A Digital Learning Ecosystem to Scaffold Teachers' Learning

Kairit Tammets, Manisha Khulbe, Linda Helene Sillat, and Tobias Ley

***Abstract*—Technology-enhanced learning solutions carry the potential for transforming teacher learning and the delivery of professional development activities. This article proposes that the tools that professionals use in their practice can be considered an important mediator for professional learning. We carried out three design experiments, the results of which were used to formulate the conceptual design of a digital learning ecosystem for fostering teachers' professional learning, which is operationalized through different phases, namely competency-based planning of professional development, designing pedagogical practices, enactment of student-centered learning enriched with technology, and reflection upon own practice to plan comprehensively for competency-based professional development.**

***Index Terms*—Digital learning ecosystem (DLE), learning technologies, situated learning, teacher professional learning.**

I. Introduction

The important role that various learning technologies play in student-centered learning (SCL) has been widely acknowledged. However, the mere presence of technologies does not change the learning process and may not always support learning and teaching. For the successful adoption of technology-enhanced learning (TEL) and SCL in the classroom, not only initial teacher education but continued teachers' professional development (PD) is also critical.

However, the relationship between the technologies that teachers use in their classroom practice, and those which could at the same time support their PD, has not often been considered. TEL solutions hold the potential to not only enrich students' learning process but also allow teachers to become more aware of their professional practices while constructing knowledge about the SCL in their practice [1].

According to Brown and Duguid [2], knowledge is situated, and it is part of actions, context, and culture regarding its development and usage. Learning in this sense is fostered by the authentic tasks that professionals are working on and are engaged in [3]. Currently, there is a gap in teacher PD programs, as the TEL solutions introduced do not create a link between the training program, classroom practice, and teachers' PD. As a result of this gap, PD programs for TEL are often perceived by teachers as training on "how to use digital tools," but they leave the rich experience of teachers' classroom practices and the teachers' collaboration as a valuable source of learning experience out of consideration.

The role of physical and social contexts in learning has been highlighted for decades as indicated in the work of Lave and Wenger [4]. Teachers' professional learning can be considered social in nature and distributed across persons and tools that scaffold the construction of knowledge. This kind of professional learning is not a fixed formulation but is strongly shaped by the context of a teacher's practice—classrooms, teachers' networks, and schools.

A focus on the situated nature of knowing and learning suggests that teachers' classrooms are powerful contexts for their learning [5]. This assertion is relevant in the context of implementing new TEL practices in the classroom. A rich perspective in situated learning considers the tools that professionals use in their practice as an important mediator that facilitates learning. For example, teachers as professional learners need to be mindful of the technologies they use for designing, implementing, and reflecting on instructional practice because these indicators play an important role in contextualizing their learning [6]. Novel TEL solutions have great potential for transforming teacher learning and the delivery of PD activities [7]. As teachers create artifacts (learning resources, lesson plans) for students' learning, the technologies used by the teachers potentially mediate the teachers' learning as well. For instance, authoring tools could act as cognitive tools that provide a common language for creating digital learning resources (DLRs), thus scaffolding teachers' understanding of how to better design tasks to foster students' learning.

In this article, we will discuss how to link teacher situational learning—supported by different learning technologies to make teacher PD meaningful in a technology-enriched classroom. We assume that the symbiosis of the pedagogical and technological environment will make it possible to create a digital learning ecosystem (DLE) for teacher PD.

In the work of Laanpere et al. [8], DLE is defined as an adaptive socio-technical system consisting of mutually interacting digital species (tools, services, content used in the learning

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process) and communities of users (learners, facilitators, experts) together with their social, economic, and cultural environment. In contrast to initial teacher education where learning is often supported by institutional learning management systems, our proposed DLE consists of various digital tools that interact with each other, a variety of situated learning practices, and different levels of scaffolding that together support teachers' learning in their authentic professional contexts. Based on several design experiments with teachers in authentic educational settings, we aim to seek an answer to the question: of how to design the DLE to support teachers' situated learning.

II. Teachers' Situated Learning in a DLE

A. Digital Learning Ecosystem

The metaphor of "ecosystem" was borrowed from biology into education to describe the interactions and connections between humans, practices, environment, and resources [9], [10], [11]. The term has also been widely used in the field of TEL to describe the learning environments and interactions between users, practices, technologies, and data flows. According to Laanpere et al. [8], the components of a DLE function mutually to achieve an established goal and they suggest that three main structural components are important in the design framework of a DLE:

1) vocabulary (concepts implemented in the user interface);
2) software architecture (software elements, relations, and properties);
3) affordances (functionalities and models designed into the user interface, invoking certain activities).

The vocabulary depends on the pedagogical goal of the DLE. Here, we emphasize the notion of "scaffolding," which could be mediated by the social processes and technologies as already observed in the work of Pea [12]. Pea asserted the relationship between "social scaffolding" and "technological scaffolding" and the synergy between them to effectively promote the learning process. Learning technologies have been developed to scaffold teachers' PD, but there has been little research on how to integrate situational learning and the technologies that support it into a single whole.

The architecture of DLEs is often open and distributed in nature. Different services interact with each other to support the learning process. From the insights of other authors, such as Kirschner et al. [13], we recognized three types of dimensions while conceptualizing the design of a DLE:

1) the technological dimension (functionalities to scaffold teachers' learning);
2) the pedagogical dimension (properties of a system suggesting how learning behavior could be enacted);
3) the social dimension (socio-contextual facilitation needed for learning).

Research shows that DLEs have been mainly described in the context of higher education [8], [14] or secondary schools [9], [15]. Academic studies have focused less on how DLEs could support teachers' development. Laanpere et al. [8] emphasized that a DLE should foster competency-based and collaborative learning and enhance the self-regulation of learning using appropriate pedagogy, technology-mediated feedback loops, and interactions between the services and the community members. These elements are not only important for learners in formal learning environments such as secondary or higher education, but applicable for professional, workplace-based, and informal learning settings as well.

In addition to DLEs, there are other types of approaches that try to support teachers' PD in a systematic manner; and they emphasize the aspects of social learning and supporting technologies. For instance, the concept of networked professional learning builds synergies between teachers' professional learning and different technologies and it has been found that purposeful integration of technologies into professional learning practices could support teachers' learning experience [16]. Additionally, a well-established approach to support teachers comes from the field of learning design (LD). It has been found that technologies that guide teachers along the main phases of the LD process and enactment could have a positive impact on teachers' attitudes toward ICT integration [17]. However, the same authors emphasize that there is a need to build synergies between teachers' PD programs and LD technologies and integrate the technologies in a meaningful way to support PD holistically.

B. Teachers' Professional Learning

In this study, we conceptualize a DLE in the context of teachers' professional practice, and for this purpose, we rely on the situated perspective of experiential learning. Experiential learning models build on the constructivist theory suggests that a learner creates new knowledge and builds mental models based on their own experience; and theory aims to understand how the experience and reflection—the cores of the learning process—promote the learning experience [18].

Experiential learning has been used to explain how teachers develop their practice in the classroom: experimenting, reflecting, and adapting new theories and practices introduced in their professional context [19]. The well-known application of experiential learning is Kolb's experiential learning cycle [20] which involves four steps, namely

1) concrete experiences (being involved in a situation);
2) active experimenting (testing a theory by planning and following it);
3) reflective observing (looking at an experience and thinking about it);
4) abstract concept-making (forming theories about why an experience happened the way it did).

Central to this model is the understanding that without reflection there is no learning. In general, when one reflects on a situation, a conscious network of concepts is developed which helps describe practice [21]. Reflective practice is a widely known concept, which is rooted in the works of Dewey [22] and Schön [23]. In its application, reflective practice tackles the pedagogical challenges by reflecting on the action during classroom events and actions to improve future classroom interventions.

Kolb, however, did not emphasize social, historical, and cultural aspects of learning in his cycle. Therefore, the situated perspective on experiential learning has been chosen in this research. While for Kolb, learning takes place through reflection, situational learning models suggest that it is participation that supports learning. In situated learning, learners construct meaning from their experiences, action is grounded in authentic situations, and learning occurs in the social contexts in which new knowledge is to be applied [4]. Kolb's learning cycle is rooted in the individual's experience, but by combining this cycle with situated learning, we can emphasize the importance of an individual's experience within a community of practice as the way knowledge is constructed [24], [25]. Individual reflection is seen as a key process in situated work-based learning [26], depicting the individual's experience and how it is construed in the context of collective knowledge [27]. By enriching experiential learning with a situational perspective, we can emphasize the practice and reflection in the teacher's everyday environment, which is characterized by working with colleagues, participating in in-service training, etc. Teachers' professional learning should be embedded in their everyday context as they engage in daily activities [21].

Based on the premise that learning takes place through practice offers insights into learning technologies that teachers use as tools for support learning. Such technologies could be seen as mediators of the learning process. In this context, the tools change human behavior and advance knowledge and work—which is organized around collaboration and shared, technology-mediated knowledge artifacts and practices [28].

The trialogical learning paradigm is linked with the cultural historical activity theory (CHAT) [29] and is characterized by shared objects, sustained interpersonal knowledge, and collective knowledge advancement. According to Vygotsky [30], experiences are always mediated by a tool, and therefore in CHAT, knowledge is perceived as a collaborative construction mediated by cultural and social artifacts grounded in practical activities. As alluded to already, the trialogical learning approach is organized around shared knowledge artifacts as mediators of thought and behavior of individuals [31]; that mediation is between individual learning, group cognition, and organizational knowledge building. Learning technologies are not just a medium that transmits knowledge to a user, but tools that are structuring and mediating the learning accomplished through activity [32].

By and large, the teachers' professional learning might be more meaningful if it is experiential, situated, reflective, and mediated through their everyday learning technologies, which could stimulate change in teacher practice. Attempts have been made to have an ecosystem view on teacher professional learning [33], [34]. At the same time, there is little research on the design of DLE that would be embedded in the teacher's daily activities and support the teacher's PD through feedback loops. Feedback loops could raise teachers' awareness about their learning, scaffold their learning and revise the role of learning technologies through social, contextualized, and artifact-mediated learning processes. In Fig. 1, we illustrate our pedagogical approach to DLE design derived from the work of Kolb [20]. We have mapped the stages of teachers' learning with relevant artefacts that can be created at each stage, and which could mediate the learning process.

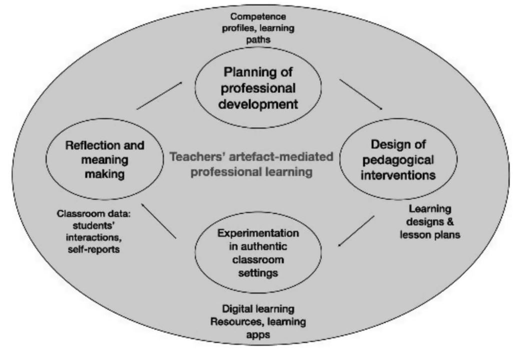

Fig. 1. Teachers' artifact-mediated learning process.

1) Development of Teachers' Competence: A teacher's task is to create a learning environment that provides students with deep learning experiences. For this reason, teachers need appropriate technological, pedagogical, and content knowledge [35] coupled with digital competence. In this research, we narrowed down the teachers' competence to digital competence due to the nature of the research carried out in the study. Digital competence has been defined by Ferrari [36] as "the set of knowledge, skills, attitudes that are required when using ICT and digital media to perform tasks, solve problems, communicate, manage information, collaborate, create and share content, and build knowledge effectively, efficiently, appropriately, and critically."

Digital competence plays an essential role in response to the challenges posed by digitalization, and practically the educational field is the key to promoting such developments [40]. However, this requires that teachers are digitally competent [41].

A variety of international and localized digital competence models and frameworks have been developed for use by teachers (ISTE, Mentep, DigCompEdu among others). Such frameworks are used by researchers to understand, what factors predict teachers' digital competence [37], the reliable means through which the teachers' digital competence could be assessed [38], and how to support the development of digital competence [39].

Even though frameworks, models, and policies have been formulated about digital competence there is a lack of discussion about how teachers perceive the assessment process and its benefits for their practice. This assertion is made with the backdrop that studies published on the evaluation of teachers' digital competence and the factors affecting the level of digital competence have not successfully addressed the subject matter. In this light, learning is conceptualized as a competence development activity in this article. One of the steps to competence development could involve teachers' periodic use of relevant frameworks to guide the planning of their development, classroom interventions, adoption of new methods, and reflection. Currently, these frameworks are not embedded into teachers' daily practices. There seems to be a lack of use of a self-reflection tool that translates framework indicators into professional activities to which teachers can relate. Practically, feedback on possible paths for enhancing teachers' competence which can contribute to transforming a framework tends to be externally imposed in a bottom-up, participatory movement [35].

Frequent use of competence frameworks in training courses or other collective development exercises and the ensuing discussion among participants may further underscore the frameworks' meaningfulness. Competency models should not be used merely to measure competence levels, but in the correct settings, can be an important tool for eliciting professional dialogue, engagement, and activity. This enhances the potential in promoting teacher motivation, agency, and voice, effectively harnessing the potential of digital technologies.

2) Teachers as Designers Supporting Students' Learning: A variety of TEL solutions offer different possibilities for transforming students' learning experiences. DLRs, digital textbooks, educational games, robotics, and the Internet of Things all provide ways of engaging students through an SCL approach and active learning methods. However, the availability of new technologies is not enough. Technology has always created high expectations in education, but technology alone has not yet produced sustained changes in the field [42]. A study by Camilleri and Camilleri [43] demonstrated that teachers are aware of the need to adapt their educational practices to contemporary reality and enrich them with learning technologies, but they are not very confident in using certain technologies in their practice.

Especially in the field of TEL, the importance of the role of teachers as designers is stressed to address the challenges discussed earlier [44], [45]. Although the design is a routine part of educators' practice while planning lessons, choosing study topics, presenting content, planning learning activities and assessments, etc., there is a need to go beyond the conventional such as building choices and challenges for the students, anticipating student needs, gathering feedback, making adaptive changes while teaching, improving one's practice, etc [46].

LD is a field that has been linked with TEL research [47]. Broadly speaking, LD is "the description of the teaching-learning process that takes place in a unit of learning for instance a course, a lesson, or any other designed learning event" [48]. LD specifies the educational objectives and the pedagogical approaches that teachers can reflect upon and make improvements to [49], but while embedded into the broader ecosystem of educational practice, it offers a lot of space for improving the workplace learning of educators [46].

The uptake of LD has fostered the concept of reusability in education—good practices created by teachers in different educational contexts can be used, validated, and adapted in other situations. Recently, the field of LD has focused on using computer-based tools to support teachers in the design of pedagogically sound learning environments. The co-creation of LDs and the development of tools supporting this process have been studied by several authors [50]. Research supports the notion that scaffolding when the design process is scaffolded, the uptake of LD in teacher communities is improved [51].

However, despite more than a decade of research LD has not yet widely impacted teaching practice [34]. For instance, Mettis and Väljataga [52] analyzed LDs created by teachers with online tools and concluded that teachers did not make use of the full potential of mobile technologies; and that this situation could be addressed by scaffolding the design process. Research holds that current LD tools should provide support to all the phases in the design process (from conceptualization to enactment with learners to reflection) [53]. It has also been pointed out that there is a need to equip teachers with the appropriate LD mindset for making design decisions in their practice [54]. Consequently, appropriate training is required to foster the adoption of LD tools [55]. Finally, researchers have rarely focused on the role of design practices in teachers' PD.

3) Teacher Inquiry and Reflection: Although the concept of reflective practice has been part of research, practice, and policy developments for decades, it has become more relevant again in recent years due to developments in learning analytics (LA) and the availability of LA tools for teachers. Although it is universally accepted that teachers' reflective practice and inquiry is an important component of teachers' professional learning, it is still not a widespread practice in the TEL field [56]. Teachers are monitoring their students' learning and improving their practice, but this process is not systematic and not always grounded in evidence collected with LA tools.

Researchers have made several attempts to tackle these challenges. First, different models have been proposed to guide teachers in the inquiry and reflection process. In the context of this study, the teacher inquiry into student learning model proposed by Hansen and Wasson [57] is relevant as it includes the elements of an individual and collaborative inquiry using data generated by students during TEL activities. Second, a variety of tools have been developed to support teacher inquiry. Although LDs describe pedagogical intention, they do not identify how students are engaged in that design during enactment [53] and this is where LA can provide information for a more holistic perspective regarding the impact of learning activities. Well-designed teacher-facing dashboards can fit seamlessly into the activities of teaching professionals [58]. Additionally, Michos et al. [56] have proposed a tool, TILE, to guide teachers in the design of, and reflection upon, TEL interventions. Prieto et al. [59] have proposed a tool to help teachers reflect upon their practice daily and with minimal resources. Again, however, there could be more discussion on how LA dashboards could act as artifacts mediating teachers' learning. Third, different approaches to support teacher inquiry have been proposed. For example, Schildkamp et al. [60] have suggested that teachers' participation in data teams could support their PD; and this is underpinned by their willingness to use data in instructional and school improvement practices. Vermunt et al. [61] propose the lesson study approach that integrates features of effective PD programs, namely addressing the problem of practice, focusing on students' learning, modeling, and sharing of instructional practices, active learning, teacher inquiry, and professional learning communities. Despite the efforts to propose models, methodological approaches, and technological solutions, evidence of long-term uptake of evidence-based teacher inquiry outside of research and training contexts is scarce. One of the challenges could be that PD is often carried out separate from classroom practice [62] and teachers are prepared to work with educational data through decontextualized

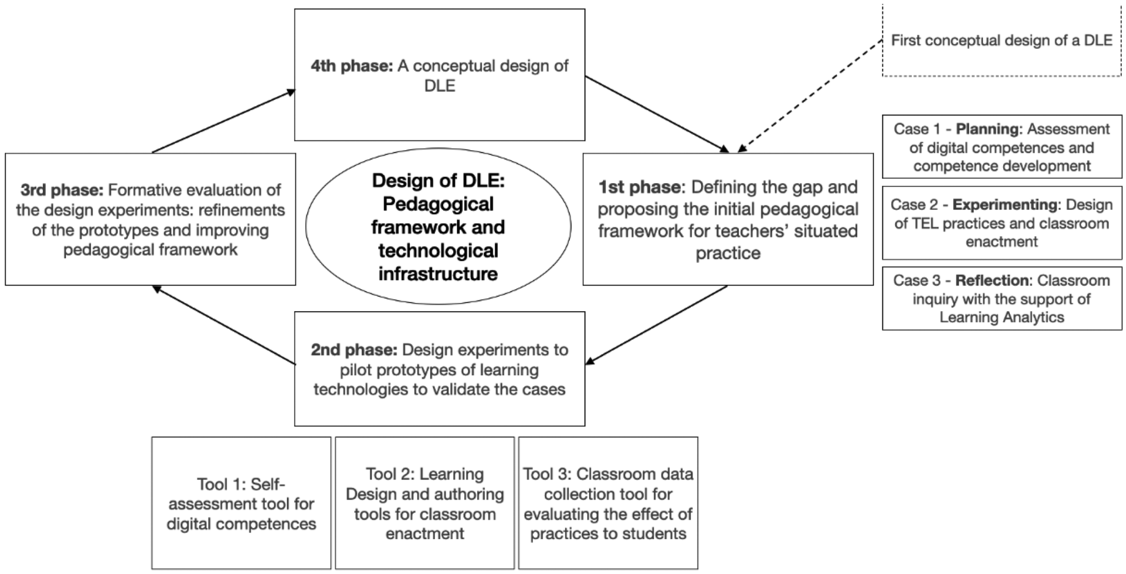

Fig. 2. DBR phases of the research.

courses [57]. Therefore, using data for inquiry does not become a part of teachers' daily practice.

In the light of the above, this study aims to bring together technologies that can provide holistic support for the stages of teachers' PD and create opportunities for analyzing teachers' learning situations.

III. Methodology

The previous sections of this article demonstrated that a lot of progress has been made to support individual phases of teachers' professional learning with technological means, but a holistic view and integration of these approaches would be needed to realize untapped potential for feedback loops. To realize such integration, we set out to evolve a conceptual design of a DLE for teachers' situated learning.

A. Research Design

We employed design-based research (DBR) which helps to understand the complex nature of real-life LD problems [63], [64]. This methodology is frequently employed for improving learning and teaching in TEL environments. DBR is characterized by iterative cycles of theory-based reflection, analysis, and refinement, and aims to produce guidelines and principles for tackling problems in the field of TEL [65]. Usually, DBR focuses on the creation of single tools or services and their respective learning practices to address specific learning challenges. In doing so, a DBR project creates a design and iteratively develops it through cycles of testing and evaluation in realistic settings to advance knowledge about the domain, learning theory, and design [65]. For the current research, DBR was extended to focus not only on individual learning tools that teachers would use in their professional learning but on a holistic design and practices for teachers' long-term professional competence development. To this end, we followed the idea of creating a DLE that supports longer processes of PD with the intention that teachers would interact with several learning technologies that are dynamically configured toward a long-term development goal. This means that in our case, DBR processes are conceivable on two levels of abstraction (see Fig. 2)—development of each individual service follows a DBR process, addressing more targeted challenges in the overall PD cycle (e.g., how to self-assess professional competence). Additionally, a more long-term DBR process focuses on the connections between the tools and their conceptual and technological integration into an ecosystem of services. In this article, we emphasize the latter DBR process, while still drawing on evidence of the design and evaluation processes of the former.

Resultantly, we present the first version of an integrated conceptual design of the DLE that is validated through a reanalysis of some of the prior design experiments with individual services. This article first proposes a common comprehensive framework for a DLE, and then presents the results of three design experiments in the context of this comprehensive framework, from which we derive a conceptual specification of the DLE. Subsequent studies will then test these interactions in new design experiments.

1) **Phase 1** - We identified a problem and proposed the initial framework of DLE that provided the basis for the creation of three cases to validate parts of the framework. In each of the cases, practical needs were formulated, drawing upon relevant literature and the authors' previous work. Different aspects of teachers' learning were identified (competence development needs, designing practices, classroom level enactment, and reflection) to be embedded into the design of the prototypes.
2) **Phase 2** - Three design experiments were carried out to pilot the developed learning technologies in authentic classroom settings: Tinda for supporting teachers' self-assessment of digital competence; LePlanner for supporting teachers' LD practices; repository of DLRs for

classroom enactment and reflection-in-action; self-reporting tool for students, LaPills for collecting data to reflect upon classroom practices.

3) **Phase 3** - Formative evaluation of the design experiments and the refinement of the prototypes and improvement of the pedagogical framework were carried out in phase 3.
4) **Phase 4** - A conceptual design of DLE for teacher PD was proposed drawing on the results of the cases. In the upcoming phases of the research, the prototype of the DLE will be piloted in teachers' situated practice and further improvements will be made to the system.

B. Design Experiment (Cases)

Design experiments were carried out to validate learning technology prototypes and approaches in authentic settings and to gather input for the design of DLE. Design experiments are often used not merely to empirically evaluate what works in practice, but also to iteratively develop theoretical insights in practical educational contexts [63]. The purpose of the experiments was to test potential components of the DLE to be designed, examine their appropriation in practice, and discover important interactions or feedback loops between the phases. All the interventions were conducted in authentic work-based settings and involved Estonian primary and secondary school teachers as participants. We aimed to understand what kind of affordances teachers perceive while interacting with the technologies and how this knowledge could be embedded into the design of DLE.

1) Case 1: Assessment of Digital Competence: **Goal**: To understand how teachers assess their digital competence, perceive the assessment experience, and how self-assessment is combined with the competence development process to validate the planning phase of PD.

Sample: A total of 1125 Estonian primary and secondary school teachers were recruited in the national level study to assess their digital competence. A total of 46% (N = 523) of the teachers who participated in Case 1 responded to an open-ended question asking them to reflect upon how useful it was for them to self-assess their digital competence. A total of 96% of the teachers who responded to open questions were female and 4% of the teachers were male. A total of 4% of the respondents were younger than 30 years, 16% of them were aged between 31 and 40 years, 28% were 41–50 years old, and 52% were older than 51. A large sample was needed here because we wanted to validate not the tool used but the methodological approach to competency assessment. With a smaller sample, it would have been difficult to identify teachers' difficulties in adequately assessing their competence.

Procedure: Teachers filled in a web-based questionnaire based on the DigCompEdu Framework which was localized by an Estonian expert working group and validated in 2019. Questionnaire items were based on six competency areas: professional engagement, DLRs, teaching and learning, assessment, empowering students, and developing students' digital competence. The questionnaire consisted of 25 items and teachers were asked to assess themselves on a scale of 0 (not applicable) to 5 (leader). Additionally, teachers reflected in the form on the experiences and usefulness of analyzing their digital competence.

Self-assessment results are described in another study [66], but for this study, we analyzed teachers' perceptions of the usefulness of assessing their competence and the examples they provided to demonstrate competence.

Prototype: Self-assessment tool for assessing competence.

Evaluation: Content analysis was carried out to analyze teachers' responses regarding the usefulness of assessing their digital competence by two of the researchers. Responses were categorized inductively as:

1) not useful, with subcategories of justifications (not useful; not useful, because I do not analyze myself; not useful, because I already know my level of competence; not useful, because I analyze myself regularly anyway)
2) useful, with sub-categories of justifications (useful; useful, because I discovered my development needs; useful because it made me reflect upon my practice).
3) not sure when the respondent marked not sure if the experience was useful or not.
4) feedback about the instrument (out of the scope of this study)

2) Case 2: Design and Enactment of Classroom Practices: **Goal**: To explore how teachers design SCL scenarios to actively experiment with DLRs and pilot them in their classrooms—to validate the enactment phase of the study. SCL is the focus of this study, because it has been argued that implementation of teacher-centered instruction to use DLRs in teaching dominates and may not lead to efficient learning [43].

Sample: A total of 21 teachers were recruited via an open call for participation in this study which involved piloting of DLRs 3–5 times a month in the teachers' classrooms. A total of 19 of the teachers were female and 2 were male teaching students from grades 10 and 11, and 1200 students were included in the study.

Procedure: A total of 6000 DLRs developed by Estonian researchers, didactics, and in-service teachers for mathematics, natural science, social science, and arts and music were piloted by the study participants. Before the piloting phase, teachers received a short training and instructional guidelines to understand the pedagogical underpinnings of DLRs, innovative learning scenarios, technological aspects, and the possibility to mix the DLRs and re-design learning scenarios.

Prototype: To develop new DLRs, interactive templates by H5P running on Drupal Content Management System were selected as the main platform for authoring. The platform was set up and developed further H5P templates and enhanced the Drupal side with the management of Learning Object Metadata, also OAI-PMH interface for automatic harvesting of the metadata of H5P learning objects by the national learning resource catalog eSchoolbag (e-koolikott.ee), where teachers had a chance to access them and share the links of the DLRs with the students who interacted with the DLRs in teaching and learning process. Teachers who piloted the DLRs (and all other teachers) can use the platform to create new DLRs as well as adapt existing ones, which makes it relevant for the design and enactment phase of teachers' situated practice.

Evaluation: Google Forms was used by the teachers after each piloted lesson to answer four questions: intended design to pilot DLRs, how was the implementation of the LDs, and what obstacles did the teachers and students face during the enactment. Content analysis was carried out to analyze teachers' responses. In the initial coding stages, two of the authors read and reread the teachers' reflections to identify how the lessons were designed (actual pedagogical practices) and whether and how they struggled with DLR use. Pedagogical practices were categorized based on three learning scenarios introduced to the teachers: flipped classroom, problem-based learning, and task-based learning. More categories like "individual interactions with DLRs" and "collaborative interactions with DLRs" was added. Results in more detail are discussed in another paper [67].

3) Case 3: Reflection and Inquiry: **Goal**: To analyze how teachers understand students' engagement data made available through LA dashboards.

Sample: A total of 21 mathematics teachers participated in teacher PD training over 9 months. The training aimed to prepare the teachers to design and implement innovative LDs to foster students' engagement in math and to make sense of the students' engagement data collected from classroom practice.

Procedure: Over 9 months, teachers created novel LDs (altogether nearly 100) and piloted these designs in their classroom settings 4–6 times. Each new LD was updated, according to the topics learned during the training. In the reflection phase, each piloted lesson teacher collected their students' anonymous data about their engagement, which was adapted from multiple engagement self-report instruments [68], [69] and required responses on the 5-point Likert scale. Instrument focused on cognitive ($n = 9$ items), emotional ($n = 9$ items), behavioral ($n = 6$ items), and agentic ($n = 6$ items) dimensions of engagement and disengagement. Students' responses were analyzed based on the mean scores for each of the dimensions of engagement and made available to teachers through a simple dashboard. As part of the training, teachers were asked to analyze students' responses and reflect upon the results using a questionnaire administered via Google Forms.

Prototype: Online self-reporting tool LaPills, which included an engagement questionnaire and displayed student responses as simple visualizations for the teachers.

Evaluation: Using Google Forms, teachers were questioned about their understanding of students' engagement data. They were also asked to write what they would do differently in future lessons, based on the data collected. Content analysis was carried out to analyze teachers' responses. In the initial coding stages, two of the authors read and reread the teachers' responses to identify how they made sense of the data.

IV. Results

In this section, we present the results of the design experiments and discuss these from the perspective of teachers' situated learning and its three aspects: competence development and design of new practices, active experimentation, and reflection. In the last section, we present the conceptual design of the DLE for teachers' PD.

A. Evaluation of Design Experiments

1) Competence Assessment as a Learning Experience: In our research, we consider competence development as part of the learning process. Development of competence could be conceptualized as walking through a piece of knowledge- and skill-oriented learning environment [70]. However, for developing competence, one needs to understand one's own development needs and the gaps in one's practice.

A total of 68% of the 523 teachers *perceived the self-assessment process as useful*. A total of 238 teachers considered the process useful, but did not provide further explanation or only mentioned laconically that the process was useful ("*was useful*"); ("*I know now that I am the beginner*") or useful because examples in the questionnaire helped them understand what the term digital competence mean. A total of 12% of teachers (68) responded that the self-assessment process made them reflect on their practice ("*I realized that I use little differentiation*"; "*The process made me think about how my teaching has an impact on students' learning and what can I do differently*"). A total of 8% (46 teachers) reported concrete examples of the development needs they identified during the self-assessment process ("*I have never thought I should collect students' data to improve my practice*"; "*I have not considered ethical aspects in my teaching with digital technologies*").

A total of 17% of the teachers reported that assessing their digital competence *was not useful for them*. A total of 53 teachers did not provide any explanations for their responses. A total of 20 teachers said that they already knew their level of digital competence and did not need more evaluation ("*I know my skills even without digital competence analysis*"; "*It doesn't help much, I know anyway what I can do and what I can't*"). Few teachers reported that they analyze themselves regularly, self-analysis is a difficult process, or that the process was not useful because the analysis was not informative ("*What did I learn from this process?—I don't know my level, I don't know what I should do to be better*"). The rest of the responses were related to the assessment instrument and not relevant to this study.

Main outcomes:

1) Most of the teachers considered the process of self-assessing their digital competence useful: it made them reflect upon their strengths and weaknesses and development needs.
2) However, currently, *teachers do not get feedback about their assessment results*, and by no means do they get feedback on how to develop their digital competence. Therefore, the process of self-assessment could systematically support, and advance development *based on the possible learning trajectories*, providing possibilities to monitor the competence development process and understand the best practices regarding how to develop competence.
3) It is noteworthy that 17% of the teachers claimed that such a self-assessment is not helpful for them, mainly

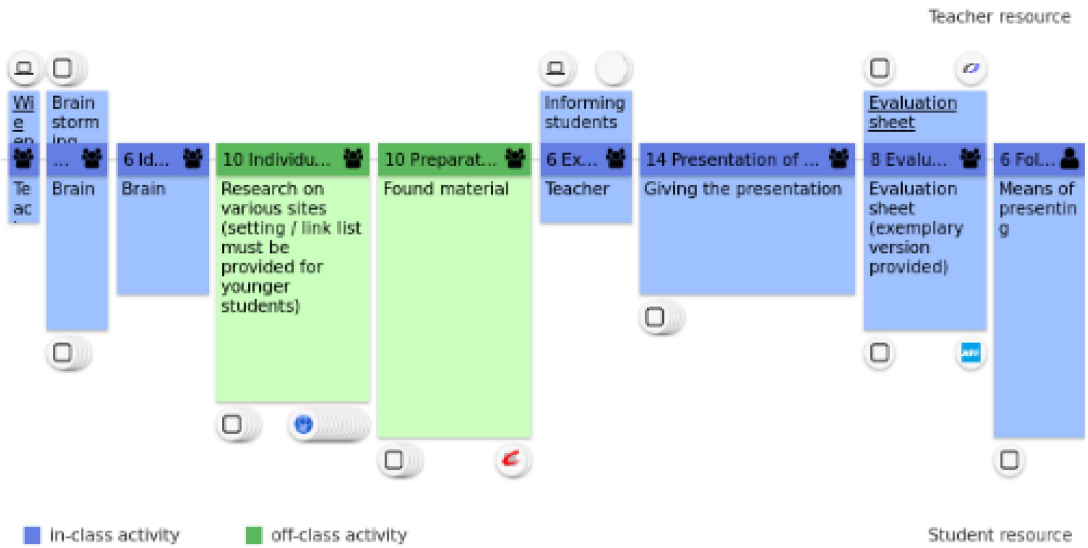

Fig. 3. LePlanner for creating LDs.

they reported that they already know their level of competence. However, such an implicit understanding of one's professionalism is not always sufficient. Therefore, we consider it important that *the assessment and planning of the development of digital competence are embedded into initial and continuous teacher training*, which provides the context and need for planning PD. But additionally, to strengthen the idea of competence development as a learner walking through knowledge- and skill-oriented learning environment, there is *a need for a competency-based portfolio system* [71] that integrates the possibilities for self-assessment and collection of evidence, and scaffolds reflection upon competence development.

2) Design and Enactment of TEL Practices: For Case 2, H5P-based DLRs were made available for the teachers to pilot in their practice. The teachers were briefly instructed about designing LDs emphasizing SCL using available DLRs. The following scenarios were proposed to fulfill the potential of developed DLRs

Flipped Classroom. Before the lesson, the student learns the basic concepts of a new topic independently or in cooperation with others, using recommended materials. In class, students collaboratively apply this new knowledge to solve problems.

Problem-based learning. Student teams are created, with each team member having a clear role. Students jointly define their interdisciplinary study project, stating expected outcomes and a timeline. To achieve the project goal, individual and collaborative interactions with DLRs are expected.

Task-based learning. Students solve increasingly complex tasks while learning a new topic, relying on the DLRs. Once the tasks given by the teacher have been solved, the students themselves create new tasks on the same topic (both simple and more complex) in pairs and give them to other students to solve.

An example of an LD designed as flipped-classroom activity is described in Fig. 3 using the web-application LePlanner. It presents a sequence of activities of varying duration from left to right where activities in blue refer to learning activities that take place in the classroom and green activities happen outside the classroom. Activities below the central line refer to student-led activities and activities above the central line are more teacher-led. Activities include the links to the DLRs that students are expected to use individually, in pairs, or collaboratively. Each specific LD has its sequence of stages, in which students perform certain tasks. These functionalities of LePlanner are an example of how the teacher is scaffolded while designing the lesson activities and support teachers to develop their digital competence through pedagogical scenarios.

Teachers' reports about how they designed the lessons and then actually implemented the design enabled us to understand how teachers adopted the DLRs into their practice. We analyzed 196 lesson descriptions according to whether the DLRs were implemented in a more teacher-led way or according to the innovative learning scenarios we introduced to teachers.

The content analysis of LDs indicated that although teachers participated in a workshop where they were introduced to student-centered LDs with the support of DLRs, most of their teaching practices remained pedagogically teacher-centered. We found out that almost 90% of the analyzed LDs indicated that teachers used a teacher-led instructional approach: first teachers introduced the new topic, next students read/watched the DLRs, and finally, students solved interactive tasks individually or sometimes in pairs ("*We watched together the material on the screen and discussed it, students read the two materials independently and solved one self-assessment test*"). Less than 10% of the actualized SCL practices were introduced to them before the piloting experience. For instance, one teacher of natural sciences piloted problem-based learning and used a hybrid learning environment for using DLRs. In this scenario, students went outside by the river to solve inquiry tasks. ("*At first students get acquainted with the topic and solved the tasks, after getting acquainted with the environmental topics, the students went to a river near the school and answered questions about the environmental topic at a selected point*").

Our results indicate that despite the training on how to design meaningful SCL LDs, teachers' practice was still one-sided. Additionally, we analyzed the feedback teachers provided after implementing DLRs. Almost half of the teachers (n = 9) mentioned that using DLRs provide automated feedback for the students based on their interactions, but they also wanted to understand the progress of the students ("*Unfortunately I did not know how my class performed and therefore it is difficult to assess the suitability of the materials for my class level*"; "*At the moment, unfortunately, I didn't get any feedback on how the students progressed; I had to ask the students to take a screenshot and send it to me*"). Based on that we can suggest that the piloting experience would have been more effective if teachers had received feedback on students' performance.

Main outcomes:

1) Despite making novel LDs available for the teachers, *they did not change their teaching practices and the DLRs were mainly used traditionally*—to replace textbooks, but not to create a new SCL experience for the students. This indicates that short training and availability of DLRs will not lead teachers to change their pedagogical practices and for this, teachers need more support. This is well-aligned with the understanding that to foster a change in teacher practice*, there is a need for training formats embedded into teachers' situated learning*. Teachers are not only expected to implement new technologies, but they are also expected to create new knowledge practices around new technologies, implement and reflect.
2) Teachers missed the feedback about their students' progress. Although it is an evident result, it still emphasizes the *need for the feedback loop between teachers' pedagogical interventions and students' interactions***.** Authoring tools can provide simple overviews for the teachers based on students' interactions about progress in learning scenarios. *The interplay between design and enactment was important for the teachers*, which needs to be better scaffolded in the reflection phase.

3) Reflection Upon One's Instructional Practice: For Case 3, a training program was developed to, among other things, enhance teachers' competence in working with their students' data (here, specifically, self-reported engagement data), with the aim of supporting teachers in reflecting upon their practice. Teachers were encouraged to use the LA tool to monitor students' engagement and reflect upon this data every month after implementing new classroom practices (see Fig. 4. The students here reported high behavioral engagement—most of the students report working hard in class—but low cognitive engagement—few students report using appropriate cognitive strategies). The teachers received guidance in different aspects of data use: monthly training sessions for teachers included time devoted to researcher-led discussion of data from a randomly chosen classroom, including responses to numerous engagement challenges indicated by the data.

Analysis of teachers' reflections on students' data they provided monthly using Google Forms demonstrated that most of the teachers were able to use data to effectively understand

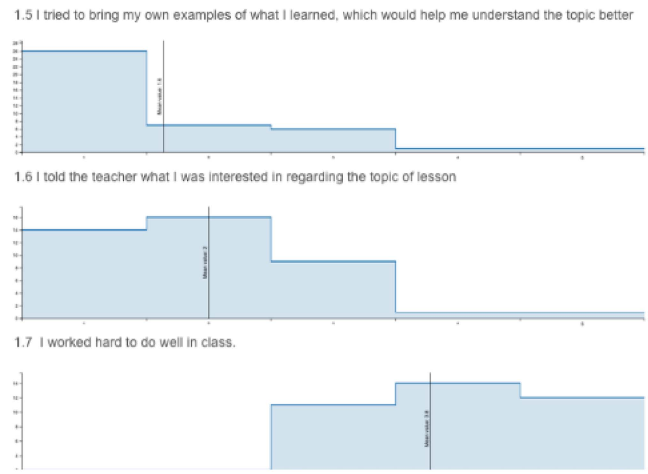

Fig. 4. Web-form visualizing data about students' self-reported engagement.

students' engagement and data were used correctly to identify gaps in students' learning in mathematics. The responses show that all the teachers who filled in the form were trying to make sense of data in the context of their class. For instance, several teachers were wondering why students did not express mathematical concepts in their own words although it was part of the LD ("*It seems to me that more could be done in the part of understanding, such as more explaining in their own words"; "rephrasing new things with their own words still needs more working on*"). The analysis of teachers' responses showed that simple feedback made them realize that implementing SCL design was difficult, and changes in students' learning did not happen as expected. However, this feedback did not help teachers to understand what other strategies they could try out and the data did not call for action. Research has shown that teachers mainly struggle to choose pedagogical actions in response to data [80], which found that the most difficult facet of data use for teachers is deciding how to respond to information presented. It has been previously proposed that LA should diagnose problems and provide suggestions about how to handle them.

Main outcomes:

1) Teachers who are introducing new practices in the class and at the same time learning about pedagogical–psychological concepts in their practice can be supported by the LA dashboard. Dashboard scaffolds them in understanding the enactment of instructional practices by providing insights into data, making connections with the theory, and recommending appropriate pedagogical actions.
2) As the provided feedback was rather descriptive and did not call for action, teachers did note that some strategies did not work, but they also did not come up with suggestions on how to improve the instructional practices. *Data analysis should be firmly grounded in the underlying learning processes—relevant pedagogical theory* (in this case, engagement) *and content knowledge* (here, mathematics), which not only informs but supports the teacher in noticing and adapting different strategies to support student learning and development of own digital competence.

3) In-service training embedded into teachers' everyday practice and focusing on technologies, pedagogical practices, and data literacy *contributes to the teacher's adoption of innovation***,** the results of which are discussed in more detail in a separate article [73].

As the main data source of engagement was students' self-reports, the feedback regarding students' learning was not as informative as it could be for the teachers. Aggregating self-reports with log data (interactions) would enable more meaningful information to understand what strategies engage students at different levels, which, in turn, supports the development of the teacher's pedagogical understandings.

V. Conceptual Design of a DLE

In this section, a conceptual design of DLE for teachers' situated learning will be proposed. Design experiments carried out as separate studies to understand pedagogical, technological, and methodological aspects are now coupled into the design of the DLE. Integrated DLE has not been validated in the design experiments, it will be part of future research. As emphasized throughout the article, it is important to implement a holistic system and pedagogical framework in the teacher's daily practice, supported by systematic in-service training focused on competence development.

As a general approach to developing this system, we have followed the paradigm of a DLE consisting of independent and coupled services. This is because we do not foresee the support that could happen through a linear process guided by some form of workflow. Rather, our insights show that teachers would be using different systems and tools in different sequences at various stages. The necessity to design feedback loops into the process (e.g., between the planning of actions, enactment, data collection, and reflection) still requires a tight coupling of these services. This could be achieved, for example, by using the same competency model across services to make semantic connections between them. Another example would be the usage of students' data (self-reports or logs data) to inform the LDs created in LePlanner to create the feedback between design and enactment. The next section will present details of coupling from a technological and pedagogical perspective.

A. Dimensions of the Proposed DLE

The technological dimension of our DLE consists of a variety of tools to aid teachers' learning. These are online web applications developed by the research group and developed as part of the design experiments described in Section IV. Data collected from a variety of applications have been integrated to enable the scaffolding of teachers throughout the process and feedback loops between the phases (see Fig. 5)

The input layer of the system consists of web services used by teachers in different phases of their learning.

Tinda is a web application based on Drupal. It allows teachers to assess their digital competence in the context of chosen qualification standards. The tool includes an item pool, an assessment module, and a PD module. The item pool consists

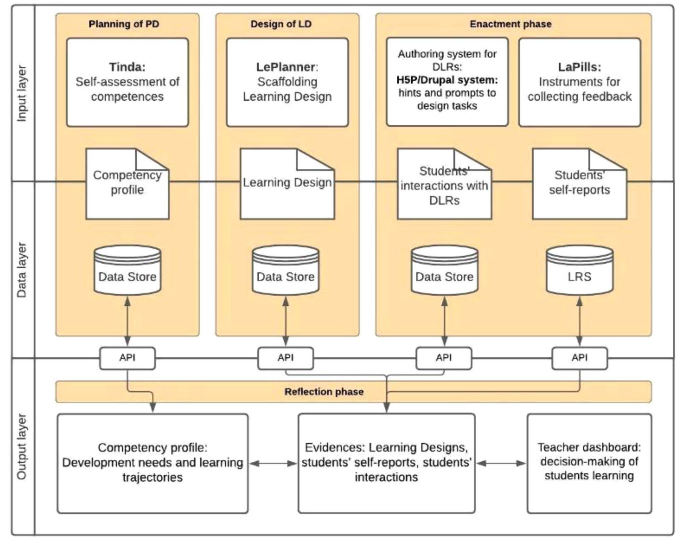

Fig. 5. Conceptual design of the DLE.

of questions based on competency models. To aid teachers' learning, the system can generate a competency profile based on self-assessment results.

LePlanner is a web application that supports teachers in designing SCL. Teachers can document, visualize, and share LDs by sequencing learning tasks and linking them with relevant DLRs, as well as with expected learning outcomes from the national curriculum. An artifact created by the system is an LD, which can also be used as evidence for certain competence from the teacher qualification standards or digital competency models. A willingness to exchange information between design and enactment is established, enabling the teacher to understand the intended design and actual implementation. For instance, if the teacher has planned an activity with DLRs to support students' engagement through problem-based tasks, the teacher will be informed later about how the students coped with the tasks and what this means for their engagement. This will help the teacher to spot opportunities for improvement in LD. Such reports about the actual design are created as artifacts for usage to use as evidence of competency profile.

For *authoring DLRs*, we employ a Drupal + H5P-based service as described in Case 2. DLRs created with H5P templates include taxonomies and metadata to describe the DLRs based on learning outcomes, curriculum topics, cognitive processes, etc. While creating and publishing DLRs, the system guides in the form of scaffolds helped plan the students' learning process. For example, the teacher might be encouraged to create tasks that allow different students to interact with different and appropriate levels of tasks, thus providing a more effective SCL approach. Artifacts created by the system supporting teachers' learning are DLRs. Students' interactions can be used in the reflection phase to scaffold the development of teachers' knowledge about the pedagogical phenomena and strategies to implement them in the classroom.

The web-application *LaPills* is developed to support teachers' understanding of certain pedagogical phenomena in the class based on students' self-reports. The system includes instruments about topics such as engagement, collaborative learning, motivation, etc., which can be used by the teacher at any time during the lesson. Students' reports are made available for the teachers for reflection and improvement purposes, but also for using them as evidence of certain competence.

Each of the after-mentioned web services collects certain data that could be used for different purposes in teachers' PD: competency profiles based on self-assessment results, created LDs, informing teachers about the effect of the pedagogical practices on students' learning based on students' self-reports and interactions with DLRs and providing actionable feedback how to develop digital competence and refine pedagogical practices.

The data layer collects all this information in databases and learning record store (e.g., data collected with H5P-based DLRs) and uses APIs for fostering communication between other services. All the content that teachers create (LDs, DLRs, reflections) are annotated with specific categories from domain models and taxonomies, which enable to translation of the interactions of students into the language of pedagogical models, which could foster the learning of teachers. Students' interactions are, therefore, automatically annotated with a specific category (e.g., domain concept used in taxonomies and domain models inserted into the system) which links students' performance with a given learning outcome. For instance, students' self-reports about the engagement and interactions with the H5P-based materials, which are linked with the certain pedagogical model, enable to analyze the level of students' engagement and feed it back to the teacher in an explainable and actionable way.

From the perspective of teachers' learning, there is a need to use a common competency model across services. Consequently, in our study, we propose that a portfolio-based environment, which communicates with other services through APIs to make connections between competence, artifacts, and learning incidents, is essential. Competency-based portfolios have been used a lot in medicine and teacher training, but less in the contexts of in-service teachers' PD. Driessen [74] has suggested that competency-based portfolios may differ in terms of content and format, but in general, they all aim to present achievements, feedback, and possibly also goals and plans. For this purpose, it is important to collect teachers' evidence about certain competence (e.g., digital competence in this study) and make them visible to understand their development, process, and scaffold future learning paths.

Fig. 5 illustrates the *output layer***,** where such a system is proposed to close the loop of PD, pulls teachers' competency assessment results, evidence of competence in the form of LDs, students' results with H5P, and students' self-reports from the other tools, and combines them as evidence of certain competence and supports teachers in planning their PD. For instance, to support the teachers' reflection phase, we have proposed an initial prototype for a scaffolding teacher reflection [73]. An API has been developed for the reflection tool to collect data from different services—DLRs and LaPills. This data is analyzed according to theory-based rules and displayed on a dashboard for teachers along with prompts and tips that encourage reflection. The reflection tool integrates the students' self-reports and log data and thus informs the creation of LDs. Teachers can use the information for instructional decision-making or to collect evidence about their performance and make sense of their PD.

The main pedagogical principle in our proposed DLE relies on the concept of scaffolding. The functionalities and affordances of the system guide and support teachers through different phases of experiential learning in their situated practice.

In the *planning* phase, the system provides prompts and supportive questions on how to analyze one's own competence. Based on the assessment results, personal trajectories are suggested for the teacher to improve the skills through different accumulated community level knowledge**:** training, best practices, and examples on how other colleagues have developed their competence. Such a personal plan helps teachers to move into the second phase—*design of SCL practices*. Scaffolding teachers to understand different pedagogical approaches, classroom challenges, principles of students' learning process helps teachers to design a lesson based on pedagogical principles to support SCL. During and after the *enactment*, it is important to scaffold teachers to reflect about the experience and understand the impact of teaching on students' learning. *Reflection* is scaffolded through data collection tools that make students' learning process visible for the teachers. Based on the students' interactions, feedback is given about the applied teaching strategies. More importantly, reflection prompts and questions are part of the system to guide teachers to think about the classroom enactment and make improvements to teaching.

Several studies have indicated that model-based LA (dashboard that integrates pedagogical-psychological models to interpret data) helps teachers to understand students' engagement in class and offers bases to intervene when needed. For instance, a study by Aslan et al. [75] revealed how real-time data supported teachers to understand how engaged students are in class. According to this study, teachers intervened more often based on the feedback they received. Case 2 from this study also demonstrated that if data is made available for the teachers to go beyond just clicks based on students' interactions with DLRs, but rather translated into pedagogical questions that teachers face in the classroom, then it becomes meaningful for the teachers. If the feedback provided through the LA dashboard takes into consideration the mechanisms underlying learning processes, it can positively influence students' learning process [76]. However, it is necessary that the system aids teachers to make sense of such pedagogical underpinnings based on students' data; and for this reason, a variety of metacognitive prompts, questions, and hints could be considered as scaffolding elements. Teachers become more knowledgeable about the pedagogical affordances of the novel technologies and tools they use in their practice and can then support their PD.

VI. Conclusion and Limitations

Teachers are using different learning technologies in their classrooms for designing new interventions, implementing teaching strategies, or reflecting upon the interventions based on students' data. In addition to that, teachers are regularly asked to assess themselves, plan their development and participate in professional training. However, so far there has been limited discussion about how such technologies and PD practices could be seamlessly integrated and to what extent the learning technologies used by teachers could support their learning.

For technologies to support teachers' learning holistically, technologies need to be integrated in a way that supports the whole cycle. This is what the DLE proposes to do. Such an integrated view is needed to ensure that tools are aligned to the phases of teachers' learning, the data collected is integrated across phases, and the sustainability of individual tools is supported. In contrast to preservice teacher education, which is usually handled by single institutions and can therefore be technologically supported by a learning management system [77], the case of in-service teacher training calls for a different approach. In that case, a more flexible approach is needed that is guided by teachers' needs and motivation [78]. The DLE we present in this article is optimized for this situation. In this research, we aimed to integrate different technologies and teachers' PD and proposed the conceptual design of a DLE for scaffolding teachers' planning, enactment, and reflection during their learning. Scaffolding is important when teachers integrate technology into their practice to foster SCL and to understand the impact of their practices on students' learning.

The conceptual design was created through an analysis of literature and backed by conducting several design experiments that involved hundreds of teachers in their natural settings—classroom practice and PD. This allowed us to address a variety of challenges in the context of teachers' PD such as 1) how to plan one's development based on competency models, 2) how to design and enact SCL practices, and 3) how to use data to evaluate the effects of classroom practices. From the results of the design experiments, it is possible to perceive teachers' resistance to adopting proposed technologies or methodological approaches in their practice. This is understandable because demands on teachers have dramatically increased. The expectation is no longer only that they will try out learning technologies in the classroom, but they are encouraged to engage systematically in collaboration and reflection using those.

From the perspective of the sustainability of the proposed DLE, and from a technological point of view; the proposal of the holistic DLE ensures that the relationship between the tools and the data layer is documented systematically. From the pedagogical point of view, the DLE is closely aligned with the teachers' PD process. This contributes to sustainability because the functionality and use of the web applications are aligned with the PD process. This also promotes future adaptability and maintenance.

The DLE proposed in the study makes a connection between different phases of teachers' learning by fostering each phase through technological, pedagogical, and social scaffolds. Design artifacts created by the teachers in each phase are seen as mediating objects of teachers' learning in a social and situated context. The proposed tools are software products that exchange information with each other and thus, a feedback loop based on pedagogical questions is developed. In the future, the whole ecosystem and the related pedagogical practices can be further validated in a longer teacher training program. Especially the framework has the potential to bridge formal and informal learning with digital technologies in teachers' workplace learning settings.

There are some limitations to this study, mainly due to the complexity of validating the DLE. This study presents only the results of a single phase of design experiments through three case studies, which aimed to validate one at a time, different prototypes in teachers' actual practice. The integrated DLE will be validated in future research as the next phase of our DBR. Comprehensive validation requires a study that covers in a single intervention all the important phases, pedagogical approaches and tools, and the pedagogical approach and social dimension. A large-scale and longer study is needed to understand the full potential of the proposed ecosystem for scaffolding teachers' situated learning. Understandably, embedding such a system in the PD of the teacher through training is a major challenge because, in addition to the technical (systems working and exchanging data) and pedagogical aspects (teachers' readiness to follow the phases of the pedagogical framework), the level of digital competence of the teacher to implement the system and readiness to change needs to be considered.

Another aspect that needs to be further developed and empirically tested is the social dimension of the DLE that focuses on the interplay between teachers' individual and collective knowledge. This need has been acknowledged by earlier research [79], [80]. The next phase of the study should focus on the social practices of teachers' learning with the intention to find out how knowledge collected from phases of teachers' situated learning and made available for teachers through a DLE could foster their PD.

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