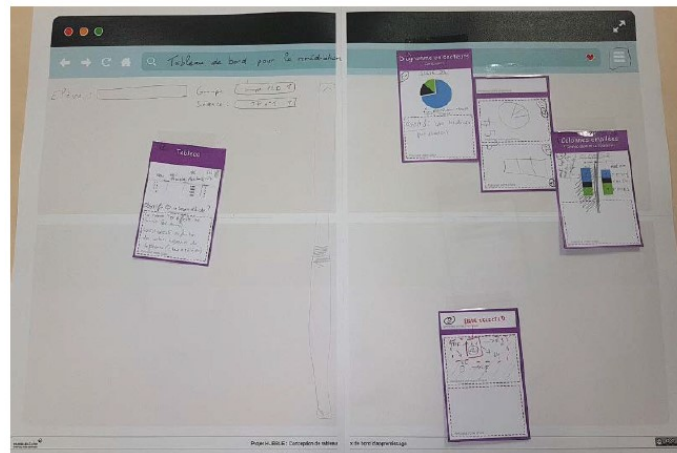


Figure 3: An example of a prototyping plateau at the end of the first user workshop

the design space. Compared to the previous workshop, we observed two other modes of progress, which seems to confirm that the proposed tool does not restrict the flow of exchanges. Both groups actually propose dashboards corresponding to a need identified in a limited time.

4.4.5. Questionnaire results

The size of the group does not allow for a statistical analysis of our questionnaire. This questionnaire includes seven questions asking for a level of agreement on a Lickert scale with 5 levels. Two questions deal with the handling of the tool (plateaux and maps), three questions on the quality of the resulting solution (precision, originality, relevance) and two on group work (dynamics, convergence). Two open-ended questions allow the participants to express their opinion. Overall, the level of satisfaction seems high (no answer below 3), with a majority of answers at level 4 or 5. Among these, the question "The plateaux and the cards helped to create a good group dynamic" received the best result with a response rate at level 5 of more than 75%.

4.4.6. Future test

Following the workshop with the national education inspectors, we were asked to make the materials available to facilitate the organization of workshops in the academies. A kit is thus available in the Productions section of the Hubble project website.

5. Conclusion

Drawing inspiration from participatory design approaches used in game design [28] or in entrepreneurship [40], we propose in this article a design space through a support tool for the participatory design of learning dashboards, and its implementation in the framework of participatory workshops. This tool combines a board and maps supporting both decision support and the provision of design alternatives. It meets the dual objective of expressing user needs and capitalizing on these needs and the corresponding dashboards.

The initial feedback from a test workshop is encouraging, and shows that this type of workshop effectively facilitates cooperation and further exploration of alternatives. According to Mackay and Fayard [36] and Knibbe [33], participation in such workshops can also contribute to developing the appropriation of such tools by the participants. This hypothesis seems particularly interesting in the context of Learning Analytics in which potential users often lack maturity in the use of such digital devices, whereas relevant feedback is a source of appropriation of digital practices.

References

- [1] Troy D Abel and Michael Evans. Cross-disciplinary participatory & contextual design research: Creating a teacher dashboard application. *Interaction Design and Architecture(s) Journal - IxD&A*, (19):63–76, 2013.
- [2] Sakinah SJ Alhadad. Visualizing data to support judgement, inference, and decision making in learning analytics: Insights from cognitive psychology and visualization science. *Journal of Learning Analytics*, 5(2):60–85, 2018.
- [3] Kimberly E Arnold and Matthew D Pistilli. Course signals at purdue: Using learning analytics to increase student success. In *Proceedings of the 2nd international conference on learning analytics and knowledge*, pages 267–270. ACM, 2012.
- [4] Kimberly E Arnold, Steven Lonn, and Matthew D Pistilli. An exercise in institutional reflection: The learning analytics readiness instrument (lari). In *Proceedings of the fourth international conference on learning analytics and knowledge*, pages 163–167, 2014.
- [5] Liam Bannon, Jeffrey Bardzell, and Susanne Bødker. Introduction: Reimagining participatory design—emerging voices, 2018.
- [6] Scott Beattie, Carolyn Woodley, and Kay Souter. Creepy analytics and learner data rights. *Rhetoric and reality: Critical perspectives on educational technology. Proceedings ascilite*, pages 421–425, 2014.

- [7] Liz Bennett and Sue Folley. Four design principles for learner dashboards that support student agency and empowerment. *Journal of Applied Research in Higher Education*, 2019.
- [8] Robert Bodily and Katrien Verbert. Review of research on student-facing learning analytics dashboards and educational recommender systems. *IEEE Transactions on Learning Technologies*, 2017.
- [9] Robert Bodily and Katrien Verbert. Trends and issues in student-facing learning analytics reporting systems research. In *Proceedings of the seventh international learning analytics & knowledge conference*, pages 309–318, 2017.
- [10] Christy Boscardin, Kirkpatrick B Fergus, Bonnie Hellevig, and Karen E Hauer. Twelve tips to promote successful development of a learner performance dashboard within a medical education program. *Medical teacher*, 40(8):855–861, 2018.
- [11] Francis Brouns, Marta Elena Zorrilla Pantaleón, Pedro Solana González, Ángel Cobo Ortega, Marta Collantes Viaña, Carlos Rodríguez Hoyo, Mariana De Lima Silva, Carmen Marta-Lazo, José Antonio Gabelas Barroso, Pilar Arranz, et al. Eco d2. 5 learning analytics requirements and metrics report, 2015.
- [12] Simon Buckingham Shum, Rebecca Ferguson, and Roberto Martinez-Maldonado. Human-centred learning analytics. *Journal of Learning Analytics*, 6(2):1–9, 2019.
- [13] Rubiela Carrillo, Clément Renaud, Yannick Prié, and Élise Lavoué. Dashboard for monitoring student engagement in mind mapping activities. In *Advanced Learning Technologies (ICALT), 2017 IEEE 17th International Conference on*, pages 433–437. IEEE, 2017.
- [14] Mohamed Amine Chatti, Anna Lea Dyckhoff, Ulrik Schroeder, and Hendrik Thüs. A reference model for learning analytics. *International Journal of Technology Enhanced Learning*, 4(5-6):318–331, 2012.

- [15] Inès Dabbebi, Sébastien Iksal, Jean-Marie Gilliot, Madeth May, and Serge Garlatti. Towards adaptive dashboards for learning analytic: An approach for conceptual design and implementation. In *9th international conference on computer supported education (CSEDU 2017)*, pages 120–131, 2017.
- [16] Shane Dawson, Dragan Gasevic, and Negin Mirriahi. Challenging assumptions in learning analytics. *Journal of Learning Analytics*, 2(3):1–3, 2015.
- [17] PA Dearnley and Pam J Mayhew. In favour of system prototypes and their integration into the systems development cycle. *The Computer Journal*, 26(1):36–42, 1983.
- [18] Betsy DiSalvo, Jason Yip, Elizabeth Bonsignore, and Carl DiSalvo. *Participatory design for learning: Perspectives from practice and research*. Taylor & Francis, 2017.
- [19] Mollie Dollinger and Jason M Lodge. Co-creation strategies for learning analytics. In *Proceedings of the 8th international conference on learning analytics and knowledge*, pages 97–101, 2018.
- [20] Erik Duval. Attention please!: learning analytics for visualization and recommendation. In *the 1st International Conference on Learning Analytics*, 2011. ISBN 9781450310574.
- [21] Vanessa Echeverria, Roberto Martinez-Maldonado, Roger Granda, Katherine Chiluiza, Cristina Conati, and Simon Buckingham Shum. Driving data storytelling from learning design. In *Proceedings of the 8th International Conference on Learning Analytics and Knowledge*, pages 131–140. ACM, 2018.
- [22] Mica R Endsley. *Designing for situation awareness: An approach to user-centered design*. CRC press, 2016.
- [23] Stephen Few. *Information Dashboard Design: The Effective Visual Communication of Data*. O’Reilly Media, Inc., 2006. ISBN 0596100167.

- [24] Stephen Few. *Information Dashboard Design: Displaying data for at-a-glance monitoring*. Analytics Press, 2013.
- [25] Stefano Fiorini, Adrienne Sewell, Mathew Bumbalough, Pallavi Chauhan, Linda Shepard, George Rehrey, and Dennis Groth. An application of participatory action research in advising-focused learning analytics. In *Proceedings of the 8th International Conference on Learning Analytics and Knowledge*, pages 89–96, 2018.
- [26] Dragan Gašević, Shane Dawson, and George Siemens. Let’s not forget: Learning analytics are about learning. *TechTrends*, 59(1):64–71, 2015.
- [27] Sergio Gutierrez-Santos, Eirini Geraniou, Darren Pearce-Lazard, and Alexandra Poulouvassilis. Design of teacher assistance tools in an exploratory learning environment for algebraic generalization. *IEEE Transactions on Learning Technologies*, 5(4):366–376, 2012.
- [28] Stuart Hallifax, Audrey Serna, Jean-Charles Marty, and Élise Lavoué. A design space for meaningful structural gamification. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, pages 1–6, 2018.
- [29] Kenneth Holstein, Bruce M. McLaren, and Vincent Aleven. 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 ’17*, pages 257–266, New York, NY, USA, 2017. ACM. ISBN 978-1-4503-4870-6.
- [30] Kenneth Holstein, Gena Hong, Mera Tegene, Bruce M McLaren, and Vincent Aleven. The classroom as a dashboard: Co-designing wearable cognitive augmentation for k-12 teachers. In *Proceedings of the 8th international conference on learning Analytics and knowledge*, pages 79–88, 2018.
- [31] Joel A Howell, Lynne D Roberts, and Vincent O Mancini. Learning analytics messages: Impact of grade, sender, comparative information and message style on

- student affect and academic resilience. *Computers in Human Behavior*, 89:8–15, 2018.
- [32] Jeonghyun Kim, Il Hyun Jo, and Yeonjeong Park. Effects of learning analytics dashboard: analyzing the relations among dashboard utilization, satisfaction, and learning achievement. *Asia Pacific Education Review*, 17(1):13–24, 2015. ISSN 1876407X. doi: 10.1007/s12564-015-9403-8.
- [33] Cédric Knibbe. *Concevoir avec des technologies émergentes pour la construction conjointe des pratiques et des artefacts : apports d’une méthodologie participative à l’innovation technologique et pédagogique*. Theses, Conservatoire national des arts et metiers - CNAM, December 2016. URL <https://tel.archives-ouvertes.fr/tel-01635882>.
- [34] Hoo Yong Leng, Noris Binti Mohd Norowi, Siti Aisah Binti Atan, Azrul Hazri Jantan, and Rahmita Wirza OK Rahmat. Designing a natural musical interface for a virtual musical kompang using user-centered approach. In *Proceedings of the 4th International Conference on Human-Computer Interaction and User Experience in Indonesia, CHIuXiD’18*, pages 38–42, 2018.
- [35] Andrés Lucero, Peter Dalsgaard, Kim Halskov, and Jacob Buur. Designing with cards. In *Collaboration in creative design*, pages 75–95. Springer, 2016.
- [36] Wendy Mackay and Anne-Laure Fayard. Radicalement nouveau et néanmoins familier: les strips papiers revus par la réalité augmentée. *Actes des journées IHM*, 97, 1997.
- [37] Janet R McColl-Kennedy, Stephen L Vargo, Tracey S Dagger, Jillian C Sweeney, and Yasmin van Kasteren. Health care customer value cocreation practice styles. *Journal of service research*, 15(4):370–389, 2012.
- [38] Tamara Munzner. *Visualization analysis and design*. CRC press, 2014.

- [39] Scott Nicholson. A user-centered theoretical framework for meaningful gamification. *Games+ Learning+ Society*, 8(1):223–230, 2012.
- [40] Alexander Osterwalder and Yves Pigneur. *Business model generation: a handbook for visionaries, game changers, and challengers*. John Wiley & Sons, 2010.
- [41] Yeonjeong Park and Il-Hyun Jo. Development of the learning analytics dashboard to support students’ learning performance. *Journal of Universal Computer Science*, 21(1):110–133, 2015.
- [42] V Podgorelec and S Kuhar. Taking advantage of education data: Advanced data analysis and reporting in virtual learning environments. *Elektronika ir Elektrotehnika*, 114(8):111–116, 2011.
- [43] Alejandro Ramos-Soto, Manuel Lama, Borja Vázquez-Barreiros, Alberto Bugarín, and M Mucientes S Barro. Towards textual reporting in learning analytics dashboards. In *2015 IEEE 15th International Conference on Advanced Learning Technologies (ICALT)*, pages 260–264. IEEE, 2015.
- [44] Gabriel Reimers and Anna Neovesky. Student focused dashboards. In *Proceedings of the 7th International Conference on Computer Supported Education-Volume 1*, pages 399–404. SCITEPRESS-Science and Technology Publications, Lda, 2015.
- [45] José Matías Rivero, Julián Grigera, Gustavo Rossi, Esteban Robles Luna, Francisco Montero, and Martin Gaedke. Mockup-driven development: providing agile support for model-driven web engineering. *Information and Software Technology*, 56(6):670–687, 2014.
- [46] Lynne D Roberts, Joel A Howell, and Kristen Seaman. Give me a customizable dashboard: Personalized learning analytics dashboards in higher education. *Technology, Knowledge and Learning*, 22(3):317–333, 2017.
- [47] Elizabeth B.-N. Sanders and Pieter Jan Stappers. Co-creation and the new landscapes of design. *CoDesign*, 4(1):5–18, 2008. doi: 10.1080/15710880701875068.

- [48] Elizabeth B-N Sanders, Eva Brandt, and Thomas Binder. A framework for organizing the tools and techniques of participatory design. In *Proceedings of the 11th biennial participatory design conference*, pages 195–198, 2010.
- [49] Douglas Schuler and Aki Namioka. *Participatory design: Principles and practices*. CRC Press, 1993.
- [50] B. A. Schwendimann, M. J. Rodríguez-Triana, A. Vozniuk, L. P. Prieto, M. S. Boroujeni, A. Holzer, D. Gillet, and P. Dillenbourg. Perceiving learning at a glance: A systematic literature review of learning dashboard research. *IEEE Transactions on Learning Technologies*, 10(1):30–41, Jan 2017. ISSN 1939-1382.
- [51] Mary Shaw. The role of design spaces. *IEEE software*, 29(1):46–50, 2011.
- [52] Kin Wai Michael Siu. Users’ creative responses and designers’ roles. *Design Issues*, 19(2):64–73, 2003.
- [53] Clay Spinuzzi. The methodology of participatory design. *Technical communication*, 52(2):163–174, 2005.
- [54] Christina M Steiner, Michael D Kickmeier-Rust, and Dietrich Albert. Learning analytics and educational data mining: An overview of recent techniques. *Learning Analytics for and in Serious Games*, 6:61–75, 2014.
- [55] Simone Taffe. ”the hybrid designer/end-user: Revealing paradoxes in co-design”. *Design Studies*, 40:39–59, 2015.
- [56] Russ Unger and Brad Nunnally. *Designing the Conversation: Techniques for Successful Facilitation*. New Riders, 2013.
- [57] Katrien Verbert, Erik Duval, Joris Klerkx, Sten Govaerts, and José Luis Santos. Learning analytics dashboard applications. *American Behavioral Scientist*, 2013.

- [58] Olga Viberg, Mathias Hatakka, Olof Bälter, and Anna Mavroudi. The current landscape of learning analytics in higher education. *Computers in Human Behavior*, 89:98–110, 2018.
- [59] I Vilpola. A method for improving erp impementation success by the priniples and process of user-centered design “. enterprise information systems (eis), vol. 2, issue 1, 2008.
- [60] Karel Vredenberg, Scott Isensee, and Carol Righi. *User-Centered Design: An Integrated Approach with Cdrom*. Prentice Hall PTR, 2001.
- [61] Alyssa Friend Wise, Jovita Maria Vytasek, Simone Hausknecht, and Yuting Zhao. Developing learning analytics design knowledge in the “middle space”: The student tuning model and align design framework for learning analytics use. *Online Learning*, 20(2), 2016.
- [62] Franceska Xhakaj, Vincent Aleven, and Bruce M McLaren. How teachers use data to help students learn: Contextual inquiry for the design of a dashboard. In *European Conference on Technology Enhanced Learning*, pages 340–354. Springer, 2016.
- [63] Franceska Xhakaj, Vincent Aleven, and Bruce M McLaren. Effects of a teacher dashboard for an intelligent tutoring system on teacher knowledge, lesson planning, lessons and student learning. In *European conference on technology enhanced learning*, pages 315–329. Springer, 2017.
- [64] Yesom Yoo, Hyeyun Lee, Il-Hyun Jo, and Yeonjeong Park. Educational dashboards for smart learning: Review of case studies. In *Emerging Issues in Smart Learning*, pages 145–155. Springer, 2015.