The LATUX Workflow: Designing and Deploying Awareness Tools in Technology-Enabled Learning Settings

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ABSTRACT
Designing, deploying and validating learning analytics tools for instructors or students is a challenge requiring techniques and methods from different disciplines, such as software engineering, human-computer interaction, educational design and psychology. Whilst each of these disciplines has consolidated design methodologies, there is a need for more specific methodological frameworks within the cross-disciplinary space defined by learning analytics. In particular there is no systematic workflow for producing learning analytics tools that are both technologically feasible and truly underpin the learning experience. In this paper, we present the LATUX workflow, a five-stage workflow to design, deploy and validate awareness tools in technology-enabled learning environments. LATUX is grounded on a well-established design process for creating, testing and re-designing user interfaces. We extend this process by integrating the pedagogical requirements to generate visual analytics to inform instructors’ pedagogical decisions or intervention strategies. The workflow is illustrated with a case study in which collaborative activities were deployed in a real classroom.

Categories and Subject Descriptors
J.1 Administrative Data Processing: Education; K.3.1 Computer Uses in Education: Collaborative learning, Distance learning.

General Terms
Design, Experimentation, Human Factors, Standardisation.

Keywords
Design, groupware; visualisations; design; dashboard; studies in the wild, awareness.

1. INTRODUCTION
The field of learning analytics (LA) has emerged in recent years as a multidisciplinary research area with the aim to improve the overall learning experience for instructors and students. Several authors have highlighted the potential impact of this discipline to enhance teaching practice and student learning [12, 29, 30, 33] but at the same time, there is also a recognition of the importance of establishing a connection with other research fields such as the Learning Sciences [29] and Human-Computer Interaction (HCI) [33]. As a consequence, designing tools in this space demands challenging interdisciplinary processes [2] so as to satisfy multiple goals and stakeholder requirements and leverage the expertise provided from the different disciplines. There is substantial research demonstrating the value of LA [12, 30], describing the basic requirements that the LA tools can target [11], envisioning the future of this field [29], and providing general analytical solutions for specific contexts [11]. However, little attention has been paid to exploring frameworks that can help designers to systematically develop, evaluate, and deploy effective LA tools.

The area of Software Engineering (SE) provides established methodologies to help designers recognise processes, understand the requirements for interactive systems and iteratively evaluate these as they are built [31]. Similarly, the HCI and User Experience (UX) disciplines have a large array of methods for establishing user needs, and designing and evaluating interfaces [15]. However, these methodologies alone are not sufficient for building LA tools because they do not consider the learning context. Dillenbourg et al. [8] stated that traditional usability testing (mostly focused on individual or group interactions with computers) is not enough to prepare designs for the complexity of a learning context. The same authors suggested considering ‘usability at the classroom level’. For example, in a classroom, instructors typically have to deal with constraints and contingencies such as time limitations, curriculum alignment, lesson plans, physical space constraints, unexpected events, and tool usage. This complexity can also be found in blended and online learning settings [27] where LA tools are commonly used. Similarly, Siemens [29] proposed a holistic view of LA that includes such practical issues, but additional aspects related to the data such as openness, accessibility, and ethics; and the particular pedagogical goals and context of usage of the LA tools (e.g. detecting at-risk students, supporting self-awareness or enhancing instructors’ awareness).

These complexities suggest the need for new design methodologies for LA tools encompassing a pedagogical underpinning and considering the different actors (e.g. instructors and students), the dimensions of usability in learning contexts [8] (individuals, groups of students, and the classroom), the learning goals, data sources, and the tasks to be
accomplished. This paper proposes LATUX (Learning Awareness Tools – User eXperience), a workflow for designing and deploying awareness tools for technology-enabled learning settings. By awareness tools we refer to those that provide a user (e.g. the instructor) with an enhanced level of awareness of what other actors (e.g. students) are doing in the learning space.

The proposed workflow extends well-established design processes for developing user interfaces (UI’s) by integrating the pedagogical requirements, collecting the relevant data from students, and evaluating the awareness tools. The evidence supporting the design of the LATUX workflow is illustrated with a case study of the iterative development of visualisations for in-classroom technology-enabled group activities to assist instructors in monitoring student collaboration and progress [23].

The rest of the paper is organised as follows. The next section provides an overview of the current related LA methods followed by a brief description of the most relevant methods for interface development and evaluation used in SE and HCI. Then, we define the LATUX workflow, with its four principles and five stages. The workflow is illustrated in the final section with the description of the iterations of design, evaluation, and the deployment of visualisations of student group activity in our case-study.

2. RELATED WORK
2.1 Learning Analytics Methods for Pedagogical Intervention

Technology-enabled learning environments, whether online or face-to-face in the classroom, have the advantage of capturing copious amounts of data left behind from students’ digital footprints [10, 14] that when made accessible to instructors can provide valuable objective insight into students’ learning. Using data mining techniques, the data captured from students’ interactions can be aggregated and analysed by instructors to make informed pedagogical decisions. For example, data on students’ use of a Learning Management System (LMS) can reveal patterns regarding student engagement with certain tools [3, 19]. However, these patterns are best understood by instructors when made available and visualised through user-friendly and intuitive LA tools. The challenge for these tools is to offer a low adoption threshold for non-technical users while offering additional functionality for more advanced users [29].

The target audience of LA tools must be considered during the design process to ensure the insights gleaned from the data become actionable [26]. In the case of course-level analytics, visualisation tools should highlight the intended goal identified by the instructor and whether achieved [13], or even allow instructors to apply the performance indicators appropriate for their learning context [11]. The ability to observe whether students are engaging with a learning tool or progressing as intended, allows instructors to identify when to intervene, in order to support the students, which is specially challenging in online learning environments [11] and in large classes. For example, Social Networks Adapting Pedagogical Practice (SNAPP) represents student interactions within an online discussion forum to help instructors identify when to consult with students who are not engaging or when to change the nature of the activity [18]. Other learning analytics dashboards, such as Purdue University’s Course signals, provide data visualisations (e.g. traffic signals) to monitor performance and trigger early intervention when students may be at risk of poor performance or dropping out of a course [1]. While there is no shortage of evidence to support the argument that LA tools to visualise students’ activity at the course-level are needed to inform instructors about their students’ learning behaviour, there is limited research on effective workflows for designing such tools, particularly when focusing on data collected from face-to-face learning environments. This paper addresses this gap by proposing a design workflow that combines the rigor of HCI paradigms with respect to the user experience with a solid pedagogical underpinning.

2.2 Designing User Interfaces

A variety of methodologies have evolved over the years, to facilitate the process of software development and, specifically, user interface design. From a general SE perspective, these methodologies are commonly known as lifecycles [3] which for example, may include waterfall, spiral development, prototyping, and extreme programming approaches. The purpose of the lifecycles in HCI is to help designers develop more efficiently and, for the case of user interfaces, to enhance the user experience. In other words, the lifecycles provide best practices to other developers and designers.

The lifecycles in both SE and HCI disciplines have similar structure and activities, such as requirement identification, design, and evaluation. However, the methodologies for designing user interfaces in SE and HCI have been formulated almost independently [15]. There exists a number of specific HCI lifecycles, such as: Mayhew’s usability lifecycle; the Star lifecycle; the LUCID framework of interaction design; and the Wheel model [15]. The latter is a more recent elaboration of the iterative process model for usability engineering which provides a general framework into which designers can fit existing or new techniques or methods to apply “best user experience practices” [16]. This is particularly relevant as a foundation for the workflow we propose in this paper. Overall, most of the lifecycles mentioned above have four generic stages (analysis, design, implementation, and evaluation) that can be performed iteratively, with potential for each stage to feed back to refine an earlier one. This iterative process for interface design can lead to a higher quality user experience.

Adding to the challenge for LA, Bevan [4] argued for greater use of usability standards, but acknowledges that generic standards may fail to meet all the needs of designers in specific areas (e.g. for LA tools design). A widely accepted standard that is relevant for developing interfaces for LA is the “Human-centred design for interactive systems” standard (ISO 9241-210 [9]). Its six principles are: 1) the design should be based upon an explicit understanding of users, tasks and environments; 2) users should be involved throughout the design; 3) the design should be driven by user-centred evaluation; 4) the process is iterative; 5) the design should address the whole user experience; and 6) the design team should be multidisciplinary in terms of skills and perspectives.

The workflow proposed in this paper is based on this standard, and the evaluation-centred UX model (the Wheel) lifecycle concept [15]. Its novelty resides in the fact that it instantiates the user experience lifecycle with specific evaluation stages and requirements for designing awareness tools aimed at improving
the learning experience, using data captured from students’ activity with learning technologies.

3. The LATUX Workflow
The LATUX workflow is defined by a) the principles on which it is grounded, and b) the evaluation-oriented stages that compose it (see Figure 1 on pg. 4). The entire workflow is evaluation-oriented. Hence, each stage evaluates different parts of an awareness tool. The workflow has one problem identification stage and four evaluation stages. These principles and the stages are described in the rest of this section.

3.1 LATUX Principles
Based on LA literature and our first-hand experience, we identified a set of principles to take the workflow beyond generic development lifecycles. These principles are:

**Principle 1: The development process in LA has a strong research component.** In traditional software design, development is commonly based on requirements elicitation, with iterative refinement. The classic UX approach consists in exploring the design space and gaining feedback iteratively, with careful evaluation in each iteration. By contrast, developing effective awareness tools for learning settings also requires carrying out research to explore the new possibilities that learner data can offer for supporting instructors. As with every field that has been revolutionised by technology, LA tools can have a transformational power in education, in addition to improving its processes. Research needs to be carried out concurrently to understand how these changes can take place. At the current state-of-the-art, there is a prominent gap between research and practice in LA [29] indicating the importance of this principle in the proposed workflow. This opportunity to close the gap is what Duval [10] has highlighted as “Data-based Research on Learning”.

**Principle 2: The impact of authenticity;** where the term authentic captures the nature of existing learning contexts, without LA tools. In line with recognised UX practice, we need to distil the nature of learning contexts and how these impact the needs of each stakeholder and act as drivers for interface design. This point highlights the need to go beyond standard usability. Usability testing with a small number of users is a general method to evaluate interfaces and user experience. However, for awareness tools, the contingencies that may occur in real learning scenarios may affect and be crucial for the adoption of technology [8]. As also noted by Rodriguez-Triana et al. [28], we need to align the design of the learning activities (tools usage, tasks, pedagogical strategies) and the learning analytics solutions to support instructors more effectively. In our workflow, each evaluation stage aims to increase the level of compliance of the awareness tool with the demands of authentic learning contexts while advancing towards the deployment of the tool in-the-wild (e.g. the classroom).

**Principle 3: Holistic design and evaluation.** In the same way that the LA field is multi-disciplinary and focused on understanding systems as a whole [30], the design process to build LA tools must consider the complexity of the learning environments. This includes the features of the learning tools, the adopted pedagogical approach, the physical space, the student social roles, etc. Additionally, the evaluation of the tools should also be holistic. For example, rather than evaluating the effectiveness of the tool itself (in isolation with the purpose of generalising findings), the evaluation should consider the tool in the context of the learning setting and its further impact on the actual learning-related activities (e.g. student retention, change in learning behaviour [33] or instructor’s attention [23]). This holistic view translates into a close relationship with Learning Sciences [30].

**Principle 4: Evaluation is oriented on data and its meaningfulness.** In addition to the evaluation of the UI, the design of LA tools contains an additional dimension for evaluation which is making sense of the student activity data or interpreting it in order to inform pedagogical decisions. A crucial part of the design and evaluation process includes the ways to distil data, present it, and validate it accordingly to the pedagogical elements of learning and instruction [17] including representation, purpose, timing, context, learning goals, teaching goals, epistemic beliefs, and assessment approaches. For example, a specific data visualisation may enlighten instructors while they reflect on student progress over the semester, but may be useless in the classroom, or in other learning contexts. Thus, the design process should not only respond to the questions about what data and how the data should be presented, but also where and how it will be used. While the evaluation in terms of usability and user experience still applies for LA tools, the workflow presented in this paper is not a software development or user experience lifecycle. It is a design that incorporates and draws on the body of knowledge about learning contexts such as the learning cycle, where the students’ learning activity or instruction is at the focus of attention. Further, the design and evaluation of LA tools should be connected to both, the context of the learning activity and the context of usage.

3.2 LATUX Stages
Figure 1 illustrates the conceptual representation of the stages featured in our proposed iterative workflow for designing and deploying awareness tools in the classroom. The problem definition is the first stage of recommended practice in HCI and SE. The figure also shows the four evaluation-oriented stages that compose iterations towards deployment.

3.2.1 Stage 1 – Problem definition
Most literature presented above, concerning LA, has explored the different elements of the problem definition [29, 30, 33]. The first stage aims to identify the requirements for LA and user interface design. This process offers an opportunity to identify possible new and radical features that can be offered by the data to address stakeholder needs, but where the stakeholders may not realise this. Other elements of the problem definition that have been addressed by LA research as discussed below are the following: stakeholder identification, data sources, types of data logging, features of the learning setting and design for evaluation.

**Stakeholder identification.** Although LA has mostly focused on informing and empowering instructors and learners [30], Siemens [29] identified other relevant stakeholders including faculties, departments, the whole institution, researchers, corporations, and government funders. From a SE perspective, stakeholder identification is a basic step for successful design [31]. Hence, the design of LA tools should adopt this, carefully identifying the target stakeholders.
**Data sources.** According to Verbert et al. [33], to date, research on LA has mostly focused on using student data linked to resource usage, interaction time, number of artefacts created, collaborative interactions, and task results. By contrast, assessing the impact of the data displayed in awareness tools has not been deeply explored. In addition, there are many additional data sources that can offer new insights into student learning [5], but have been under-explored in the LA field such as gesture sensing, wearable bio sensors, head trackers, infrared imaging, depth imaging and eye tracking. Even manual tracking of activity has not been widely used in LA [33].

**Data Logging:** As a continuation of the data source identification, Verbert et al. [33] also indicated that the design of LA tools should include an analysis of the feasibility and trade-offs of considering alternative data sensors used to capture more complete student data. Currently, most LA solutions are based on application logs and forms of audio and video capture. The problem definition should include the analysis of the implications of introducing additional sensors in terms of affecting the authenticity of the learning setting.

**Features of the learning setting:** Verbert et al. [33] further identified the need for more research to identify the settings where particular LA approaches work well, and also to identify limitations and alternatives for learning environments where some LA solutions have been unsuccessful. This suggests a strong link between the development of LA tools and the context as a whole; and the risk of over-generalising LA solutions.

**Design for Evaluation:** Finally, it is important to define how to evaluate the effectiveness of the use of LA tools in the target learning setting. This means, designing the evaluation of the user experience according to the principles this workflow is grounded upon (e.g. considering the authenticity of data orientation, meaningfulness, etc). Different measurement techniques should be used, as perception may not be an accurate way to evaluate the impact of a tool [15]. Measuring users’ actions and the impact of such actions are also an indirect measure of the effectiveness of the learning analytics tool. These include: usability testing; measuring the impact on teaching; learning gains; reduction in misconceptions; improved collaboration; enhanced instructor awareness; reduced load on the teacher; enhanced management of instructor time; etc. In addition, the conditions in which the evaluation will be performed (e.g. in the classroom, with simulated class conditions, simulated data, etc.) are required. Further details on this point will be discussed in the following stages of the proposed workflow.

**3.2.2 Stage 2 – Low-fidelity prototyping**

The idea of prototyping in early stages of the development is to provide a quick and flexible preliminary vision of the proposed system [15]. To accomplish this, a prototype must contain some key elements of the system without actually building the system. Low-fidelity prototypes are initial high-level representations of the intended design. They are appropriate when the details of the tool have not been defined or are likely to change, hence the construction of prototypes should involve little effort. In this stage, we propose the construction of low-fidelity prototypes with the purpose of: a) testing a wide range of possible visualisations that can be part of the intended awareness tool; b) testing usability and data sense making in the early stages of the design; and c) evaluating and triggering dialogue with stakeholders before building the LA tool. To achieve these Figure 1 lists a set of questions that may guide a designer to decide how to generate and evaluate low-fidelity prototypes of awareness tools. They include, for example, the selection of the indicators of the learning activity that will be visualised by the tool. The designer may also want to consider either sketching or using graphical tools to generate visualisations according to the LA goals.

In LA, low-fidelity prototyping may focus on either the evaluation of the UI (user interface oriented prototype, e.g. a paper-based version of the interface where some visualisations can be drafted with simulated data) or the actual information conveyed in the visualisations (data oriented prototype e.g. visualisations of data captured by the actual learning system or from shared datasets). The first case is closer to a typical HCI evaluation, while data oriented prototyping is perhaps more relevant (and useful) in LA. We will provide an example of this in the Case Study described in the next section.

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**Figure 1. Conceptual Representation of the LATUX Workflow for Designing and Deploying Awareness Tools.**
In either case, low-fidelity prototypes are commonly paper-based representations of parts of a system or tool. They have a low cost and are highly effective to inform the design compared with subsequent versions of the tool [32] (see Table 1, column 1, first row). They also allow evaluations with multiple users and under controlled lab conditions (e.g. it is much easier to evaluate paper-based versions of a dashboard in one hour interviews with multiple instructors than when the actual system is used).

By contrast, low-fidelity prototypes in LA have many limitations (see Table 1, column 1, second row). They cannot replicate the connection between what occurs in an environment and the generation of data in that precise instant. Also these evaluations completely ignore the effect of interventions (e.g. instructors’ actions or provision of feedback) or changes in student behaviour. They also afford very limited understanding of the user experience under authentic learning conditions (see Table 1, column 1, rows 3 and 4).

3.2.3 Stage 3 – Higher-fidelity prototyping
The next stage in the workflow is to enhance the fidelity of the prototypes by generating a programmed version of the system. From a HCI perspective, a high-fidelity prototype is a representation of the designed tool that is more detailed and realistic than a low-fidelity prototype [15]. It may include details of either the appearance or interaction behaviour needed to further evaluate how users interact with the tool or the data. High-fidelity prototypes require more effort and time, but the evaluation of such prototypes are still less expensive, faster to produce, and more flexible than developing the final tool.

For LA awareness tools, specifically, we discuss the simulation of generation of student data and the conditions of the learning setting. This adds some degree of authenticity to the evaluation since the simulation may involve real student data and real-time usage. As indicated in the first row of Table 1, column 2, using simulation prototypes allows the inclusion of the time factor and, therefore, the evaluation of the decision making process on the fly (e.g. it is possible to analyse what an instructor would decide to do, right after looking at the tool). Similar to low-fidelity prototypes, evaluations with more users can be performed under lab conditions compared with more authentic but costly pilot studies. In addition, some aspects of interaction design can be evaluated (e.g. analysing how users would explore the data).

More complex experiments can be designed to evaluate the user experience with a simulation tool since subjects can entirely focus on the details of the visualisations while the tasks can be replicated for multiple people in less time. However, as noted in the second row of Table 1, column 2, the impact of students’ or instructors’ actions is still ignored. Hence, the simulation of a tools’ usage does not reflect what would actually happen in a real environment where students or the instructors can actively respond to the data presented via the awareness tool. Therefore, the effect of the tool on instructors’ or students’ actions cannot be tested. As a result, the designer should consider the trade-off between the low degree of authenticity with this type of prototyping and the effort that is needed to build it. Figure 1 presents some questions that can help the designer identify the conditions of the learning setting that can be simulated to evaluate the awareness tool, and how to address or simulate interventions or changes in behaviour in the design of the evaluation, or how the impact of the tool can be evaluated without actually measuring learning or behavioural change.

3.2.4 Stage 4 – Pilot studies - Classroom use
The fourth proposed stage before deploying an awareness tool in-the-wild is the evaluation of the user experience in pilot studies. A pilot study is commonly accomplished under conditions that are similar to a real deployment but at a smaller scale (e.g. in a limited number of classroom sessions or during a limited period of time in a course). A pilot study can help prove a concept and observe the live usage of the tool in an authentic scenario. This is recommended as a part of the design workflow to minimise the risk of deploying an LA tool at a large scale while still performing the necessary research and evaluation.

Key additional knowledge can be gained from pilot studies including testing interactivity and evaluation, which can include the analysis of the impact of the interventions and change of behaviours as a result of using the tool. In pilot studies, it is also possible to test the effect of the tool and the unexpected events

Table 1. Strengths and limitations of the evaluation-oriented stages of the workflow.

<table>
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<th></th>
<th>Low-fidelity prototyping</th>
<th>Higher-fidelity prototyping</th>
<th>Pilot studies</th>
<th>Validation in-the-wild</th>
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| **Strengths**       | • Testing usability and sense making in early stages  
                      • Testing with multiple people  
                      • Very cheap   | • Simulated decision making on the fly  
                      • Testing with multiple people  
                      • Deeper evaluation by users  
                      • Interactivity can be tested  
                      • Cheap | • Authentic – live usage of the tool  
                      • Interactivity can be tested  
                      • Interventions affect the use of the tool  
                      • Impact of the tool on users’ can be tested  
                      • Contingencies considered | • Cheaper than full deployment  
                      • More generalisable  
                      • Testing with multiple people  
                      • Reduced ‘novelty-effect’ |
| **Limitations**     | • Time factor missing  
                      • Interventions cannot be tested  
                      • Interactivity cannot be tested | • Interventions cannot be tested  
                      • More expensive than static prototypes | • More expensive than prototyping  
                      • Testing with less people  
                      • Less generalisable | • The most expensive  
                      • Contingencies  
                      • Limited experimental conditions |
| Controlled conditions |                          |                             |               |                        |
| Authenticity        |                          |                             |               |                        |
that may occur on learning and instruction (see Table 1, column 3, first row). These are issues that the designer should inquire for a successful accomplishment of pilot studies (see Figure 1–4).

However, pilot studies are typically more expensive in terms of effort and coordination, compared with evaluating low or high fidelity prototypes [15]. Added to that, results obtained from pilot studies are not necessarily generalisable. Setting controlled variables can be restrictive; depending on how authentic the learning conditions are (e.g. pilot studies in real schools may impose limitations on the range of items that can be evaluated). In addition, the amount of evidence and subjects can be more limited than performing shorter but more numerous evaluations with prototypes under lab conditions (see limitations in Table 1, column 3, second row).

3.2.5 Stage 5 – Validation in-the-wild - Classroom use
Evaluating in-the-wild has become a standard method within HCI testing [6]. In-the-wild testing consists of field trials of experimental systems with groups of subjects in relatively unconstrained settings outside of the laboratory, in a larger scale and for a longer duration than in pilot studies. For LA research and practice, this can help designers recognise the actual deployments as another evaluation stage of user experience. Similar to a pilot study, deployments in-the-wild provide an authentic test-bed to analyse not only usability and user experience, but also the usage and the impact of awareness tools in unpredictable learning environment and within the context of the pedagogical requirements and goals (see Table 1, column 3, first row).

The usage of the awareness tool can be tested considering the possible contingencies that may occur. As the authenticity of the setting is higher and the duration of the study can be longer than a pilot study, the results of the evaluation of the awareness tool can be more generalisable to real world contexts and use. Also the longer-term usage of an awareness tool can minimise the ‘novelty-effect’ inherent in introducing new technology. This effect cannot be easily analysed in smaller pilot studies or in prototype testing. This aspect is important for designing and testing LA tools since the ultimate goal of a successful deployment is the sustained usage of the tool for the learning or teaching goal that was envisaged for.

In addition, testing the tool in-the-wild may require more challenging learning management, ethical and privacy issues to be addressed given the larger scale of the tools usage compared with pilot studies (Table 1, column 3, second row); these are aspects that may impact the design of an awareness tool and that the designer should be aware of (Figure 1–5). At the same time, evaluating LA tools in authentic deployments is the most expensive stage in a design workflow. Testing under authentic conditions can also affect the use of the tool and the evaluation as they offer less flexibility in setting control-experimental conditions (Table 1, column 4, second row).

3.2.6 Iterative Design-Deployment-Evaluation
Finally, bridging the gap between practice and research calls for communication of what happens in the deployment to inform the possible tuning or re-design of the tools. This invites the definition of iterations of design to either develop the LA tools in small incremental steps, or to improve certain elements of the UI or data processing. Mendiburo et al. [25] argues the importance of iterative interaction design to generate their LA tool, but other than this example, iterative design in LA design has not been explored and reported in depth. The designer may want to respond to some questions once the system, or part of it, has already been deployed, such as: what evaluation stages may be needed in an iteration (e.g. some functionality of the awareness tool may not require all types of prototyping testing or pilot studies)? What is the goal of the current iteration? What knowledge should be gained from a research perspective? How much iteration is required? As depicted in Table 1, rows 3 and 4, each stage within an iteration of the proposed workflow features a trade-off between the authenticity and degree of control of the learning setting condition.

4. Case Study
We illustrate our proposed workflow’s effectiveness by describing the iterative development of the MTDashboard, which has proven effective in enhancing instructor awareness and drove the provision of informed feedback in higher education technology-enabled classroom studies with >500 students.

4.1 Stage 1 - Problem identification
We describe the context of the study in terms of the problem definition as a starting point of our design workflow. The objective of the project is to design, evaluate and deploy a number of visualisations of student group work in a classroom. The purpose of this is to enhance instructor awareness of students’ small-group collaboration and task progress. The group activity was supported either in the lab or in the classroom through the use of interactive tabletops. These are shared multi-touch devices that allow students to manipulate digital media while communicating face-to-face. Figure 2 (top-left, in the next page) shows three students working on a collaborative activity. The main requirement, from a LA point of view, was to generate an awareness tool (like the one shown in Figure 2, bottom-right), in the form of an instructor dashboard that would inform the instructor of student activity and progress while students work in small groups using multiple tabletops (Figure 2, top-right).

Data sources and Data logging: Two main sources of student data were targeted in the project: the physical manipulation of virtual objects on the tabletop and quantitative dimensions of student speech (e.g. presence and duration of utterances). In regards to the tabletop technology, there has not been much research on sensing technology to capture the above student data. Part of the project included the production of the technology to differentiate touches on the tabletops and synchronise those with the detection of audio activity. More information about how the speech and touch activity can be automatically captured in this face-to-face setting can be found in [23].

Features of the learning setting: For the prototyping stages and pilot studies, most students were posed with problem solving and case-based resolution tasks to be solved with the construction of a concept map. Collaborative concept mapping is representative of a group learning activity that requires students to share their perspectives, visually represent their ideas, and agree on a group solution [7]. For the in-the-wild deployment, two additional learning applications were used: a brainstorming application and a tool for supporting project management meetings [24].
4.2 Series of studies
The design process of the case study included the following series of smaller studies, which support stages 2 to 5 respectively of our proposed workflow: the first explored candidate visualisations based on paper prototypes [20]; the second consisted of trials in the lab with real data but simulated classroom sessions [21]; the third included two pilot studies conducted in two different semesters [22]; and the fourth was a longitudinal class experience with four instructors [24].

4.2.1 Stage 2 – Validation of prototypes
Description of the study: The first study focused on exploring visualisations of small-group face-to-face work that could be generated from the data captured from a tabletop device in a lab setting such as the one shown in Figure 2. An initial set of visualisations was designed to provide key indicators of accountability of students’ contributions to the group solution, the progress of the task, and how egalitarian the activity was amongst learners. A total of five visualisations were generated using a computer drawing editor. Details of these visualisations can be found in [20]. Two sets of the visualisations were printed on paper, which were generated based on real data obtained from the video recordings of two groups of three students each collaborating at the tabletop on a concept mapping task.

Evaluation: The usability and meaningfulness of the visualisations were tested using these prototypes with five experienced instructors. Regarding usability, an instrument was first applied to investigate if all the facilitators were able to easily understand the visualisations. Then, a second instrument addressed a series of hypotheses that questioned if the set of visualisations revealed some facets of the group process to the instructors (e.g. about equity and amount of participation, overall collaboration, equity of intellectual contribution and the creation process.

Main lessons learnt: In accordance with UX literature, [32] this inexpensive paper-based prototyping allowed the exploration of initial user experience to drive the design of the awareness tool. For example, the evaluation showed that instructors identified visualisations they would use in class and those they would prefer to use for post-hoc reflection. This drove the goals of the following studies and the iterative design of the awareness tool in general. Results from this evaluation also helped to refine the design of the visual aspects of the group indicators as well as to detect what other visualisations would be useful to explore.

4.2.2 Stage 3 – Simulations with real instructors
Description of the study: Based on the results of the evaluation of low-fidelity prototypes described above, in this study, a high-fidelity prototype of a dashboard was built. This summarised student data captured from four group sessions recorded in the lab. The result was a dashboard with two levels of detail: 1) the class level, that showed minimal information of multiple groups
at the same time (with three visualisations per group); and ii) the **detailed group level**, that allowed instructors to drill down to more specific information about a select group when required (with five visualisations in a timeline, e.g. Figure 2 - bottom-left). More details of the study can be found in [21].

**Evaluation:** This study evaluated how instructors used the dashboard to intervene in a group and what visualisations were most effective in conveying key information to inform their decisions. Controlled trials were conducted in a lab with real data but simulated classroom sessions involved eight instructors (all different from the previous evaluation stage). This high-fidelity prototype went beyond providing functionality by simulating the real-time generation of data for each instructor, as if he or she was monitoring up to three groups for 30 minutes. In parallel, each group video was manually analysed by an external person to diagnose a groups’ collaboration. The evaluation recreated the classroom orchestration loop documented by Dillenbourg et. al. [8], where instructors monitor the classroom (at the **class level** of the dashboard), compare it to some desirable state, and intervene to adapt the scenario (selecting the key visualisations that helped in the decision making process and drilling down to the **detailed group level** of the dashboard). If the instructors decided to intervene, they had to wait at least two minutes in the **detailed group level** simulating the time taken to talk with the group. Instructors followed this loop throughout the duration of the trials. Data captured from the instructors’ use of the dashboard, a questionnaire, and interviews were used to understand the instructors’ experience with the tool.

**Main lessons learnt:** Even though the construction of a programmed simulator is a more expensive task, it provided a more realistic user experience than using static paper-based prototypes [15]. It forced instructors to experience the visualisations and analyse student data on-the-fly. This helped them think if they would realistically use the awareness tool in the classroom. For example, in this study instructors were able to identify the key features that gave them clues of groups encountering collaboration problems. The simulator also provided an opportunity to test a visualisation generated from a complex data mining algorithm that processed student data on the fly. Results from this evaluation showed that those visualisations which provided less processed data facilitated more effectively the management of instructors’ attention and interventions in comparison with the use of visualisations generated using more sophisticated data processing (e.g. a graph showing levels of collaboration as detected by a data mining algorithm). The **detailed group level**, showing chronological information, was considered effective for assessing task progress after class.

### 4.2.3 Stage 4 – Pilot studies

**Description of the study:** Two pilot studies in the classroom were conducted in two different weeks for two courses with a single instructor conducting 22 classes (14 and 8 with 236 and 140 students in each, respectively). Similarly to the setting shown in Figure 2 (top-right), the classroom featured four interconnected interactive tabletops logging student’s actions to a central repository. The instructor was provided with a handheld device where a new version of the dashboard was deployed. This showed real-time selected visualisations of either 1) group task progress, or 2) equity of student’s participation, within each group.

**Evaluation:** In this case, to evaluate the impact of the tool in the classroom we collected information from a number of sources to triangulate evidence. These sources included: automated capture of the tabletops, notes from an external observer focused on instructor’s actions, notes from a second external observer focused on assessing each small group’s work. The evaluation focused on investigating if the instructor attended the ‘less achieving’ groups from the information provided in the dashboard and then if the instructor’s intervention accomplished in this way had some effect on student’s learning or their task. Further details of this evaluation process can be found in [22] and [23].

**Main lessons learnt:** This study made it evident how important it is to evaluate the tools in a real classroom environment. The instructor had to cope with many constraints (e.g. time limits, answering student’s questions, aligning to the curriculum, student’s arriving late, organising the activity and orchestrating the whole class), and the provision of the awareness tool added complexity to the already multifaceted instruction activity. This study also proved that instructors can greatly benefit from having quick access to information that is not easily visible in class time, for example, aspects of the quality of student’s solutions. The realism of this study also made it difficult to test experimental conditions (e.g. alternating visualisations in the awareness tools or comparing the usage of the tool with not using it at all) due to practical or ethical issues (e.g. all students had to have similar opportunities of learning). Additionally, the evaluation of pilot studies allowed testing the impact of the use
of the awareness tool in pedagogical and learning terms beyond usability. This could not be done in the previous two studies.

4.2.4 Stage 5 – Classroom use

Description of the study: this study consisted of a longitudinal class experience running across two full university courses (1 semester) with four instructors (all different from the previous evaluations stage), three different learning tasks and 145 students [24]. In this study, a full version of the awareness tool was provided. As shown in Figure 3, it featured a number of functions so the instructor could control the learning technology (Figure 3-A and B). It also showed one visualisation per group (Figure 3-D) and it included the provision of notifications (rounded squares around visualisations – Figure 3-E) that were triggered when misconceptions were detected.

Evaluation: Similar to the previous study, testing the awareness tool in-the-wild allowed understanding of the impact of the tool on learning and instruction. The visualised data reflects the change of student behaviour or the interventions performed by the instructor. For example, if the instructor attends to a group that has a misconception, the dashboard will update in real-time when that misconception has been addressed by the students.

Main lessons learnt: The evaluation of the awareness tool in-the-wild in this larger study allowed a higher degree of generalisation of the results [6]. Although the visualisations provided in the dashboard were not necessarily final, they proved useful and meaningful not only for the concept mapping activity but for other learning activities as well (such as brainstorming and face-to-face meetings). Additionally, the in-the-wild study allowed for testing the tool with more instructors than the pilot studies and for a longer time, thus minimising the novelty effect.

4.2.5 Iterative Design

The design of effective awareness tools, similar to other user interfaces, can be addressed with an iterative process. The purpose of this case-study is not to recommend the details of the visualisations and dashboards themselves (for this there has been nascent but extensive work [33]), but on the process of designing and refining visual awareness tools that may be effective for a specific context. For example, Figure 4 shows the evolution of two visualisations that were deployed in a classroom and were initially evaluated with prototypes. Although they may be simple, they present useful information to the instructor. It can be observed that: 1) there was a tendency towards minimalism. For example, for the visualisations “radars of participation” (see the three visualisation shown in Figure 4, on the top row) the prototypes featured two triangles depicting equity of verbal (blue) and touch (red) participation with the interactive tabletops. In the classroom, given the challenges to capture clean speech data, the visualisation had to be simplified to only show students’ touch activity data from the tabletops and names of students rather than symbolic representations (e.g. coloured circles). Additionally, 2) there was an increased focus on higher level indicators and less on accountability. For example, for the “contribution charts” (see the three visualisation shown in Figure 4, on the lower row), the pie chart used for the prototypes was simplified to indicate size of the solution (outer orange circle, in the rightmost visualisation) and the portion that matched essential elements expected by the instructor (the inner yellow circle), instead of individual contributions depicted by the slices of the pie chart. This project is continuing to explore other visualisations of group activity that can be useful by instructors or students. Therefore, it is important to have an iterative perspective from the beginning of the design process though to the end.

5. Conclusions

The design of effective LA tools requires the convergence of methodologies from multiple disciplines such as software development, human-computer interaction and education. Even though these disciplines provide guidelines and frameworks to guide designers towards effective applications, the LA community may benefit from paradigms that reflect its multidisciplinary approach. There is a need for systematic processes to tackle the critical challenge of designing effective interfaces for LA applications. In this paper, a workflow has been described to design LA awareness tools. It proposes an iterative process with five stages with the objective of producing robust tools suitable for large-scale adoption, and based on the combination of well-established techniques to improve user experience while maintaining an explicit connection with the underpinning learning environment. Our proposed workflow draws on the substantial body of work from SE and UX disciplines but also considers the pedagogical requirements and challenges designing LA tools to support teaching and learning in technology-enabled learning environments.

The workflow has been supported with a case study on the development of an awareness tool for instructors to observe small group interactions in a classroom. Even though the case study discussed involves rather leading edge technology (e.g. interactive tabletops), the core lessons learnt and the proposed workflow have broader applicability to both existing and future learning technology. Further work is needed to validate the application of the workflow in blended and online learning environments, and explore cases where awareness tools are given to students or other stakeholders. Future work is also needed to explore the time and effort required in order to put the proposed workflow into practice in other domains of application (e.g. into
a production environment). We believe that this work is an initial step towards much research needed to provide methodologies for the design of LA awareness tools. We consider the area of design frameworks as a crucial aspect to contribute to the holistic view of LA, foster its widespread adoption, and improve the overall learning and teaching experience.

6. REFERENCES