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EXPLORING HOW TEACHER AGENCY UNFOLDS WITHIN THE CO-DESIGN OF A SMART LEARNING ENVIRONMENT-SUPPORTED LEARNING ACTIVITY: A CASE STUDY

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ABSTRACT

Aim/Purpose

This paper studies how teacher agency is shaped by the affordances and autonomous functioning of a Smart Learning Environment (SLE) through the co-design of a learning activity. Specifically, it addresses the following research question: *How does participation in the co-design of a learning activity supported by a Smart Learning Environment shape the development of teacher agency?* The reported case study offers a novel contribution by connecting specific facets of teacher agency with SLE affordances while highlighting the decisive role of stakeholders in technology-supported teaching.

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Background	The affordances of Smart Learning Environments (SLEs) can have positive and negative effects on teachers' roles. Prior studies highlight the benefits of involving teachers as co-designers of the technological solutions to foster teacher agency. However, these studies do not fully address the extent to which teacher agency may be empowered through educators' involvement in co-design processes aimed at developing learning activities to be supported by SLEs. A case study was set up to reveal how teacher agency unfolds in such scenarios, considering the affordances of the SLE and the role of the SLE researchers as core mediating elements. Thus, this research delves into the study of a concept that requires further investigation, which is key to ensuring the trustworthy deployment of intelligent technologies.
Methodology	A qualitative case study was conducted grounded in the interpretivist research paradigm. Data was collected from multiple techniques and sources (e.g., semi-structured interviews, audio recordings of co-design meetings, artefacts generated in the process). The study spanned a multi-phase evaluation event design process, including: (i) the co-design of a learning activity to be supported by the SLE, (ii) the enactment of the learning activity, and (iii) a post-hoc reflection. The participants in this process were a Higher Education Teacher responsible for a course on *School Organisation and Planning* (which involved 71 first-year kindergarten pre-service teachers at a Spanish university), a lead researcher who was also responsible for the development of the SLE, and two researchers supporting the co-design. The naturalistic nature of the study, densely described, aims at strengthening the transferability of findings. Inductive coding was performed, and thick and context-related descriptions are reported to support credibility and transferability.
Contribution	This study proposes a foundation for comprehending how aspects of teacher agency relate to affordances and functions of SLEs within the co-design process of a learning activity. The findings were synthesised in a comprehensive model relating facets of teacher agency to the SLE by means of the co-design. A complete evaluation of the deployment of a novel SLE is reported through the lens of teacher agency. This work contributes to the ongoing discussion about the impact of intelligent technologies on teacher agency in Technology-Enhanced Learning (TEL).
Findings	The results showed that relevant SLE affordances aligned with the teacher's pedagogical stances (e.g., the connection between formal and informal learning spaces and the support for contextualised learning) and empowered the teacher to create a learning activity that went beyond her past practices. However, the lack of support for collaborative learning deprived the teacher of fully attaining agency. The researcher's role in facilitating the co-design was a key supporting element for the teacher agency. The individual nature of the student model of the SLE created a tension with the teacher's pedagogical stances. While the autonomous functioning of the SLE was not perceived as a threat to the teacher's practice, the teacher reported a preference to have more control over the SLE.
Recommendations for Practitioners	Teachers need to be granted opportunities to shape the operation of SLEs to align with their pedagogical stances, goals, and constraints of higher education courses. Educators should also be involved in the development process of the SLEs or in the co-design process of learning activities that motivate and enable adjustments in the technology. Participatory co-design processes are necessary to materialise meaningful, innovative learning activities supported by intelligent technologies such as SLEs. These strategies could allow teachers to cultivate and

	preserve agency in evolving and complex TEL scenarios. Educators should also carefully consider the balance between their workload and their capacity to review automated suggestions provided by SLEs.
Recommendations for Researchers	We recommend the TEL community to conduct in-depth studies and co-design processes of learning activities to identify constraints that may hinder teacher agency and to maximise opportunities for supporting it, specifically in scenarios in which SLEs have not been designed involving teachers. Researchers and developers should strive for simplicity and representativeness when designing student models embedded in SLEs. They should also ensure that teachers are given opportunities to remain in the loop when SLEs begin functioning autonomously.
Impact on Society	The concept of agency is central to current debates in educational research, in which technologies with intelligent features (e.g., Artificial Intelligence or SLEs) are being embedded. The impact of these technologies on teachers' practice should be assessed at different levels of technological integration (e.g., design, enactment). This study shows how teacher agencies are shaped by the co-design process and emphasises the importance of early human involvement and strong communication among stakeholders. SLEs hold significant potential to help teachers transform their practice and sustain agency.
Future Research	Future research should deepen the understanding of how teacher agency develops during co-design and enactment with intelligent technologies, extending these findings to diverse contexts. We point out the need for an explicit study of how the best practices regarding student modelling can be achieved. This implies examining the configuration of SLEs' student models and teachers' stances.
Keywords	teacher agency, smart learning environments, co-design, technology-enhanced learning, case study

INTRODUCTION

Teacher agency refers to educators' capacity to make intentional decisions that influence their teaching and classroom environment to achieve their educational objectives (Biesta & Tedder, 2007; Sang, 2020). Teachers manifest their agency by exhibiting ownership of their professional activity and their ambition to tackle educational challenges (Biesta et al., 2015). Teacher agency has recently become a topic of strong interest within the Technology-Enhanced Learning (TEL) research field. Researchers are aiming to uncover the extent to which teachers can actively engage and incorporate new technologies into their teaching and learning contexts (Gudmundsdottir & Hathaway, 2020; Ibrahim et al., 2022). The implications for teacher agency are intrinsically tied to the features of the technology (e.g., which learning analytics should be displayed to the teachers, and which automatic reactions should be communicated). Hence, retaining control over what the technology does remains a key requirement for not hindering teachers' autonomy and their ability to make decisions. Albion and Tondeur (2018) advocated for empowering educators' agency when shaping and implementing technologies in ways that suit their concrete classroom needs. This empowerment perspective values teachers' knowledge and experiences over prescriptive directives (Albion & Tondeur, 2018).

Smart Learning Environments (SLEs), as instances of intelligent educational technologies, provide adaptive support to students by taking into account their learning statuses, individual needs, and the online and real-world contexts in which they learn (Hwang, 2014; Hwang et al., 2008). SLEs can provide autonomous recommendations to learners (Tabuenca et al., 2021) that may challenge teachers' roles. Thus, involving teachers in the development of SLEs has been suggested for achieving more

sustainable and trustworthy solutions (Gros, 2016; High Level Expert Group on Artificial Intelligence, 2019). Co-design is frequently used in the TEL area for developing solutions that require stakeholders' active involvement (Penuel et al., 2007). When teachers can participate actively in designing and developing digital tools, their ownership and reflection on practices increase, leading to a reinforced agency (Roschelle et al., 2006). Previous research in higher education contexts shows that collaborative practices can support educators in navigating constraints when using technology, thereby enhancing their agency since it is modulated by the support from the *educational-work* environment (Ehren et al., 2021; Nøhr et al., 2023). Approaching the integration of technologies from a collaborative and relational perspective of teacher agency (Novoa-Echaurren, 2024) might benefit the adoption of technologies with the capacity to influence teachers' range of choices when enacting learning activities (Brod et al., 2023; Nazaretsky et al., 2022). Furthermore, there is a need to study changes in the division of labour (i.e., task allocation) originated by adaptive systems (du Boulay, 2021). In cases where the technology assumes the provision of recommendations, guaranteeing mechanisms for teachers to resume control is a key principle (Molenaar, 2021).

When planning the integration of SLEs, the focus should also be placed on studying the most adequate conditions for promoting an active role for teachers (e.g., through co-designing SLEs, their components, or learning activities to be supported by them) (Dron, 2018). Carruana Martín et al. (2023) found that control over the creation of learning activities that are supported by SLEs influences teacher agency positively. Whereas Carvalho et al. (2022) underscored the importance of empowering teachers in decision-making in the co-creation process, they have a sense of agency when designing learning activities supported by intelligent technologies. However, research has not sufficiently focused on how teachers' involvement in the co-design of learning activities that will be supported by SLEs influences their agency (Lin & Van Brummelen, 2021). Therefore, we formulate the following research question:

> **RQ:** How does participation in the co-design of a learning activity supported by a Smart Learning Environment shape the development of teacher agency?

This paper presents a study in which a higher education teacher participated in the co-design of a learning activity to be supported by an SLE. Following an interpretive approach through a case study, we studied how teacher agency unfolded during the co-design process of a learning activity. The influence of the learning activity's enactment was also evaluated as a means to elicit further implications from teachers' practice beyond those that were observed at co-design time. We emphasised identifying the alignment or misalignment between the SLE's affordances and the teachers' pedagogical stances, the role played by the lead researcher (and developer of the SLE), and the implications that emerged during the enactment of the learning activity.

BACKGROUND

TEACHER AGENCY IN TECHNOLOGY-ENHANCED LEARNING

Human agency has been conceptualised from different perspectives. From a sociological perspective, Archer (2000) emphasised the role of autonomy and power in determining human agency, which depends on the contexts in which humans operate. However, Bandura (2006, 2018) offered a psychological perspective, positing agency as the capacity that enables humans to shape their life circumstances, choose their actions, and assess them through cognitive self-evaluative mechanisms.

From another perspective, Emirbayer and Mische (1998) proposed that human agency is a socially embedded process that unfolds over time. In this view, agency is not static; it evolves dynamically as individuals interact with their environment. It is achieved through the materialisation of significant changes in people's realities (Biesta & Tedder, 2007; Emirbayer & Mische, 1998). In light of that foundation, Priestley et al. (2015) developed a framework to characterise teacher agency as a complex phenomenon resulting from the interplay among individual intentions (future projections), personal

stories (informed by past experiences), and social structures (present constraints or opportunities). Teacher agency is crucial for ensuring educational change as it implies that teachers exhibit ownership of their professional activity and ambition to tackle educational challenges (Biesta et al., 2015). However, despite this conceptualization, in education, and more concretely in TEL contexts, teacher agency requires further investigation to formulate more effective strategies that support teachers' professional growth and everyday practice (Deschênes & Parent, 2022; Elm et al., 2023).

Previous works drew on teacher agency as a vehicle to understand how teachers cope with new technologies or new scenarios, emphasizing how teachers exercise ownership of their practice, make decisions, and face changes (e.g., redesigning learning activities for remote teaching during the COVID-19 pandemic). In this sense, Ehren et al. (2021) found that positive past experiences in combination with supportive professional networks are likely to contribute to change practices in technology-mediated educational contexts. However, teachers should also develop their digital competence to seamlessly incorporate technology with their pedagogical approaches, which typically requires continuous professional learning (Pathiranage & Karunaratne, 2023). Although educators should carefully plan the implementation of emerging technologies, considering the uniqueness of their contexts, it is crucial that mandating practices do not restrict teacher autonomy, allowing them enough *room for manoeuvre* to adapt these innovations to their specific needs (Albion & Tondeur, 2018). For this purpose, advocating for collaborative agency perspectives in which raising awareness of teachers' practices among other stakeholders involved in educational ecosystems can lead to more nuanced decision-making regarding the implementation of technologies (Novoa-Echaurren, 2024).

The recent rise of intelligent technologies able to provide adaptive support to learners (e.g., Artificial Intelligence, Smart Learning Environments) has introduced new challenges for educational actors (Molenaar, 2022). In fact, there are still open issues related to the ethics of AI in education, e.g., concerning the application of computational approaches and the role to which teachers might be relegated (Holmes et al., 2019). For the agency to be preserved, the technology should be designed to assist teachers in making better and more informed choices and not restrict their autonomy (High Level Expert Group on Artificial Intelligence, 2019). Implications for teacher agency with respect to intelligent technologies have partially been studied at enactment time. This has been the case of Carruana Martín et al. (2023), who analysed the implications of an SLE for teacher agency through the study of orchestration load.

Additional insights show that when teachers enact learning activities supported by intelligent technologies, they should be granted opportunities to review, edit, and override automatic recommendations as a requirement for enhanced trust in the systems (Nazaretsky et al., 2022). Nevertheless, we claim that shifting the focus to the pre-enactment stage (i.e., design of the learning activity) can provide insightful evidence for understanding the development of agency in educational settings in which intelligent technologies are embedded. This approach, combined with an analysis of teachers' post-activity reflections, may offer crucial evidence for deploying these systems, as suggested by Wang et al. (2022). Additionally, Lipponen and Kumpulainen (2011) pointed out the importance of studying how agency emerges within the particular contexts in which it is embedded, including tools and practices. For these reasons, we opted to study how teacher agency unfolds during the co-design process of a learning activity and what its implications are when enacted with the support of an SLE. For this paper, we framed our understanding of agency in accordance with Priestley et al. (2015) as an ecologically rooted phenomenon informed by past experiences, oriented towards the future, but enacted in a concrete situation, both being restricted and supported by cultural, structural, and material resources available to educators. We also followed Lipponen and Kumpulainen's (2011) premises in terms of understanding agency as situationally constructed as a result of the interactions with the contextual elements of the co-design.

Smart Learning Environments and the Role of Teachers: Towards the Co-Design of Learning Activities to Reinforce Teacher Agency

To provide personalised learning experiences, SLEs keep track of students' prior knowledge, changes in learning status, and learning objectives (Hwang & Fu, 2020). SLEs represent students' learning status in a particular domain and context is regarded as a student model, which is a key component for enabling adaptive support (Sison & Shimura, 1998). A student model heavily depends on the data that can be pragmatically collected through the learning technologies (Abdi et al., 2020). However, collected data and the corresponding learning analytics should not only be aligned with findings of learning sciences but also with the teachers' pedagogical stances and the design of the learning environment (Gašević et al., 2015).

The three core functions performed by SLEs were defined by Tabuenca et al. (2021). *Sense* implies the collection of data traces from artefacts and applications that learners interact with. *Analyse* entails the filtering of collected data to extract meaningful indicators. *React* refers to the provision of customised interventions (e.g., adaptive feedback) based on analysed data. The basic operation of AI in education was defined by Molenaar (2021) based on three operations (*detect-diagnose-act*) with similar implications to those described above for the SLEs. Concerning teachers, they may benefit from SLEs' autonomous functioning by a more effective allocation of resources (Molenaar, 2021). Therefore, teachers' workload may be diminished by these systems (Jørnø et al., 2022). However, teachers are not free from risks if proper mechanisms for awareness and resuming control are not provided (Molenaar, 2021). Consequently, educators might not be fully aware of the decisions and actions taken by the system, which may ultimately hinder teacher agency by limiting educators' autonomy and ability to oversee its functioning (High Level Expert Group on Artificial Intelligence, 2019; Holmes et al., 2019).

Additionally, the widespread use of context-aware devices, such as smartphones, has enriched learning environments by integrating rich contextual data and has enabled smooth, personalised interactions through SLEs (Koper, 2014). Hence, SLEs provide educators with the opportunity to reconceptualise their activities by incorporating ubiquitous learning, linking physical and digital spaces across formal, non-formal, and informal contexts (Hernández-Leo et al., 2023; Hwang et al., 2008). The phenomenon in which teachers are empowered by smart technologies has been characterised by Holstein et al. (2019) as goal augmentation. It remains to be fully explored in terms of understanding the impact on teachers' practice of designing learning activities that extend beyond their usual practice (e.g., considering formal-informal spaces for learning, blurring times, and extending feedback provision). du Boulay (2021) argued that potential changes in the distribution of roles between adaptive systems and teachers, when orchestrating learning activities, need to be studied to better understand the new orchestration requirements derived from the use of these systems.

Effective implementation of SLEs requires educators to leverage technology to enhance pedagogical practices. However, this can be particularly demanding due to the complexities of intelligent technologies. In the realm of TEL, co-design offers an approach that enables educators, researchers, and developers to collaborate in partnerships to develop innovations seamlessly integrated into classroom settings (Roschelle et al., 2006). Co-design can involve the design of technological systems to provide support to teaching-learning practices, or it can involve the design of curricular materials (e.g., learning activities) (Barbera et al., 2017). These co-design operationalizations allow researchers and developers to gain insights into teachers' goals, needs, and expectations of the innovation. These can be the technology itself or a novel learning activity to be supported by a technology. Conversely, teachers have the opportunity to reflect on how the technology can support their practices (Matuk et al., 2016). In co-design, teachers are often the stakeholders who drive the change, since the technology needs to comply with their own instructional course requirements (Barbera et al., 2017).

The engagement of teachers in the development of innovations typically leads to a heightened sense of ownership, a phenomenon associated with a reinforced agency as teachers can leverage the role of technology to maximise their pedagogical practices and better respond to students' needs (Ketelaar et al., 2012). The study of social and situated practices (i.e., co-design in this case) provides a ground for identifying forms of transformative agency (Lipponen & Kumpulainen, 2011). Transformative agency involves proactively initiating changes to existing structures and practices, typically exercised collectively (Lipponen & Kumpulainen, 2011). Such a study would allow the extraction of the most adequate mechanisms for supporting teacher agency in co-design processes involving projecting future learning activities supported by SLEs. Furthermore, analysing co-design processes in detail is critical for advancing the knowledge of the TEL community on how innovations crystallise in authentic learning contexts (Treasure-Jones et al., 2019).

We build on the ecological model of teacher agency (Priestley et al., 2015) to synthesise the theoretical implications of the role of co-design for educators in TEL contexts. This model features three dimensions: the iterational, the projective, and the practical-evaluative (corresponding to past, future, and present time). Within this framework, agency is understood as being enacted in the present, yet affected by past experiences and future goals and desires. Co-design, as described in this section, serves as a means of operationalizing teacher agency as an output, where an innovation is expected. Such innovation manifests how teachers are reconfiguring recurrent practices and materializing transformations. Support from other stakeholders (typically researchers and developers involved in co-design) is critical for maximizing the synergies between SLEs and the instructional context, particularly when learning activities or curricular transformations are intended. Figure 1 illustrates Priestley et al.'s (2015) adapted model, which includes the concepts of co-design, agency, SLE affordances, and stakeholder support.

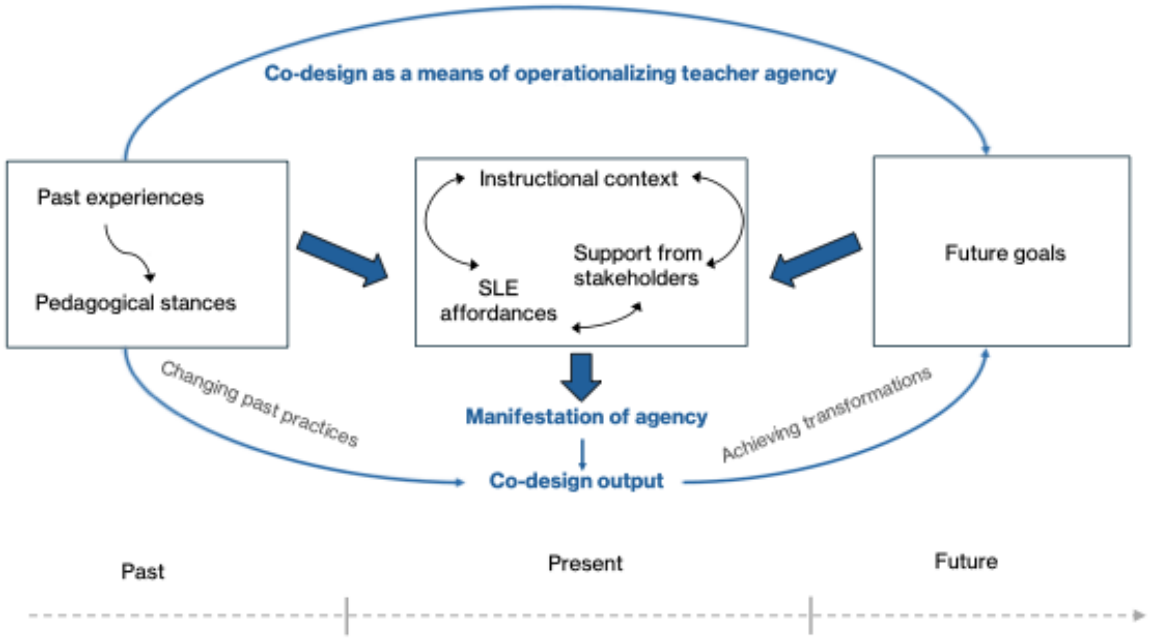

Figure 1. Mapping co-design and stakeholder involvement onto the ecological model of teacher agency: A visual summary of concepts (adapted from Priestley et al., 2015, p. 4)

The literature shows that the earlier teachers' requirements are considered by technological developers when designing intelligent technologies, the better developers strive to support teachers' pedagogies and augment their capacities (Mavrikis et al., 2019). However, it is not uncommon for teachers to

encounter tools that have already been designed without their involvement. In such cases, there is likely to be less flexibility to accommodate educators' stances and needs, and, therefore, teacher agency achievement may be mitigated. In such cases, the co-design of learning activities before their enactment stands as an opportunity to reinforce teacher agency while granting researchers opportunities to better comprehend in what sense teachers' practice would be altered by the technology they are to adopt. With the purpose of studying that phenomenon, we formulated the following research question (RQ):

> *How does participation in the co-design of a learning activity supported by a Smart Learning Environment shape the development of teacher agency?*

We opted for a qualitative study, as it has been empirically demonstrated to be effective in describing how the phenomenon of agency unfolds in technology-mediated contexts (Digón-Regueiro et al., 2023).

METHODOLOGY

A qualitative single-case study was conducted to answer the aforementioned research question. Our case study aimed for a qualitative in-depth exploration and analysis of complex activities under special circumstances (Stake, 1995). The case was purposefully selected as an instrumental case, given its potential to illuminate implications for teacher agency within a bounded context (Stake, 1995). This research follows an interpretive inquiry approach, aiming to generate a comprehensive picture of the research problem by drawing from the multiple meanings that participants provide (Creswell, 2009). The case study design aligns with the naturalistic approach, in which no interventions were introduced by the case researchers themselves. This enabled a real-world account of how teacher agency emerged within the situated nature of a co-design process. Given the naturalistic nature of the research study reported in this paper, we prioritised a comprehensive and detailed description of a particular phenomenon (Guba, 1981, p.86) to achieve maximum transferability to other contexts, in line with other similar studies published in related literature. The single-case design seeks an accurate understanding and not generalization (Stake, 1995), while enabling emergent data to inform theory-building, particularization, or the enrichment of existing models (Guba, 1981, p.81). In this case study, we aim to gain a better understanding of how teacher agency is shaped when a teacher co-designed a learning activity supported by an SLE. For ensuring a detailed comprehension of the phenomena, we defined three sub-research questions (SRQ1-3) (see Figure 2):

> **SRQ1:** To what extent do the affordances of the SLE align with the teacher's pedagogical stances?

We aimed to analyse whether such alignment is a critical factor in facilitating agency attainment.

> **SRQ2:** How does the involvement of the SLE lead researcher in the co-design process shape teacher agency?

We assumed that the role of the lead SLE researcher and the co-researchers in the co-design process might influence teacher agency in various ways.

> **SRQ3:** How do the specific functionalities of the SLE impact the teacher's role during the enactment of the learning activity?

The enactment of the learning activity was used to understand whether the functioning of the SLE had implications for the teacher's role beyond what was observed in the co-design phase. We assumed that the autonomous functioning of the SLE could ultimately impact teacher agency.

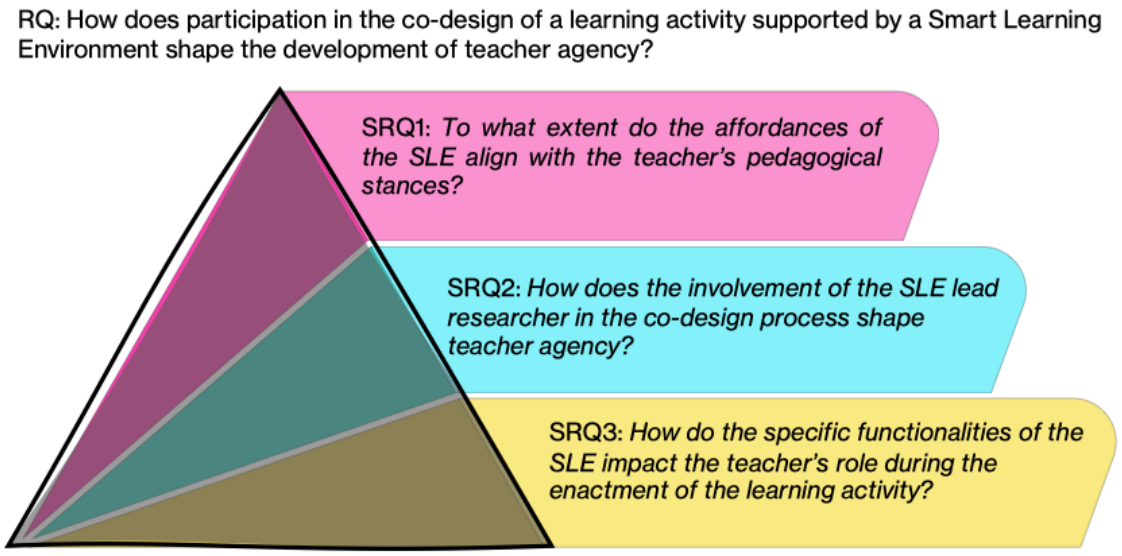

Figure 2. Scheme depicting the hierarchy between the research question (RQ), represented by the triangle, and the three sub-research questions (SRQ1-3) guiding the study

Context of the Study

The study took place during the undergraduate course School Organisation and Planning (OSP) with 71 1st-year kindergarten pre-service teachers at a Spanish university. The OSP course aimed to present the main school functions in terms of legislation, roles, and resource distribution. The third content block, in which the current intervention is framed, deals with the transformation of school spaces. The teacher was a 40-year-old female with 8 years of overall experience (approximately 1 year of experience in primary education and 7 years in higher education). She was responsible for the OSP course for the second time. One characteristic of the teacher is that she tends to implement technological innovations. In particular, she has experience designing and implementing activities that favour the connection between formal and informal learning spaces supported by technology. Apart from the OSP teacher, the study involved a lead researcher and two co-researchers. For clarification, the lead researcher and co-researchers are not the same individuals who conducted the case study reported in this article.

The case study was carried out by researchers who acted as observers and were not involved in the development or evaluation of the SLE. The lead researcher was responsible for testing and evaluating the functionalities of an SLE named SCARLETT, which he had developed, within an authentic context, meeting the educational needs expressed by the teacher during the co-design meetings. The dual role of the SLE lead researcher, including both a development agenda and evaluation deadlines, led them to steer the direction of the co-design process. This proactive role of SLE researchers in staging the co-design was not incompatible with the aim of achieving an outcome that satisfied both parties (Pedersen, 2020), especially if researchers try to stay flexible (Barbera et al., 2017; Pedersen, 2020). The co-researchers provided guidance in the design of the SLE and in the process of co-designing the learning activity.

The code of good research practices, established by the institution where the research was carried out, was followed. An informed consent form was signed by the participants expressing their willingness to participate in the study and to allow the processing of the data for publication. In this consent form, participants were informed about how their data would be handled, the purposes of the study, and their right to edit or withdraw their data from the study. Participants' identities have been removed from both the datasets and the publications, and a unique tag has been assigned to each participant to prevent reidentification. However, given the rich contextual description of this single case

study, reidentification of the participants (teacher and SCARLETT researchers) in the co-design process is still possible. The participants have been informed and explicitly agreed to assume the risk.

The following subsections describe the co-designed learning activity, then the characteristics of SCARLETT, and the SLE that supported the learning activity. The co-design process of the learning activity is presented, and finally, the data collection and analysis of the study are presented.

The Co-Designed Learning Activity

The learning activity supported by the SLE had the following pedagogical aim: to review content related to the spatial and temporal organisation of schools (e.g., layout and organisation of classrooms, playgrounds, school building, school schedules), as well as content related to governing school management bodies and school planning documents (e.g., school council, annual plans). The learning activity consisted of three phases.

Phase 1: During a 2-hour in-class session, the teacher implemented a Kahoot (https://kahoot.com/) quiz to retrieve information on the status of students' knowledge about several topics of the course (e.g., time of educational legislation, physical design of school spaces: classroom and playgrounds).

Phase 2: During the following five days, students were encouraged to perform outdoor geolocated tasks at nearby school playgrounds using a web-based application developed specifically for their smartphones. These tasks were automatically generated by SCARLETT, considering the student model previously built as a result of Phase 1 (and updated throughout Phase 2). Once students completed these tasks, they eventually received recommendations for new tasks to perform related to topics they needed to reinforce. Additionally, SCARLETT generated individualised learning portfolios that the teacher could check. This phase also aimed specifically to reinforce significant learning of the architectural features of playgrounds by encouraging students, whenever possible, to observe school playgrounds directly.

Phase 3: Students performed a location-based activity to reinforce their knowledge of the course topics. The activity involved QR codes placed around the university campus. The QR codes, which had to be found by the students using a map, pointed to questions based on the contents that students struggled with in the previous phases. The teacher designed the questions taking into account the students' set of answers. The SLE had no further implications in this phase. Nonetheless, once this phase concluded, SCARLETT generated a personalised quiz for each student that was integrated into the course Learning Management System (Moodle), to review content based on students' answers in the previous phases of the learning activity.

The Smart Learning Environment: SCARLETT

SCARLETT (Smart Context-Aware Recommendation of Learning Extensions in ubiquiTous seTtings) is an SLE that enables the connection between formal contents (e.g., contents and quizzes in the Learning Management System) with real-world contexts out-of-the-classroom (i.e., city landmarks) (Serrano-Iglesias et al., 2021). Additionally, SCARLETT performs the following actions based on the sense-analyse-react model (Tabuenca et al., 2021): (i) it collects students' data from the learning activity (i.e., answers to quizzes and physical locations via students' smartphones); (ii) it monitors students' progress and derives relevant performance indicators; and ultimately (iii) it suggests geolocated tasks (e.g., personalised quizzes, videos) related to the contents that students are struggling with most. Figure 4 illustrates the mapping between the co-designed learning activity and SCARLETT's operational model. Phase 1 of the learning activity provided SCARLETT with an initial dataset (*sense*), which allowed it to create appropriate learning analytics and build the student model (*analyse*). During Phase 2 of the learning activity, SCARLETT provided real-time adaptive support to the students (personalised recommendations) through reaction scripts (*react*). Although SCARLETT did not directly support students during Phase 3, the data provided from Phase 1 and Phase 2, once curated by the researcher, proved valuable for the teacher in refining questions posed in Phase 3 (see dashed green line in Figure 3). A personalised quiz was launched after the end of Phase 3. Students

used a web-based application (SCARLETTapp) during Phase 2, in which they received personalised notifications and completed the suggested tasks (see Figure 4). This app was ad hoc developed by the lead researcher for this study.

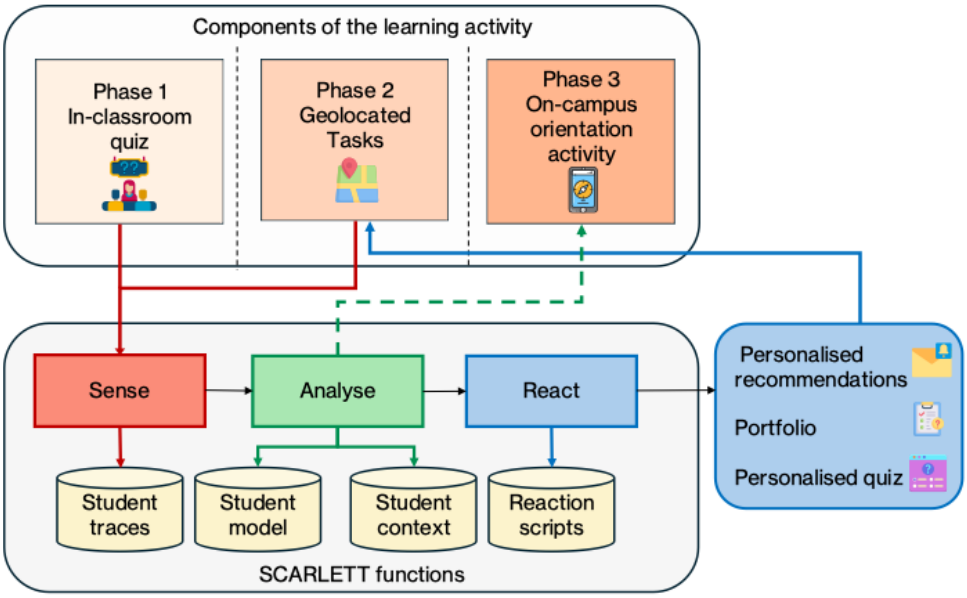

Figure 3. Mapping of the learning activity phases and the functions of SCARLETT

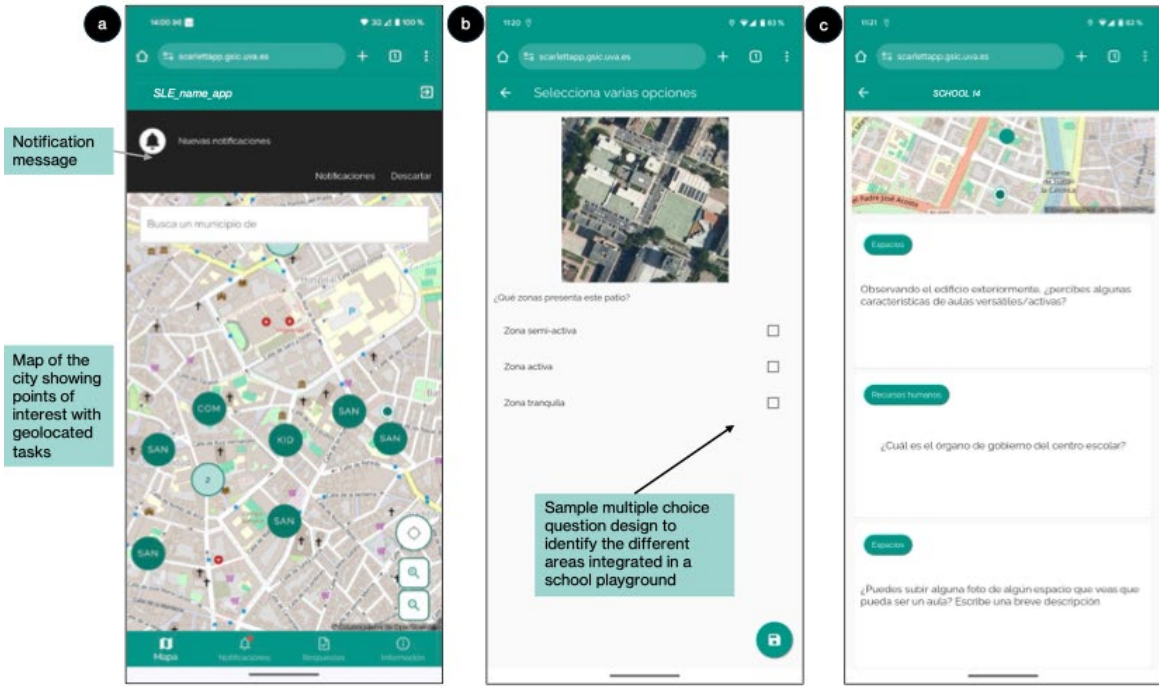

Figure 4. Screenshots of SCARLETTapp

Notes: (a) Shows a view of a city in which a student is performing phase 2 of the learning activity. Different points of interest are displayed. Each one of them contains geolocated tasks that are unlocked when the student is physically within a 100m radius. (b) Displays one of the tasks. Students are asked to identify whether a school playground integrates active, quiet, or semi-active areas. In some cases, students can

physically observe the playground where the task is geolocated, which helps them provide a more grounded answer. (c) Shows a list of tasks in which students are asked to observe the school, recall theoretical knowledge, and upload a photo of a space that could resemble a classroom.

The Co-Design Process of the Learning Activity

The co-design process is summarised following the framework proposed by Pedersen (2020). An initial meeting served to *define the groundwork and set the minimum requirements for the collaboration* towards the co-design objective: to ideate a learning activity to be supported by SCARLETT in the context of the OSP course. The fundamental requirement set by the SLE researchers was that SCARLETT should provide personalised, data-driven recommendations to facilitate the connection between formal and informal learning (as a basis for evaluating the system). The *initial exploration of ideas* led to the generation of a first version of the learning activity by the teacher. Then, the *negotiation* process took place, and it required stakeholders to navigate through pragmatic restrictions (i.e., temporalization and curricula), pedagogical foundations (i.e., teachers' preferred stances), and technical details (i.e., feasible implementations). Within this process, the teacher and the researchers exchanged several emails and had a meeting to refine the learning activity. The back-and-forth communication process strengthened certain aspects of the collaboration (e.g., the teacher could visualise better the support of SCARLETT, making it possible to improve the learning activity). However, other aspects were just partially solved since the researchers were not able to offer the optimal solution (e.g., supporting collaborative learning by configuring a different student model that would consider group work). The results of the negotiations led to a *reconceptualization* of the learning activity that demonstrated better suitability with the course restrictions and satisfied, to a certain extent, all involved stakeholders. Immediately before launching the second phase of the learning activity (see Figure 3), a beta-testing session with the teacher was conducted to make the teacher familiar with SCARLETT's interface and dashboard.

Data Collection and Analysis

Different data gathering techniques and data sources were employed to gain a deep understanding of the phenomena (see Table 1). Among the materials generated during the co-design process, we analysed the learning activity and the emails exchanged among the involved stakeholders. We observed and audio-recorded the co-design meeting and the beta-testing session. Two semi-structured interviews were conducted with the teacher to gain insights into her pedagogical approaches (i.e., how she tackled the co-design process and her perspectives on implementing SCARLETT in her course). The interviews were ad hoc designed following the ecological model of teacher agency (Priestley et al., 2015) (see Appendix A for the full interview script). The first interview took place before the enactment of the learning activity, while the second one was conducted once the course was over, which allowed for a reflection on the impact of the learning activity on the students' performance in the course assignments and the final exam.

Additionally, one semi-structured interview was conducted with the researcher once the enactment of the learning activity concluded to elucidate the motivations underlying the design of SCARLETT's smart features, including its *reactions* (i.e., recommendations provided by SCARLETT based on students' models). The latter interview was also useful in exploring the importance the researcher placed on preserving the teacher's role in the co-design of the activity. The structure and contents of the learning activity itself served as a source of information since it substantiated the teacher's pedagogical stances. We conducted follow-up inquiries with both the teacher and the lead researcher, as a member-checking technique, to clarify our interpretation and gain a deeper understanding of the phenomenon. Table 1 describes these data gathering techniques and documents. Finally, a validated questionnaire on teacher agency related to Information and Communication Technologies (ICT) use in teaching (Leijen et al., 2024) was completed by the educator. All data, except for the previously mentioned questionnaire, were collected and analysed in Spanish and have been translated into English for this manuscript. A label has been added to refer to each data source in the subsequent results and discussion sections.

Table 1. Data sources and data gathering techniques, along with the labels used to reference them, are provided throughout the text

Data sources and data gathering techniques	Description and label
Collection of materials generated by the involved stakeholders	A collection of electronic materials generated by the teacher and the researchers participating in the study. The collection included: The components of the learning activity (previously described/detailed in Figure 3) [LA] Emails Exchanged between the teacher, the lead researcher, and the co-researchers to negotiate, clarify, or agree on aspects of the learning activity [EE][a]
Audio recordings	These audio recordings included: A Co-design Meeting involving the teacher, lead researcher, and the co-researchers [CM][a] A Beta-Testing session of SCARLETT's teacher interface in which the teacher tested the web environment of the SLE [BT][a]
Interviews	Semi-structured face-to-face individual interviews with the teacher and the researcher, which were audio recorded and transcribed. The following interviews were conducted to understand the co-design process and the subsequent implementation of the learning activity: Exploratory Interview with the Teacher, conducted before the implementation of the learning activity [TI1][b] Evaluation Interview with the Teacher, conducted after the implementation of the learning activity [TI2][b] Interview with the lead Researcher, conducted after the implementation of the learning activity [RI][b]
Follow-up inquiries	Follow-up Inquiries were conducted with both the teacher and the lead researcher, as a member-checking technique aimed at clarifying interpretations and deepening understanding of the phenomenon. These inquiries are referred to as follows: Follow-up Inquiry with the Teacher [TFUI] Follow-up Inquiry with the lead Researcher [RFUI]
Teacher agency within the use of ICT questionnaire	Validated questionnaire for the assessment of Teacher Agency related to ICT use in teaching according to eight factors (Leijen et al., 2024). The questionnaire consists of 24 items rated on a 7-point Likert scale [TAQ]

Notes: [a]The following labels are used to identify each stakeholder in each of the referred data sources: T for teacher, R for lead researcher, or CR1/2 for each of the co-researchers. [b]The semi-structured interview scripts are included as supplementary material.

The study was divided into three evaluation events. The first event was the *co-design* of the learning activity, and its main source of data was the learning activity itself. The second event was the *enactment* of the learning activity. The last event was the *reflection* phase, in which both the teacher and the researcher shared their overall perception of the experience. Figure 5 depicts the relation among data sources and collection techniques along the three evaluation events and how they contribute to illuminating the defined sub-research questions.

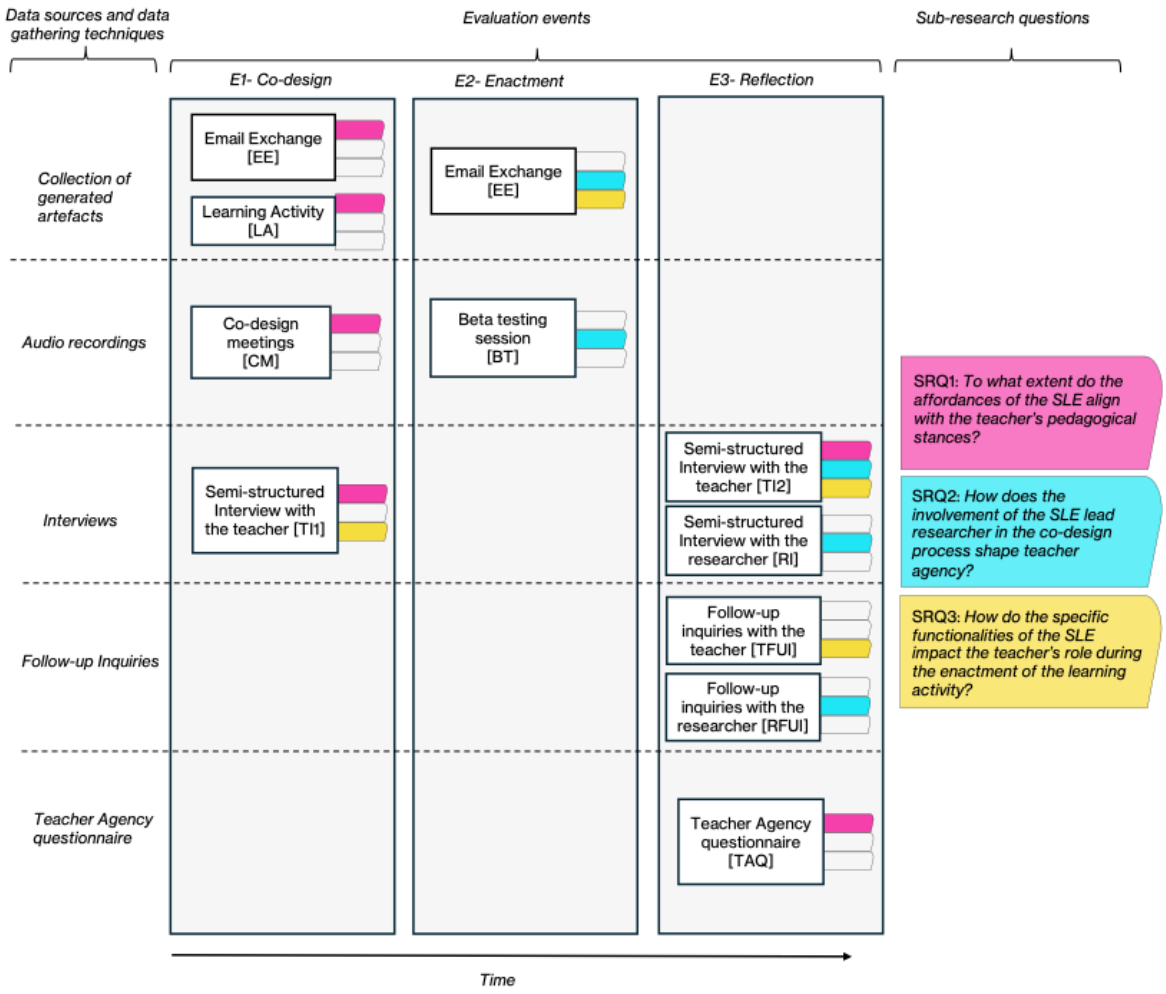

Figure 5. Evaluation events, data sources, and gathering techniques used during the evaluation (colours are used in cases where a data source informs a specific SRQ)

We performed inductive coding to ensure a thorough understanding of the case based on empirical evidence (Miles et al., 2014). Coding was performed initially by one researcher, who developed a preliminary set of codes through iterative familiarization with the data and the derivation of preliminary interpretations. The other members of the research team collaboratively reviewed and discussed interpretations to reduce subjectivity. Subsequently, theory-informed interpretation of emergent findings was conducted collaboratively, following Priestley et al.'s (2015) ecological framework of teacher agency.

Following Miles et al. (2014) guidelines, we report the findings, including thick and context-related descriptions to increase credibility and transferability. Data collection across the full range of events aims to increase the reliability of the results. The use of multiple data collection techniques and data sources allows triangulation of evidence. Interpretations are explicitly linked to displayed data as a procedure to increase confirmability. As a strategy for guaranteeing credibility, we sought a team of evaluators with different perspectives (i.e., pedagogy, human-computer interaction, computer, and telematics engineering) to limit bias in interpreting data (Stake, 1995). Furthermore, as advocated by Guba (1981, p.85), we further validated the coding process, the credibility of the findings, and the accuracy of our interpretations through the implementation of a member-checking mechanism (McKim, 2023) with case study participants. In follow-up inquiries, study participants were invited to

assess whether the researcher's interpretations accurately reflected their meanings. It should be noted that this study does not aim to generalize. Instead, following the rigorous criteria expressed in the seminal work of Guba (1981) for naturalistic studies, through thick descriptions of contexts and actual excerpts, we aimed at increasing the opportunities for transferring the insights to other contexts with similar characteristics. Given the naturalistic nature of the research study reported in this paper, we prioritised a comprehensive and detailed description of a particular phenomenon (Guba, 1981; Twining et al., 2017) to achieve maximum transferability to other contexts, in line with other similar studies published in related literature (Digón-Regueiro et al., 2023). The inclusion of diverse data sources across various evaluation events stems from extensive observation of the phenomena. This strategy enhances both authenticity and credibility (Creswell, 2009).

Findings and interpretations are presented in an integrated manner, as typically done in qualitative case studies. In this sense, Bloomberg and Volpe (2019, p. 398) argued that in qualitative research, "you as the researcher are telling the story of what you learned from participants. As such, participants' quotes are used to illustrate the points that you are making". Consequently, we crafted a narrative that guides readers through the data. At the same time, we considered Wolcott's (2009) assertion, which acknowledges that although pure description is unattainable, the narrative should be presented as unobtrusively as possible. Therefore, we sought to strike a balance between these approaches by prioritizing the most meaningful data for descriptive soundness, while accompanying it with interpretive insights.

RESULTS

This section presents the main findings of our study related to the SRQs, together with the supporting evidence (see the data sources labels listed in Table 1) and the associated interpretations. We present the evidence that has emerged in relation to each sub-research question.

SRQ1 - To What Extent Do the Affordances of the SLE Align With the Teacher's Pedagogical Stances?

Finding 1: Relevant SLE affordances aligned with the teacher pedagogical stances: connection between formal and informal learning spaces and support to contextualised learning.

Two important affordances of SCARLETT are its ability to connect formal and informal learning and support contextualised learning. These features aligned with the teacher's pedagogical stance, which was expressed through: *"For me it's necessary to work on both the formal and informal [contexts]. In the end, learning is not confined solely to the strict classroom setting, but rather it can extend outside and connect those realms through virtual or in-person means, or as you prefer"* [TI2]. The teacher perceived the support that SCARLETT would provide to the students as beneficial for reinforcing the course: "*All contents in informal settings of this [contextualised learning] will favour formal learning in class and informal learning out-of-class, in which they [the students] can walk around, the notification will pop up, they will answer, and they will reinforce this learning"* [TI1]. Particularly, providing students with opportunities to learn within their own contexts was positively valued by the teacher: *"I don't doubt that their learning is going to be much more contextualised at the moment, so that's fantastic"* [CM-T]. SCARLETT allowed students to observe real school playgrounds and assess their inclusiveness according to various physical elements. The fact that students could learn outside the classroom, supported by SCARLETT, was coherent with the teacher's pedagogical approach:

> *It's also learning on the move, meaning that they are with their tool across various city contexts. And they learn through this, through movement. We also depart from the traditional standard of sitting and listening to the teacher's narrative; instead, they go out and contrast [with other sources of knowledge].* [TI2]

All in all, according to the teacher's past experiences, SCARLETT was perceived as a tool that could foster ubiquitous and active learning opportunities: *"[SCARLETT] has a number of functionalities that*

support ubiquity and allow students to be on the move. Based on my previous experience as a teacher, it seems to me that there are many factors in favour of using [SCARLETT]" [TI2].

Finding 2: The SLE did not support the teacher's pedagogical stance on collaborative learning.

In spite of the alignment between SCARLETT and the teacher's pedagogical stances, some tensions between SCARLETT's affordances and the teacher's approach emerged. The teacher expressed her intention to include collaboration as a fundamental component of the learning activity: "*I am interested, for example, in activities in which they [students] can collaborate, share their knowledge and experience*" [TI1]. Moreover, the teacher pointed out that collaboration and shared knowledge building in relation to playground observations could have helped address the lack of information she was able to collect about some of the city's playgrounds: "*students observe directly from the environment [situated-contextualised learning], they also learn from the comments and contributions of their peers and then integrate it into their final work (as it is planned) together with screenshots"* [EE-T]. The teacher reaffirmed the value of hypothetical collaboration in carrying out phase 2 of the learning activity: *"So maybe [answering to] this question would be quicker if everyone can contribute something and see what their colleagues have answered"* [CM-T].

We also discovered that the *classroom environment* was the highest-rated factor (7 = "fully agree") (see full table of results in Appendix B) [TAQ]. This factor, which includes the classroom atmosphere, suggests that the teacher is significantly influenced by it when making decisions about technology use in her day-to-day teaching. Consequently, she prefers to integrate systems that support collaborative approaches, indicating that the affordances of SCARLETT are not fully aligned with her practice.

SCARLETT, by design, was intended to provide individual rather than group support (given its individual student model). This built-in characteristic made it impossible for SCARLETT to support collaborative activities, as acknowledged by the lead researcher: "*It is complicated because the modelling is being done on an individual basis. And because I have no information about the groups beforehand*" [CM-R]. Additionally, one of the co-researchers stated that providing support for collaborative activities would be a challenge for SCARLETT:

> *It's actually a challenge for SCARLETT. The problem is that it's something we haven't really thought about... or we haven't thought about it very much. Of course, here it would be to build a group model out of the individual models, but that's something we haven't thought about.* [CM-CR2]

To address this misalignment, the researcher developed an ad hoc solution, clearly suboptimal, that did not involve changes to the student model:

> *Taking advantage of the fact that we already had all the data collection and annotation, what we enabled was a specific visualisation for the traces related to visits to the city, and it was presented in a different way depending on whether it was a teacher or a student [...]. What was presented were the different options and the volume of responses. In the case of the students, it was only presented how many answers there were as a survey, as a poll, so that they could discuss the answers in class.* [RFUI]

Finding 3: The SLE affordances empowered the teacher to create a learning activity that went beyond her past practices.

The various conversations held with the researcher(s) during the co-design process led the teacher to conceive a learning activity [LA] that was somewhat different from her previous designs and which she would not have conceived without SCARLETT: "*My perception of the tool has evolved from a lack of knowledge to having high expectations of its functioning […]. And the SLE has brought about a scenario that I had not initially thought of"* [TI2]. When asked how the support of SCARLETT aligned with her intentions and how she would like to continue working, she added:

> *Well, I had thought of using the geolocation at the nearest environments [physically close to the university campus], but I hadn't thought of implementing the geolocation in any context where they [students] can observe the schools, that is, at the city level, or regional level.* [TI2]

Thus, the very possibilities of the tool enabled the teacher to expand the geographical scope of the activity and make it more meaningful. The physical structure of the class, item 21 of the [TAQ], ranked the highest (7= "fully agree"). This suggests the importance of this aspect for the teacher when making decisions regarding the use of technologies in the classroom. We interpreted that SCARLETT is one of the resources that fits well within her ecology (Priestley et al., 2015).

SRQ2 - How Does the Involvement of the SLE Lead Researcher in the Co-Design Process Shape Teacher Agency?

Finding 4: The researcher's role, as a facilitator in the co-design process, was crucial for generating the learning activity.

The teacher acknowledged that the support provided by the lead researcher during the co-design process was crucial to materialise the creation of the learning activity:

> *At the beginning, I was quite unfamiliar with SCARLETT, that is to say, I had doubts about the extent to which SCARLETT would provide support; I didn't visualise how to create the learning activity. So, thanks also to the researcher and the meetings we were having when implementing the design in the tool. Well, he was also providing me with guidance on how to create the learning activity.* [TI2]

This process was not without tensions, as the researcher(s) aimed to evaluate SCARLETT: "*The main objective in our case is to show how Smart Learning Environments can make the formal-informal connection. My intention is to facilitate the use of these environments by non-technically specialised staff*" [RI]. The lead researcher himself was also particularly concerned about the issues that typically arise when teachers are involved in the process of adopting new technologies:

> *The aim is to encourage the inclusion of SLEs in more general learning situations. Because what we were noticing is that, although there are proposals of intelligent [learning] environments in the literature, [...] generally what was covered was a very concrete, very closed situation. Hey, I'm not saying it's wrong, but this limits its use in general teaching [...] if a teacher has to invest a lot of work in adapting their entire way of teaching to integrate it, it is going to fail.* [RI]

The intentions declared by the researcher were coherent with the role of facilitator he adopted throughout the co-design. He showed openness to consider teacher's needs, and during the process they all reached agreements on how SCARLETT would support the learning activity without forcing the teacher to include undesired features in it: "*When I met the teacher, we were discussing the type of questions and tasks that can be proposed, but we agreed that it would not be necessary that all the types of tasks supported by the SLE were included in the learning activity"* [EE-R].

Finally, evidence points at how the co-design process of the learning activity was valuable not only for the teacher, but also for the researcher, since he remarked the relevance of this process to understand to what extent SCARLETT can support similar learning activities: *"It is helping me a lot not only to refine but also to be able to check [in a real scenario] to what extent this type of learning activity can be supported [by SCARLETT]"* [BT-R].

SRQ3 - How Do the Specific Functionalities of the SLE Impact the Teacher's Role During the Enactment of the Learning Activity?

Finding 5: The teacher recognised the student model's limitations in accurately reflecting the learners' state, but she refused to add new tasks in the learning activity to avoid overwhelming the students.

The student model is an essential component of SCARLETT that enables learners to receive personalised recommendations (Serrano-Iglesias et al., 2021). However, the teacher considered that the student model may not fully reflect the complexity of the learners' statuses:

> *Maybe it is not possible for such a student model to even exist [in terms that it will fully correspond to the real learner status], or it simply pigeonholes a person, which is dangerous too. [...] Even if I could see and observe, I probably wouldn't take them into account. I would take into account the answers not so much in terms of the categorization the student model does, but maybe in terms of participation in collaboration [if students could collaborate].* [TI2]

According to the teacher, contextual contingencies can affect how students respond to geolocated questions, which in turn impacts the student model: "*I do not know ...humans are so complex, and many reasons may explain [our actions] …There exist external conditions…*" [TI2]. Since the design of the learning activity did not contemplate collecting data other than answers to questions and locations, the teacher was not confident of the student model.

The teacher felt that the student model might over-categorise students. Therefore, she decided to approach it with caution, as she expressed in the interview:

> *… beyond the fact that the recommendations go with one student model or another … I think that it can be beneficial to them [students] to receive recommended questions that they have not answered well. I think we have too many edges to pigeonhole someone, we are very complex.* [TI2]

On the possibility of reinforcing the student model, one of the co-researchers suggested including an additional quiz to provide extra sources of data to enrich the student model:

> *Another suggestion for the first week would be to pose some questions in Moodle. These could be the same as in the Kahoot, but as a review. From the SLE's point of view, this would be interesting to illustrate that the system utilises student activity data from two different sources [...] The benefit of having them done before the geolocated ones is that we will have more info to build the student model, and that it is a bit less simplistic.* [EE-CR1]

However, the teacher did not want to overload the students with more tasks at the beginning of the learning activity, and she stated that:

> *I understand that having more data makes the profile tighter [student model], but I also understand that they [the students] are at their limit […]. It seems to me to be duplicating a task. If I wanted more data or more questions from them, I would have put them in a single resource.* [TFUI]

Thus, the teacher dismissed the inclusion of new tasks and the integration of additional data sources due to pedagogical and contextual reasons, rather than because of a lack of understanding of how the student model works.

Finding 6: The teacher did not perceive SCARLETT's autonomous recommendations as a threat, although she would have preferred more control over SCARLETT.

The teacher did not perceive that the autonomous functioning of SCARLETT (i.e., sending personalised recommendations to students without her intervention) posed a threat to her role as an educator. She did not think that SCARLETT might replace her: *"[...] Can it replace me? Well, no, no. It is just another resource that can support me or not. It also depends on how you design it [the learning activity]"* [TI2]. She positively valued a tool operating automatically to support a learning activity:

> *But I am hypothesising that if I could see everything that has been stored and create the questions in the next session, it would help me. Or that the tool would automatically do it [create the questions] by monitoring the students' profiles, that would be fantastic.* [TI1]

Knowing students' progress in order to adapt phases of the learning activity or even transferring the ability to do so to SCARLETT would be an appropriate complementary support for this teacher. This reflects the teacher's approach to managing a learning activity and the role she attributes to smart technologies.

The educator would have liked to have more control over SCARLETT to increase her ability to make decisions: "*To increase my decision-making capacity [...] I would need it to be something easier in terms of use,*

that I could manage, enter, change [...] according to the progress I see" [TI2]. She attributed this desire to intervene to her vision of the design of the learning activity as something that evolves and should be open to modifications:

> *We are talking about how I can get my decision-making capacity reinforced. I suppose it is linked to having clearer control and management. If I constantly depend on a developer [who in this case was also the lead researcher] ... For me, a design [referring to the design of a learning activity] is something that mutates. It can't be prefixed, and that's because it's, well, driving the lead researcher crazy with changes here and there. So, if not [in the absence of such a dependency], I give functions to the tool, and it's not a problem. But, on the other hand, I look for a way to ensure that I can continue working in other scenarios, in class, with design, etc. Yes, I can rely on the tool, with remote control [through the lead researcher]. But of course, my capacity to manage is overridden there.* [TI2]

The teacher showed consistency with her statement on the evolutionary nature of the learning activity design, as evidenced during enactment. She refined the questions from one phase to another, considering those that required reinforcement: *"According to these percentages [of failure], perhaps some of the questions I had eliminated for the geo-positioning phase will have to be re-integrated given the low rates of correctly answered questions"* [EE-T].

Besides that, we found that the need to supervise the enactment of the learning activity was important for the teacher. Given that SCARLETT did not provide a monitoring dashboard and a learning activity management function, the teacher felt that she did not have full control over the progress of the learning activity, which impeded her ability to act agentically:

> *I don't feel confident, not because this tool might have malfunctioned, but because, in the end, I need to keep track of what's going on as a teacher. And in the current situation, where there is no dashboard that allows you to monitor it [progress], I feel even more tension because we don't have a dashboard where you can see how many tasks have been completed, which students haven't done any yet, who has completed all of them.* [TFUI]

Although the teacher could check in the portfolio integrated in Moodle the individual answers on a certain task, she asked for a function that would display the status of the learning activity (i.e., via a teacher dashboard). Eventually, the dashboard might have contributed to reducing her orchestration load and enabled her to make better decisions supported by actionable insights, which ultimately could have reinforced her sense of control during the enactment of the learning activity.

Synthesis of Findings

In summary, in this study, we have analysed the alignments and tensions between teacher agency and SCARLETT that emerged in the co-design process of a learning activity and its subsequent enactment. Following the main dimensions of Priestley et al.'s (2015) model on teacher agency, we found that: (i) **the pedagogical stances and past experiences of the teacher were aligned with some key affordances of SCARLETT**, such as its capacity to *connect formal and informal learning* experiences and provide *contextualised support* to students, taking advantage of its flexible s*ense-analyse-react functions*. These affordances allowed the teacher to configure a learning activity that was consistent with her teaching preferences. By means of the decisions taken at the negotiation stage of the co-design process, the teacher could leverage past experiences with a glimpse of future possibilities supported by this tool. The support received by the researcher(s) was also likely to have contributed to attaining agency. Nonetheless, (ii) **the individual student model of SCARLETT produced a significant tension with the pedagogical stance of the teacher**. She could not clearly design for *collaborative learning* in the learning activity, due to the inherent configuration of the individual student model embedded in SCARLETT (that drove its sense-analyse-react architecture). On the other hand, (iii) **the teacher perceived herself *not to be threatened* by *the autonomous recommendations* provided by SCARLETT, although she asked for *greater control* of all components of SCARLETT's operational model**, so that she could reconfigure the design and enactment of the learning activity. Finally, (iv) **the co-design process allowed both the teacher and researchers to go**

through a progressive mutual understanding and identification of opportunities. This process crystallised in an innovative learning activity that exemplified the resolution of the emerging tensions between teacher agency and SCARLETT. A graphic representation of the interplay of the previously described aspects is depicted in Figure 6.

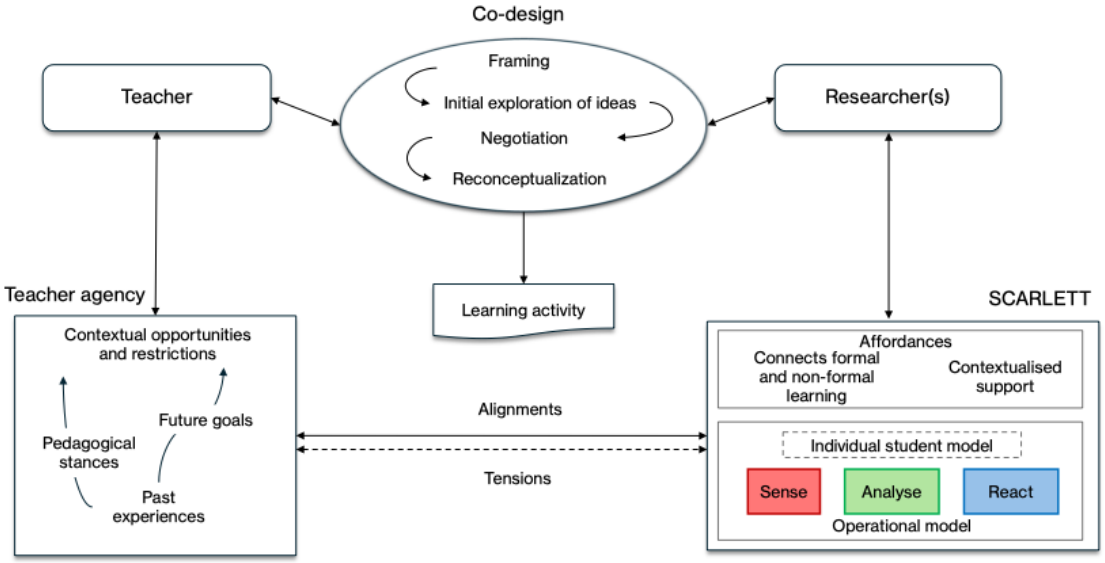

Figure 6. Co-design as mediation between teacher agency and SCARLETT affordances and operational model

Results show the meaningful contribution of the co-design process and the key role of the researchers as mediating elements on SCARLETT's capacity for transforming teaching practices. The findings allowed us to develop the proposed mapping between the SLE affordances/functions and the teacher's agency, laying the groundwork for extending Priestley et al.'s (2015) ecological model of teacher agency.

DISCUSSION

The evidence gathered helped us to shed light on the general RQ: How does participation in the co-design of a learning activity supported by a Smart Learning Environment shape the development of teacher agency? Based on the aforementioned findings, the discussion delves into how teacher agency develops as a consequence of SLE's affordances, functioning, and the key mediating role of the co-design process and the involved stakeholders.

ALIGNMENT BETWEEN TEACHERS' PEDAGOGICAL STANCES AND SLE'S AFFORDANCES

The study showed that the teacher's pedagogical stances and practices were aligned with the support provided by SCARLETT regarding learning activities that connect formal and informal learning settings for enabling contextualised learning. It is worth mentioning that SLEs offer an opportunity for bridging formal, non-formal, and informal contexts, according to the seminal definition of SLEs coined by Hwang (2014). Additionally, contextualised, adaptive, and personalised learning based on traces and other learning-related data is probably the most prominent feature of SLEs by design, as established in the systematic literature review on the key affordances of SLEs (Tabuenca et al., 2021). Therefore, the strong alignment between key features of SLEs and the pedagogical stances of the teacher in this study significantly contributed to reinforcing teacher agency in designing the innovative learning activity and even going beyond what the teacher had already experienced in the past.

Thus, teacher agency at design time was strengthened by means of affordances of an intelligent technology, which has been conceptualised as goal augmentation (Holstein et al., 2019). Our main source of data consists of teachers' reflections via pre- and post-hoc interviews, as suggested by du Boulay (2021) for studying research problems of this nature.

Building on the ecological model of teacher agency (Priestley et al., 2015), this case showed that SCARLETT allowed the teacher to achieve more ambitious goals while being coherent with her past practices. Therefore, during the co-design phase, SCARLETT acted as a catalyst for the future achievement of agency. As Holstein et al. (2019) stated, smart technologies have the potential to empower teachers even at design by helping them to transform past teaching practices. For the ecological perspective of agency (Biesta & Tedder, 2007; Emirbayer & Mische, 1998), the transformative potential offered by SCARLETT represents an opportunity (a material resource) embedded in the teacher's current context that eventually bridges the teacher's past experiences with the future practices that would be desirable to achieve. We argue, from this perspective of agency, that the openness to the transformative potential of technologies strongly relies on their alignment with past and intended pedagogical practices. This alignment can also reinforce teachers' positive beliefs about technologies they implement (Cheng et al., 2022; Opre, 2022). The teacher's expertise, in combination with opportunities to reflect upon the learning activity and gain knowledge on the affordances of the SLE by means of the co-design, has likely contributed to an optimised use of technologies that provide adaptive support. This is a result that aligns with the findings of Wang et al. (2022) in smart classroom contexts.

However, a full alignment was not achieved between SCARLETT's affordances and the teacher's pedagogical stances. This lack of alignment may be explained by SCARLETT's limited native support for collaborative learning. It is worth noting that providing support for collaborative learning is not a key affordance of SLEs, and few papers on SLEs report collaborative experiences, as found by Tabuenca et al. (2021). Empirical evidence from our study showed that the researchers responsible for developing SCARLETT acknowledged the challenge of providing a solution to support collaborative learning by design of the SLE. The primary reason for such misalignment is that the unit of study in the student model is individual, a common practice and a distinctive feature of adaptive systems (Brusilovsky & Millán, 2007). Since one of the main objectives of these adaptive systems is personalisation, the group is rarely considered as a focal point that may support the main SLE functions of sense, analyse, and react, which rely on student models. This finding is aligned with the need for "native" support for groups and collaborative learning in these systems (Ogan et al., 2012).

The Mediating Role of Researchers in the Co-Design

The co-design process played an important role in materialising the learning activity and helped to devise a suboptimal solution that enabled some sort of collaboration to take place. This collaborative partnership allowed the stakeholders to be placed in the same arena, enabling divergences to surface and eventually be resolved, or convergences to be reinforced (and therefore included in subsequent phases). When co-designing educational innovations (a learning activity in the presented study), tensions are likely to emerge as stakeholders belong to different domains (Penuel et al., 2007). The lead researcher sought to assess the effectiveness of SCARLETT, which sometimes collided with the contextualised needs expressed by the teacher. However, researchers showed empathy and openness to carry out modifications in a system that had not been initially designed with the involvement of an educational stakeholder. This study showed how the stakeholders navigated those tensions and how both parties considered each other's positions. This horizontal rather than vertical power relationship made it easier for the teacher to receive help and may also help explain why she felt she had better control over the deployed technology (Nøhr et al., 2023). This study showed how the teacher manifested agency when shaping the learning activity, balancing her goals, the context of the course, and SCARLETT's functions during the co-design and enactment events. The proactive role of researchers staging the co-design is not incompatible with teacher agency strengthening, especially if research-

ers try to stay flexible (Barbera et al., 2017; Pedersen, 2020). This is particularly critical when researchers have dual roles, for example, as researchers aiming to evaluate a technology and developers of such technology, as occurred in the reported study.

Student Model: A Key Component of SLEs

Concerning the student model, the findings indicated that the teacher lacked full confidence in the ability of SCARLETT's model to accurately capture the complexity of the students' learning statuses. However, the teacher rejected the option to enrich the model with more data sources derived from new tasks of the learning scenario, since the new tasks would have increased the learners' workload. Thus, this pragmatic constraint forced the teacher to accordingly adapt the design of the learning activity, despite her pedagogical view on the lack of sufficient richness of the student model. This illustrates relevant tensions regarding the way student models should be built: How can we make them simple enough to be understood and processed yet rich and representative enough to reflect the complex reality of learners' state in a given context? What data should be collected by the *sense* function of the SLE, and what tasks should be included in the design process of the learning activity so that the appropriate data traces may be generated?

These design decisions should also be in line with the pedagogical intentions of the teacher, the pragmatic orchestration constraints of the learning activity, or the alignment of learning tasks and data with sound learning theories. These issues have been raised on several fronts in the literature: (i) in the pragmatism that characterises orchestration (Prieto et al., 2011), (ii) in the need to use data and indicators that are based on learning theories (Gašević et al., 2015), and (iii) in discussions about the optimal properties of learner models in Intelligent Tutoring Systems (Abdi et al., 2020; de Antonio et al., 2009; Gumbheer et al., 2022). In this regard, Gaudioso et al. (2009) suggested that teachers and systems should collaborate to achieve student modelling. This collaborative approach may not only reduce teachers' mistrust of the student model but also strengthen the sense of control over the SLE. More evidence needs to be collected in future cases to deeply comprehend teachers' understanding of how the student model is built and how it could potentially influence their decisions in the co-design process of learning activities. On the other hand, open student models and actionable explanations provided by the SLEs could offer better guidance for teachers when monitoring the learning activity, leading to reinforced agency (Khosravi et al., 2022).

SLE's Autonomous Functioning and the Teacher's Role

At enactment time, the teacher did not perceive the autonomous functioning of the SLE as a threat to her role. Nonetheless, she expressed that she would have preferred to have more capacity to supervise the learning activity (in terms of being the administrator of the system). This way, she could adapt the learning activity to emergent circumstances. Literature has also found that this is a common trait among teachers working within this intelligent technology-enriched context (Holstein et al., 2019). Therefore, to preserve their agentic power (e.g., ability to make changes, maintain sense of control), teachers should be given opportunities to review recommendations before these are sent to students as a mechanism to reinforce their control over the learning activity (Nazaretsky et al., 2022). The distribution of control should be mediated carefully to grant teachers opportunities to exert enough control over the enactment of the learning activity (Molenaar, 2022). Since exerting control over their circumstances is an agentic capacity, as defined by Bandura (2006), it might not be fully desirable to deploy learning technologies that entirely take the role of teachers on complex and multi-layered learning activities like the one presented in this study.

Towards a Full Attainment of Agency in SLE-Supported Contexts

The drawbacks that arguably prevented the SLE from fully supporting the attainment of teacher agency in this setting could have been tackled by considering the pedagogical perspectives of the teacher from an early stage of SCARLETT's development. Approaches like human-centred design

(HCD) strive for the agentic positioning of teachers within the designing and development of technologies that involve measurement and analysis of students' performances (i.e., learning analytics), including SLEs (Dimitriadis et al., 2021). Contrary to what was observed in our study, where the learning activity had to adapt to an already designed system, HCD suggests that the learning design (referred to as learning activity in our study) has the potential to frame the generation of analytics, direct how analytics can be meaningfully interpreted, and ultimately advise teachers and students in making decisions (Dimitriadis et al., 2021). Involving teachers in the co-design of intelligent technologies alongside TEL researchers and developers fosters the potential to adopt an augmentation perspective (Holstein et al., 2019; Molenaar, 2022). If teachers' pedagogical stances, structural constraints, knowledge, and attitudes towards intelligent technologies are properly addressed, the chances for harmonising their deployment with teachers' current practices and future prospects are likely to increase.

Capturing these and other socio-technical complexities is already considered relevant by several research communities (e.g., Human-Centred Learning Analytics) (Buckingham Shum et al., 2019). In instances where the technology has already been developed (as the described study), the co-design of learning activities allows developers and researchers to unveil the pedagogical direction the learning activity needs to take within that specific context. At that stage, there remains room to create opportunities for teachers' voices to be heard and for their perspectives to significantly influence activities. Potential technological adjustments could then lay the foundation for positive agency development. For that reason, researchers and developers should carefully stage the negotiation processes intrinsic to co-design, balancing their own pretensions with an understanding of the situated context (Pedersen, 2020; Severance et al., 2016). Simultaneously, they should recognise the distributed nature of agency in the social interaction processes, along with the driving forces operating behind it (e.g., tools, temporal restrictions, beliefs), because agency is to emerge in collaborations (Lipponen & Kumpulainen, 2011). In our study, we have observed how agency is distributed across the teachers, the researcher(s), and the SLEs within a particular course and university context.

The influence between teachers and the SLE might be cyclical: the system's possibilities and functioning shape the orientation of learning activities. Conversely, if the system can be adjusted to meet the teacher's needs, it impacts the SLE, which in turn affects teaching practices. It is clear from our study that, in order to achieve full attainment of agency, teachers should have the opportunity to configure SLEs. By doing so, SLEs would operate in accordance with teachers' preferences and to the real-life contingencies of higher education courses. Apart from configuring the system, teachers tend to request sharing control when implementing intelligent technologies (Lawrence et al., 2024). Particularly, this has also been identified as an important factor in the successful implementation of SCARLETT (Serrano-Iglesias et al., 2023). The reported case study suggests that teachers should be granted opportunities to shape the operation of SLEs so that these systems align with their pedagogical stances, goals, and the instructional constraints of higher education. These opportunities may be warranted through direct involvement in SLE development or through co-design of learning activities that inform future technological adaptations.

CONCLUSIONS

The reported study has explored how teacher agency unfolded within the co-design process of an SLE-supported learning activity in higher education, and its subsequent enactment. By analysing the situated practice, this study contributes to a more nuanced comprehension of how aspects of teacher agency relate to affordances and functions of SLEs. Findings indicated that the co-design process enabled the teacher to understand the possibilities of the SLE, and it allowed her to expand her pedagogical goals, with an immediate impact on her practice. This positive effect can be attributed to the alignment between key affordances of the SLE and the teacher's main pedagogical stances. The teacher did not perceive her role as threatened by the autonomous functioning of the SLE. However, the educator also expressed the need for further control on the SLE through monitoring, which

would facilitate *on-the-fly* adaptations of the learning activity. Case study findings may lead to naturalistic generalizations (Melrose, 2009) that inform relevant design implications. The particular insights of the reported case study suggest that SLE developers should prioritise features that enable teacher oversight of learning activities and allow for flexible customisation of the autonomous recommendation mechanism (e.g., a dashboard with an intervention panel). Developers should strive to preserve the key feature of autonomous reactions provided by SLEs, as it enables the planning and enactment of ubiquitous, time-unrestricted learning activities.

Alongside these implications for SLE developers, practitioners should carefully consider their workload and their limited capacity to review automated suggestions. A potential solution is providing options for selective engagement with specific recommendations to keep teachers in the loop, while not overloading them. Additionally, redesigning student models to better support collaborative learning may augment synergies for teaching practices that value such a pedagogical stance. From the practitioners' perspective, educators should strive to familiarize themselves with the functioning and capabilities of the SLE, engaging in professional development practices or co-design. This approach may empower teachers to reimagine their existing designs, leveraging the affordances of SLEs. Additionally, the co-design process unveiled tensions regarding other goals the teacher had, such as support for collaborative learning, that was not satisfied. This study reported a real-world co-design process in which an SLE researcher has a dual role and an evaluation calendar. However, the role of the researchers during the co-design process, being very conscious of the need to respect the teachers' decisions, was crucial in supporting agency attainment in this phase.

Detailed contextual descriptions and rich excerpts dissecting the process are not only valuable for the researchers seeking a deeper understanding of teacher agency but also for the TEL community to grasp the underlying dynamics that stakeholders are likely to encounter when deploying SLE or technologies with similar affordances (Treasure-Jones et al., 2019). As Digón-Regueiro et al. (2023) note, reporting single case studies sheds light on what may be expected to encounter in settings that foster innovations.

FUTURE WORK

The reported case study belongs to a collection of studies that the authors are currently undertaking regarding: (i) the co-design of a multi-agent architecture based on generative artificial intelligence (AI) to be integrated into a social platform for the analysis and discussion of ethical dilemmas in ethics-related courses, and (ii) the formative evaluation of an AI-driven system for training communication skills. We seek to develop a holistic comprehension of the phenomena of teacher agency and report transferred findings from this study.

Future studies in other contexts might offer complementary insights and eventually reinforce the findings of this paper. We believe that the in-depth study of the co-design process of learning activities to be supported by intelligent technologies deserves more attention, as it is common, due to several constraints, for teachers to encounter tools that have already been designed without their intervention. In line with the points raised by Treasure-Jones et al. (2019), we encourage the TEL community to document these processes, thereby increasing the corpus of evidence, especially in the era of AI-driven support. It is also needed to develop guidelines or frameworks on how these reports should take form (Treasure-Jones et al., 2019). The selected case study turned into an ideal arena for studying key elements of teacher agency, typically related to ecological perspectives on agency (Biesta & Tedder, 2007; Priestley et al., 2015). Mapping the elements that conditioned the co-design helped us to generate a multifaceted representation of the phenomenon of agency. This highlights the potential of these studies to explore and advance the understanding of a problem that is likely to become increasingly recognised in our field.

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REFERENCES

Abdi, S., Khosravi, H., & Sadiq, S. (2020). Modelling learners in crowdsourcing educational systems. In I. Bittencourt, M. Cukurova, K. Muldner, R. Luckin, & E. Millán (Eds.), *Artificial intelligence in education. Lecture notes in computer science* (Vol. 12164, pp. 3-9). Springer. https://doi.org/10.1007/978-3-030-52240-7_1

Albion, P. R., & Tondeur, J. (2018). Information and communication technology and education: Meaningful change through teacher agency. In J. Voogt, G. Knezek, R. Christensen & K. W. Lai (Eds.), *Second handbook of information technology in primary and secondary education*. Springer. https://doi.org/10.1007/978-3-319-71054-9_25

Archer, M. S. (2000). *Being human: The problem of agency*. Cambridge University Press. https://doi.org/10.1017/CBO9780511488733

Bandura, A. (2006). Toward a psychology of human agency. *Perspectives on Psychological Science*, *1*(2), 164-180. https://doi.org/10.1111/j.1745-6916.2006.00011.x

Bandura, A. (2018). Toward a psychology of human agency: Pathways and reflections. *Perspectives on Psychological Science, 13*(2), 130-136. https://doi.org/10.1177/1745691617699280

Barbera, E., Garcia, I., & Fuertes-Alpiste, M. (2017). A co-design process microanalysis: Stages and facilitators of an inquiry-based and technology-enhanced learning scenario. *The International Review of Research in Open and Distributed Learning*, *18*(6), 104-126. https://doi.org/10.19173/irrodl.v18i6.2805

Biesta, G., Priestley, M., & Robinson, S. (2015). The role of beliefs in teacher agency. *Teachers and Teaching*, *21*(6), 624-640. https://doi.org/10.1080/13540602.2015.1044325

Biesta, G., & Tedder, M. (2007). Agency and learning in the lifecourse: Towards an ecological perspective. *Studies in the Education of Adults*, *39*(2), 132-149. https://doi.org/10.1080/02660830.2007.11661545

Bloomberg, L. D., & Volpe, M. (2019). *Completing your qualitative dissertation: A roadmap from beginning to end* (4th ed.). Sage. https://doi.org/10.4135/9781452226613

Brod, G., Kucirkova, N., Shepherd, J., Jolles, D., & Molenaar, I. (2023). Agency in educational technology: Interdisciplinary perspectives and implications for learning design. *Educational Psychology Review*, *35*, Article 25. https://doi.org/10.1007/s10648-023-09749-x

Brusilovsky, P., & Millán, E. (2007). User models for adaptive hypermedia and adaptive educational systems. In P. Brusilovsky, A. Kobsa & W. Nejdl (Eds.), *The adaptive web: Methods and strategies of web personalization* (pp. 3-53). Springer. https://doi.org/10.1007/978-3-540-72079-9_1

Buckingham Shum, S., Ferguson, R., & Martinez-Maldonado, R. (2019). Human-centred learning analytics. *Journal of Learning Analytics*, *6*(2), 1-9. https://doi.org/10.18608/jla.2019.62.1

Carruana Martín, A., Alario-Hoyos, C., & Delgado Kloos, C. (2023). A study of student and teacher challenges in smart synchronous hybrid learning environments. *Sustainability*, *15*(15), 11694. https://doi.org/10.3390/su151511694

Carvalho, L., Martinez-Maldonado, R., Tsai, Y. S., Markauskaite, L., & De Laat, M. (2022). How can we design for learning in an AI world? *Computers and Education: Artificial Intelligence*, *3*, 100053. https://doi.org/10.1016/j.caeai.2022.100053

Cheng, S. L., Chang, J. C., & Romero, K. (2022). Are pedagogical beliefs an internal barrier for technology integration? The interdependent nature of teacher beliefs. *Educational Technology Research and Development*, *70*(2), 5215-5232. https://doi.org/10.1007/s10639-021-10835-2

Creswell, J. W. (2009). *Qualitative, quantitative, and mixed methods approaches* (3rd ed). Sage.

de Antonio, A., Ramírez, J., & Clemente, J. (2009). Focusing the diagnosis for student modelling on an instructional design. In A. de Antonio, J. Ramírez, & J. Clemente (Eds.), *Proceedings of the First International Conference on Computer Supported Education* (Vol. 1, pp. 284-289). SciTePress. https://doi.org/10.5220/0001979902840289

Deschênes, M., & Parent, S. (2022). Methodology to study teacher agency: A systematic review of the literature. *European Journal of Educational Research*, *11*(4), 2459-2474. https://doi.org/10.12973/eu-jer.11.4.2459

Digón-Regueiro, P., Gewerc-Barujel, A., & Pérez-Crego, C. (2023). Dilemmas in the integration of technologies in a Primary school classroom: The dialogue between teacher agency, curriculum and digital technologies. *Pedagogies*, *18*(3), 333-351. https://doi.org/10.1080/1554480X.2021.2013235

Dimitriadis, Y., Martinez-Maldonado, R., & Wiley, K. (2021). Human-centered design principles for actionable learning analytics. In T. Tsiatsos, S. Demetriadis, A. Mikropoulos, & V. Dagdilelis (Eds.), *Research on e-learning and ICT in education: Technological, pedagogical and instructional perspectives* (pp. 277-296). Springer. https://doi.org/10.1007/978-3-030-64363-8_15

Dron, J. (2018). Smart learning environments, and not so smart learning environments: A systems view. *Smart Learning Environments*, *5*, Article 25. https://doi.org/10.1186/s40561-018-0075-9

du Boulay, B. (2021). Jim Greer's and Mary Mark's reviews of evaluation methods for adaptive systems: A brief comment about new goals. *International Journal of Artificial Intelligence in Education*, *31*, 622-635. https://doi.org/10.1007/s40593-020-00198-z

Ehren, M. C. M., Madrid, R., Romiti, S., Armstrong, P. W., Fisher, P., & McWhorter, D. L. (2021). Teaching in the COVID-19 era: Understanding the opportunities and barriers for teacher agency. *Perspectives in Education*, *39*(1), 61-76. https://doi.org/10.18820/2519593X/pie.v39.i1.5

Elm, A., Nilsson, K. S., Björkman, A., & Sjöberg, J. (2023). Academic teachers' experiences of technology enhanced learning (TEL) in higher education – A Swedish case. *Cogent Education, 10*(2), Article 2237329. https://doi.org/10.1080/2331186X.2023.2237329

Emirbayer, M., & Mische, A. (1998). What is agency? *American Journal of Sociology*, *103*(4), 962-1023. https://doi.org/10.1086/231294

Gašević, D., Dawson, S., & Siemens, G. (2015). Let's not forget: Learning analytics are about learning. *TechTrends*, *59*, 64-71. https://doi.org/10.1007/s11528-014-0822-x

Gaudioso, E., Montero, M., Talavera, L., & Hernandez-del-Olmo, F. (2009). Supporting teachers in collaborative student modeling: A framework and an implementation. *Expert Systems with Applications*, *36*(2), 2260-2265. https://doi.org/10.1016/j.eswa.2007.12.035

Gros, B. (2016). The design of smart educational environments. *Smart Learning Environments*, *3*, Article 15. https://doi.org/10.1186/s40561-016-0039-x

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *ECTJ*, *29*(2), 75-91. https://doi.org/10.1007/BF02766777

Gudmundsdottir, G. B., & Hathaway, D. M. (2020). "We always make it work": Teachers' agency in the time of crisis. *Journal of Technology and Teacher Education*, *28*(2), 239-250. https://doi.org/10.70725/839558bffbol

Gumbheer, C. P., Khedo, K. K., & Bungaleea, A. (2022). Personalized and adaptive context-aware mobile learning: Review, challenges and future directions. *Education and Information Technologies*, *27*(6), 7491-7517. https://doi.org/10.1007/s10639-022-10942-8

Hernández-Leo, D., Muñoz-Merino, P. J., Bote-Lorenzo, M. L., Gašević, D., & Järvelä, S. (2023). Editorial technologies for data-driven interventions in smart learning environments. *IEEE Transactions on Learning Technologies, 16*(3), 378-381. https://doi.org/10.1109/TLT.2023.3275728

High Level Expert Group on Artificial Intelligence. (2019). *Ethics guidelines for trustworthy AI*. European Commission. https://digital-strategy.ec.europa.eu/en/library/ethics-guidelines-trustworthy-ai

Holmes, W., Bialik, M., & Fadel, C. (2019). Artificial intelligence in education: Promises and implications for teaching and learning. In C. Stückelberger & P. Duggal (Eds.), *Data ethics: Building trust. How digital technologies can serve humanity* (pp. 621-653). Globethics.

GlobethicsThe Center for Curriculum Redesign. https://doi.org/10.58863/20.500.12424/4276068

Holstein, K., McLaren, B. M., & Aleven, V. (2019). Designing for complementarity: Teacher and student needs for orchestration support in AI-enhanced classrooms. In S. Isotani, E. Millán, A. Ogan, P. Hastings, B. McLaren & R. Luckin (Eds.), *Artificial intelligence in education* (pp. 157-171). Springer. https://doi.org/10.1007/978-3-030-23204-7_14

Hwang, G.-J. (2014). Definition, framework and research issues of smart learning environments – A context-aware ubiquitous learning perspective. *Smart Learning Environments*, *1*, Article 4. https://doi.org/10.1186/s40561-014-0004-5

Hwang, G.-J., & Fu, Q.-K. (2020). Advancement and research trends of smart learning environments in the mobile era. *International Journal of Mobile Learning and Organisation*, *14*(1), 114-129. https://doi.org/10.1504/IJMLO.2020.103911

Hwang, G.-J., Tsai, C.-C., & Yang, S. J. H. (2008). Criteria, strategies and research issues of context-aware ubiquitous learning. *Journal of Educational Technology & Society*, *11*(2), 81-91.

Ibrahim, S., Vasalou, A., & Benton, L. (2022). Understanding the situated practices of school technology leaders in the early stages of educational technology adoption. *Proceedings of the CHI Conference on Human Factors in Computing Systems* (Article 312). Association for Computing Machinery. https://doi.org/10.1145/3491102.3502120

Jørnø, R. L., Andersen, B. L., & Gundersen, P. (2022). The imaginary of personalization in relation to platforms and teacher agency in Denmark. *Nordic Journal of Studies in Educational Policy*, *8*(1), 20-29. https://doi.org/10.1080/20020317.2021.2022073

Ketelaar, E., Beijaard, D., Boshuizen, H. P. A., & Den Brok, P. J. (2012). Teachers' positioning towards an educational innovation in the light of ownership, sense-making and agency. *Teaching and Teacher Education*, *28*(2), 273-282. https://doi.org/10.1016/j.tate.2011.10.004

Khosravi, H., Shum, S. B., Chen, G., Conati, C., Tsai, Y.-S., Kay, J., Knight, S., Martinez-Maldonado, R., Sadiq, S., & Gašević, D. (2022). Explainable artificial intelligence in education. *Computers & Education: Artificial Intelligence*, *3*, 100074. https://doi.org/10.1016/j.caeai.2022.100074

Koper, R. (2014). Conditions for effective smart learning environments. *Smart Learning Environments, 1*, Article 5. https://doi.org/10.1186/s40561-014-0005-4

Lawrence, L., Echeverria, V., Yang, K., Aleven, V., & Rummel, N. (2024). How teachers conceptualise shared control with an AI co-orchestration tool: A multiyear teacher-centred design process. *British Journal of Educational Technology*, *55*(3), 823-844. https://doi.org/10.1111/bjet.13372

Leijen, Ä., Pedaste, M., & Baucal, A. (2024). A new psychometrically validated questionnaire for assessing teacher agency in eight dimensions across pre-service and in-service teachers. *Frontiers in Education*, *9*, 1336401. https://doi.org/10.3389/feduc.2024.1336401

Lin, P., & Van Brummelen, J. (2021). Engaging teachers to co-design integrated AI curriculum for K-12 classrooms. *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Article 329). Association for Computing Machinery. https://doi.org/10.1145/3411764.3445377

Lipponen, L., & Kumpulainen, K. (2011). Acting as accountable authors: Creating interactional spaces for agency work in teacher education. *Teaching and teacher education*, *27*(5), 812-819. https://doi.org/10.1016/j.tate.2011.01.001

Matuk, C., Gerard, L., Lim-Breitbart, J., & Linn, M. (2016). Gathering requirements for teacher tools: Strategies for empowering teachers through co-design. *Journal of Science Teacher Education*, *27*(1), 79-110. https://doi.org/10.1007/s10972-016-9459-2

Mavrikis, M., Geraniou, E., Gutierrez Santos, S., & Poulovassilis, A. (2019). Intelligent analysis and data visualisation for teacher assistance tools: The case of exploratory learning. *British Journal of Educational Technology*, *50*(6), 2920-2942. https://doi.org/10.1111/bjet.12876

McKim, C. (2023). Meaningful member-checking: A structured approach to member-checking. *American Journal of Qualitative Research*, *7*(2), 41-52.

Melrose, S. (2009). Naturalistic generalization. In A. J. Mills, G. Durepos, & E. Wiebe (Eds.), *Encyclopedia of case study research* (pp. 600–601). Sage. https://doi.org/10.4135/9781412957397.n224

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: A method sourcebook* (4th ed.). Sage.

Molenaar, I. (2021). Personalisation of learning: Towards hybrid human-AI learning technologies. *OECD Digital Education Outlook 2021: Pushing the Frontiers with Artificial Intelligence, Blockchain and Robot*s (pp. 57-77). OECD. https://doi.org/10.1787/589b283f-en

Molenaar, I. (2022). Towards hybrid human-AI learning technologies. *European Journal of Education*, *57*(4), 632-645. https://doi.org/10.1111/ejed.12527

Nazaretsky, T., Ariely, M., Cukurova, M., & Alexandron, G. (2022). Teachers' trust in AI-powered educational technology and a professional development program to improve it. *British Journal of Educational Technology*, *53*(4), 914-931. https://doi.org/10.1111/bjet.13232

Nøhr, L., Stenalt, M. H., & Hagood, D. (2023). University teachers' agency in relation to technology use in teaching: A quantitative investigation. *Edutec. Revista Electrónica de Tecnología Educativa*, *86*, 40-61. https://doi.org/10.21556/edutec.2023.86.2915

Novoa-Echaurren, Á. (2024). Teacher agency in the pedagogical uses of ICT: A holistic perspective emanating from reflexive practice. *Education Sciences*, *14*(3), 254. https://doi.org/10.3390/educsci14030254

Ogan, A., Walker, E., Baker, R. S. J. D., Rebolledo Mendez, G., Jimenez Castro, M., Laurentino, T., & de Carvalho, A. (2012). Collaboration in cognitive tutor use in Latin America: Field study and design recommendations. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1381-1390). Association for Computing Machinery. https://doi.org/10.1145/2207676.2208597

Opre, D. (2022). Teachers' pedagogical beliefs and technology integration. In I. Albulescu & C. Stan (Eds.), *Education, reflection, development: European Proceedings of Educational Sciences* (pp. 112-118). European Publisher. https://doi.org/10.15405/epes.22032.10

Pathiranage, A., & Karunaratne, T. (2023). Teachers' agency in technology for education in pre- and post-COVID-19 periods: A systematic literature review. *Education Sciences*, *13*(9), 917. https://doi.org/10.3390/educsci13090917

Pedersen, S. (2020). Staging negotiation spaces: A co-design framework. *Design Studies*, *68*, 58-81. https://doi.org/10.1016/j.destud.2020.02.002

Penuel, W. R., Roschelle, J., & Shechtman, N. (2007). Designing formative assessment software with teachers: An analysis of the co-design process. *Research and Practice in Technology Enhanced Learning*, *2*(1), 51-74. https://doi.org/10.1142/S1793206807000300

Priestley, M., Biesta, G., & Robinson, S. (2015). Teacher agency: What is it and why does it matter? In R. Kneyber & J. Evers (Eds.), *Flip the system: Changing education from the ground Up* (pp. 134-148). Routledge. https://doi.org/10.4324/9781315678573

Prieto, L. P., Holenko Dlab, M., Gutiérrez, I., Abdulwahed, M., & Balid, W. (2011). Orchestrating technology enhanced learning: A literature review and a conceptual framework. *International Journal of Technology Enhanced Learning*, *3*(6), 583-598. https://doi.org/10.1504/IJTEL.2011.045449

Roschelle, J., Penuel, W., & Shechtman, N. (2006). Co-design of innovations with teachers: Definition and dynamics. In S. A. Barab, K. E. Hay & D. T. Hickey (Eds.), *The International Conference of the Learning Sciences* (pp. 606-612). International Society of the Learning Sciences.

Sang, G. (2020). Teacher agency. In M. A. Peters (Ed.), *Encyclopedia of teacher education.* Springer. https://doi.org/10.1007/978-981-13-1179-6_271-1

Serrano-Iglesias, S., Gómez-Sánchez, E., Bote-Lorenzo, M. L., Alonso-Prieto, V., & Gallego-Lema, V. (2023). Exploring barriers for the acceptance of smart learning environment automated support. In O. Viberg, I. Jivet, P. J. Muñoz-Merino, M. Perifanou, & T. Papathoma (Eds.), *Responsive and sustainable educational futures* (pp. 636-641). Springer. https://doi.org/10.1007/978-3-031-42682-7_54

Serrano-Iglesias, S., Gómez-Sánchez, E., Bote-Lorenzo, M. L., Asensio-Pérez, J. I., Ruiz-Calleja, A., & Vega-Gorgojo, G. (2021). Demonstration of SCARLETT: A smart learning environment to support learners across formal and informal contexts. In T. de Laet, R. Klemke, C. Alario-Hoyos, I. Hilliger, & A. Ortega-Arranz (Eds.), *Technology-enhanced learning for a free, safe, and sustainable world* (pp. 404-408). Springer. https://doi.org/10.1007/978-3-030-86436-1_44

Severance, S., Penuel, W. R., Sumner, T., & Leary, H. (2016). Organizing for teacher agency in curricular co-design. *Journal of the Learning Sciences*, *25*(4), 531-564. https://doi.org/10.1080/10508406.2016.1207541

Sison, R., & Shimura, M. (1998). Student modeling and machine learning. *International Journal of Artificial Intelligence in Education*, *9*, 128-158.

Stake, R. (1995). *Case study research*. Sage.

Tabuenca, B., Serrano-Iglesias, S., Martin, A. C., Villa-Torrano, C., Dimitriadis, Y., I. Asensio-Perez, J., Alario-Hoyos, C., Gomez-Sanchez, E., L. Bote-Lorenzo, M., Martinez-Mones, A., & Kloos, C. D. (2021). Affordances and core functions of smart learning environments: A systematic literature review. *IEEE Transactions on Learning Technologies*, *14*(2), 129-145. https://doi.org/10.1109/TLT.2021.3067946

Treasure-Jones, T., Dennerlein, S., Antoniou, P., & Koren, I. (2019). Co-creation in the design, development and implementation of technology-enhanced learning. *Interaction Design and Architecture(s)*, *42*, 5-10. https://doi.org/10.55612/s-5002-042-001psi

Twining, P., Heller, R. S., Nussbaum, M., & Tsai, C. C. (2017). Some guidance on conducting and reporting qualitative studies. *Computers & Education*, *106*, A1-A9. https://doi.org/10.1016/j.compedu.2016.12.002

Wang, J., Tigelaar, D. E., Luo, J., & Admiraal, W. (2022). Teacher beliefs, classroom process quality, and student engagement in the smart classroom learning environment: A multilevel analysis. *Computers & Education*, *183*, 104501. https://doi.org/10.1016/j.compedu.2022.104501

Wolcott, H. F. (2009). *Writing up qualitative research*. Sage. https://doi.org/10.4135/9781452234878

APPENDIX A: SEMI-STRUCTURED INTERVIEW SCRIPTS

EXPLORATORY INTERVIEW WITH THE TEACHER [TI1] – SEMI-STRUCTURED SCRIPT

Can you provide a description of the learning scenario? (e.g., number of sessions, learning objectives)

What do you want students to learn?

What is your knowledge about SCARLETT?

Do you know how the SCARLETT-student interaction is designed?

What have you done in previous courses to address this content?

Considering that the learning scenario involves a Kahoot and a geolocated activity, why did you choose those tools initially?

What do you know about how the student model was generated?

Have you been able to define the type of activities?

Have you been able to define the content of each activity?

Can you define the number of activities at each location that students visit?

Do you have the ability to influence the factors that affect when a specific activity will be triggered?

How would you like the learning activity to be without the use of technology? Would it be possible?

Have you had to use tools that are not part of your usual teaching practice?

Do you have control over the implementation of the learning activity?

What would you like to be able to control in the learning scenario? (e.g., real-time monitoring)

Do you plan to/ would you like to use student responses to make decisions?

Do you feel that your own agency (understood as the ability to make decisions/orchestrate in the learning scenario) could be threatened? If so, what are those threats?

Do you feel that student agency may be threatened by SCARLETT?

Have you perceived any interference from the development/research team that could have threatened your own agency or the students'?

EVALUATION INTERVIEW WITH THE TEACHER [TI2] – SEMI-STRUCTURED SCRIPT

Once completed [the learning activity], would you be able to provide a general assessment of your experience?

What process have you followed to design the learning activity?

What limitations have you encountered while creating the learning activity?

Were you able to define both the type and number of activities, as well as their content?

Have you felt that your agency (understood in this context as the ability to make decisions/orchestrate in the learning scenario) has been compromised by any factor?

Do you consider SCARLETT to pose a threat to both teacher agency and student agency in scenarios like this?

Has there been any tension with the SCARLETT development team? How has it affected the design or implementation of the experience?

Is SCARLETT an intuitive (user-friendly) tool to use?

What is your current knowledge about SCARLETT?

Have you made modifications to the learning scenario design once you considered it set?

Have you had to use technological tools that you do not usually use in order to implement this learning scenario design?

Do you feel that student agency may be threatened by SCARLETT?

What evaluation do you make of the learning carried out in non-formal spaces and times?

Were you able to influence the factors affecting when the recommendations are triggered?

What were you able to control in the learning scenario? (During the second phase)

What decisions have you been able to take thanks to SCARLETT?

How useful have the data from SCARLETT been for you?

Why would you use or not use SCARLETT in the future to design learning scenarios?

INTERVIEW WITH THE LEAD RESEARCHER [RI]

What has been your perception of the implementation of the learning activity?

What have been the lessons learned and limitations encountered after the implementation?

What do you, as the researcher, intend to achieve with the development of the system?

How was the student model generated?

Why was it decided that it should be done in this way?

If a teacher was not used to generating the student model, why not? And how demanding do you think it would be for the teacher to add their decisions within the student model. Also, how has the matching been done between the student model and the recommendations to students? Has the teacher been involved?

How have the recommendations been made at a level and topic that the teacher wants?

What decisions of the researcher guided the development of the student model/recommendations? Are they based on any pedagogical theory? If so, which one? Why?

On what parameters is the relationship between SCARLETT and the student defined?

It has been decided that the system will interact with students. Why? Is this something configurable by the teacher? Why was it designed this way?

Are there other types of interaction without students being aware of them?

What has been the main motivation for the development of the tool?

What does the researcher intend to achieve with the development of the system?

In what way has the teaching staff intervened in the design process?

What have been the main tensions between the researcher and the teaching staff?

How have the tensions been resolved? What were the minimum requirements that the teacher wanted in order to implement SCARLETT in their classroom? Were all of these requirements met by the initial version proposed to the teacher? Finally, were they all met?

What has been the perception of the implementation of the activity?

What have been the lessons learned and limitations encountered after the implementation?

APPENDIX B: RESULTS FROM THE TEACHER AGENCY QUESTIONNAIRE

RESPONSES TO INDIVIDUAL ITEMS OF THE QUESTIONNAIRE

The following are the instructions given to participants prior to completing the questionnaire:

This questionnaire seeks to understand how you make decisions in your work when using Information and Communication Technologies (ICT) in teaching.

There are no right or wrong answers here, just answer the statements as precisely as possible. If you fully agree with the statement, mark the number 7. If you do not agree with the statement, enter the number 1. If you partially agree with the statement, find the position that best describes you between the numbers 1 and 7.

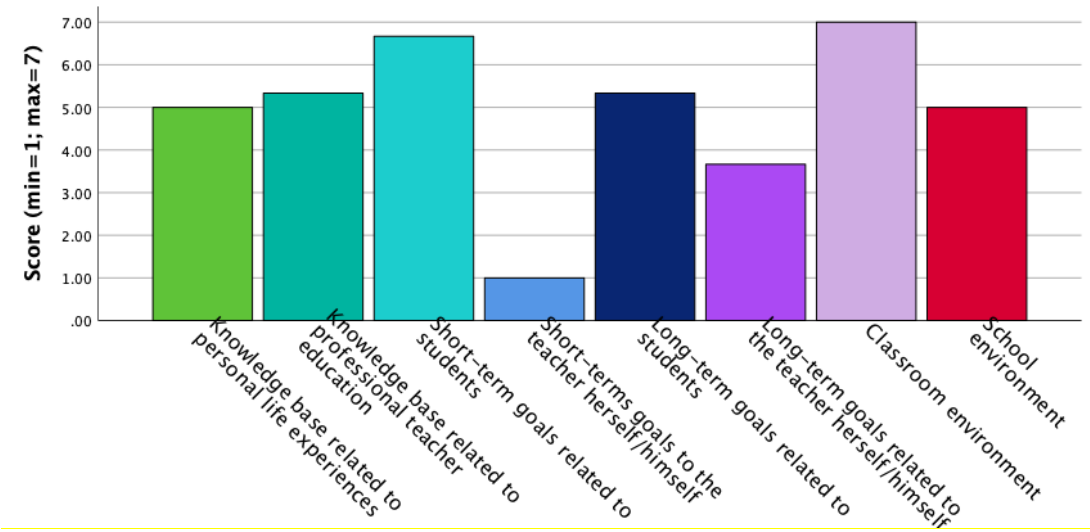
The following table displays the scores per item:

Item	Score
1. My confidence towards planning teaching and learning experiences	5
2. Values and beliefs developed based on my personal life experiences	5
3. Knowledge and skills developed based on my personal life experiences	5
4. Values and beliefs developed during teacher training	5
5. Knowledge and skills gained from teaching experiences	6
6. Values and beliefs developed based teaching experiences	5
7. Short-term goals related to learners' acquisition of content knowledge	7
8. Short-term goals related to supporting learners' motivation	6
9. Short-term goals related to learners' personal development	7
10. Short-term goals related to my personal well-being	1
11. Short-term goals related to my personal development	1
12. Short-term goals related to my calling	1

Item	Score
13. Long-term goals related to learners' acquisition of educational qualifications (e.g., secondary education)	6
14. Long-term goals related to supporting the development of learners' personalities	4
15. Long-term goals related to learners becoming active members of the society	6
16. Long-term goals related to my personal development	1
17. Long-term goals related to serving society	6
18. Long-term goals related to my calling	4
19. Classroom atmosphere (e.g., willingness to cooperate)	7
20. Class structure (e.g., group size, percentage of boys and girls)	7
21. The physical environment of my class	7
22. School organizational culture (e.g., collaborative orientation)	7
23. School administrative support (e.g., lesson plan, workload, support professionals)	6
24. Support from colleagues at school	2

The following table and figure display the scores of Recoded Item-Based Factors Categorised by Ecological Dimensions of Teacher Agency.

Factor	N	Value	Broad dimension of the ecological framework of teacher agency
Knowledge base related to personal life experiences	1	5.6667	Iterational
Knowledge base related to professional teacher education	1	6.3333	Iterational
Short-term goals related to students	1	3.6667	Projective
Short-term goals for the teacher herself/himself	1	2.0000	Projective
Long-term goals related to students	1	6.3333	Projective
Long-term goals related to the teacher herself/himself	1	3.3333	Projective
Classroom environment	1	3.0000	Practical evaluative
School environment	1	2.6667	Practical evaluative
Valid N (listwise)	1		



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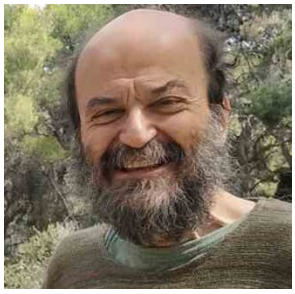

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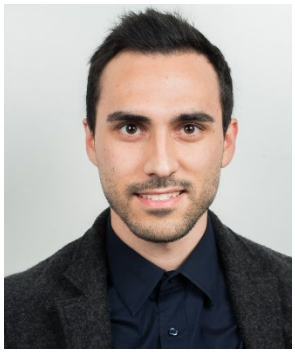

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