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ORIGINAL RESEARCH

The DTALE Model: Designing Digital and Physical Spaces for Integrated Learning Environments

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Abstract
Despite the widely recognised impact of both digital and physical spaces as active contributors to teaching and learning processes, relatively little is known about the learning environment. Furthermore, it is time to explore the interplay between these two spaces. Therefore, we proposed employing a holistic approach to develop a new conceptual model for Designing Teaching and Learning Environments (DTALE). To do this, the paper presents first a critical review of the research literature underpinning learning environments, with a particular interest in the integration of the physical and digital spaces, to develop the DTALE model. In the second step, the DTALE model has been developed and validated by applying the model to existing cases from different contexts. Based on the study's findings, we outline the implications for theory and practice. Limitations and suggestions for future research are also included.

Keywords Learning space · Learning environment · Technology · Conceptual model · Digital

1 Introduction

The learning environment comprises the physical and digital spaces in which teaching and learning occur, and the design of these spaces can impact teaching and learning processes (Barret et al., 2019). Therefore, we can think about learning environments as active contributors in educational practice and it can be understood as the 'third teacher' (e.g., Yufiarti, Erik, Fidesrinur, Rosalinda, & Garzia, 2022). Learning environments have become more visible through the recent Great Online Transition (GOT), as part of the global COVID-19 pandemic. This event catalyzed an increased use of the digital learning environment across educational levels (Carvalho, Marques, Guimarães, Araújo, & Cruz, 2022). After teaching in online learning environments during the pandemic, some teachers began to feel teaching across physical and digital spaces, e.g. hybrid/blended learning environments, were 'the new normal' (Lund-Larsen, Jørgensen & Andresen, 2021). However, despite the growing interest among some teachers, school leaders, architects, and policymakers, relatively little

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is known about the learning environment (Hermans & Tondeur, 2021) and how the physical and digital space can be integrated to create a powerful learning environment.

Interestingly, after the GOT and the pandemic, in many contexts teachers returned to 'traditional' face-to-face teaching as students came back to school. However, new online practices have already been adopted by teachers (e.g. Hanny et al., 2023). We therefore argue that it is necessary to explore the interplay between physical and the potential of digital learning spaces in greater detail, to better understand how they come together as a learning environment (cf. Nortvig, Petersen, Helsinghof, & Brænder, 2020). Sasson et al. (2022) suggest that "researching the relationships between physical space and learning and teaching processes is imperative" (p. 61). The digital and physical learning spaces present different affordances, materials, ways of interacting, and experiences for students and teachers. There is quite a bit of research on digital learning spaces (Martin et al., 2020; Martin, Polly, & Dymes, 2021), and there is a growing body of work looking at blended learning (e.g., Anthony et al., 2022; Rasheed, Kamsin, & Abdullah, 2020). However, a framework is needed to look across both physical and digital learning spaces to understand the whole environment, to be able to compare and contrast and to understand the nature of the learning design.

This concept paper contributes to the complex field of learning environments by presenting a framework to better understand the relationships between physical spaces, digital spaces, and teaching and learning. The ideas presented in this concept paper emerged from the author's participation in a thematic working group (TWG) of the 2023 UNESCO International Summit on ICT in Education (EDUSummIT) at the University of Kyoto, Japan. Specifically, the TWG 7 on learning environments highlighted the necessity of aligning action at multiple levels to develop a knowledge base for the integration of physical and digital learning environments. In this respect, the TWG addresses the opportunities for future learning environments by first conducting a scoping review with a specific focus on schooling (K-12, grades 1–13). Based on the scoping review, TWG 7 developed a new conceptual model, DTALE (Designing Teaching and Learning Environments), for integrating physical and digital spaces to design a learning environment. Finally, the conceptual DTALE model was validated by applying the model to existing cases from different contexts, as presented in the results section.

2 Background

2.1 Learning Environments: What's in the Name?

According to Rusticus et al. (2023), the learning environment comprises "the psychological, social, cultural and physical setting in which learning occurs and has an influence on student motivation and success (…) and in which experiences and expectations are co-created among its participants" (p. 161). However, learning environments and how they are defined have evolved over time to reflect changing beliefs about learning and educational contexts (Woolner & Stadler-Altmann, 2021). Early research in the 1900s focused on the physical setting and design of a classroom and the psychological well-being of children (e.g., Ayres, 1910). Over time the focus changed to school climate (e.g., Wang & Degol, 2016) and the psychological and social elements of learning, such as a means to prevent distraction and empower students to engage in learning (Choi, van Merrienboer, & Paas, 2014). Later also the quality of the learning environment with regards to thermal comfort, noise levels, lighting, and air quality has been explored (Barrett et al., 2019). The design of the physical learning environment has a measurable impact on students' academic achievement and learning experience (Daniels et al., 2019). The widest definitions of learning environments also include learning materials, learning tasks, teachers and other students, especially when addressing student-centered learning environments (Baeten et al., 2013; Land et al., 2012). According to this understanding, learning environments provide students with more choice for self-directed learning when compared to traditional classroom instruction. Thus, concepts of learning environments range from rather narrow to very complex. Today, all facets might be considered when using the term learning environment. Therefore, its importance cannot be undervalued in the learning experience.

The introduction of the Internet resulted in research exploring how practitioners (re-) designed their classrooms and reorganised daily school practices within the physical space (Hermans & Tondeur, 2021). In the digital age, a second type of learning environment has emerged; digital, virtual or online learning environments such as collaborative online spaces, learning management systems, and virtual reality spaces. Also here, there has been a notable shift from digital learning environments provided by schools in the form of Learning Management Systems to so called Personal Learning Environments where learners have more choice and more control over the use of digital applications for learning (Attwell, 2007; Castañeda et al., 2022). However, research has not fully examined the connection between the physical and online learning environments; it has generally focused on the affordances or use of a tool for learning (Singh & Thurman, 2019). As digital technologies such as virtual reality and artificial intelligence become more complex and infused into education, how teaching occurs and students engage in these environments needs to be researched in a more integrated way (Calder & Otrel-Cass, 2021). Also, the Great Online Transition during the global pandemic has forced changes in physical space and pedagogical practices (Howard et al., 2020). This provided an impetus to focus research on how online and physical learning environments integrate and blend. In the following section, we present the DTALE framework as a tool to inform research on the intersection of physical and digital learning environments.

2.2 Towards a Conceptual Model to Explore Learning Environments

The goal of the DTALE model is to operationalise connections between digital and physical spaces, in learning environments. According to Calder and Otrel-Cass (2021), tools are needed to examine and better understand these integrated learning environments. However, given the complexity of schooling, there is some difficulty in representing learning environments in simplified models (e.g., Kokko & Hirsto, 2021). With this in mind, the DTALE model is intended to guide what could be considered in a learning environment where integration between digital and physical spaces is happening or being planned.

Conceptual models have taken a number of approaches to understanding learning environments. Manninen et al. (2007) understood learning environments through five different perspectives, which can be used to consider different elements of the environment: 1) physical spaces, 2) teaching and learning approaches, 3) social and collaborative aspects, 4) digital technologies, and 5) contextual learning places outside the school (e.g., work placements and field visits in biology). Radcliffe et al., (2008, 2009) define a learning environment using the Pedagogy–Space–Technology framework for design and evaluation. This model highlights connections among different components of a learning environment. Both of these approaches prioritize the physical space, where digital technologies are treated as a resource, rather than recognising the virtual learning environment as an equally complex entity with socio-material interactions (Gourlay, 2021). The DTALE model brings digital/virtual learning environments together.

Figure 1 presents the DTALE model. The next section will describe each of the elements of the model and how they theoretically relate.

2.2.1 Digital and Physical Spaces

In 2008, Nespor (2008) stated that defining connotation-rich terms like "place" or "space" will always be difficult in education. In a broader philosophical view, spaces provide dimensions, points of reference, and boundaries in which places, subjects and objects can be situated (Agnew, 2011; Herman & Tondeur, 2021). While the notion of space describes boundaryless and unspecified areas, places are more shaped and specific. According to this understanding, places are created and connected by human agency within spaces. Although these terms have become more fluid and mobile with digital technologies, opening up

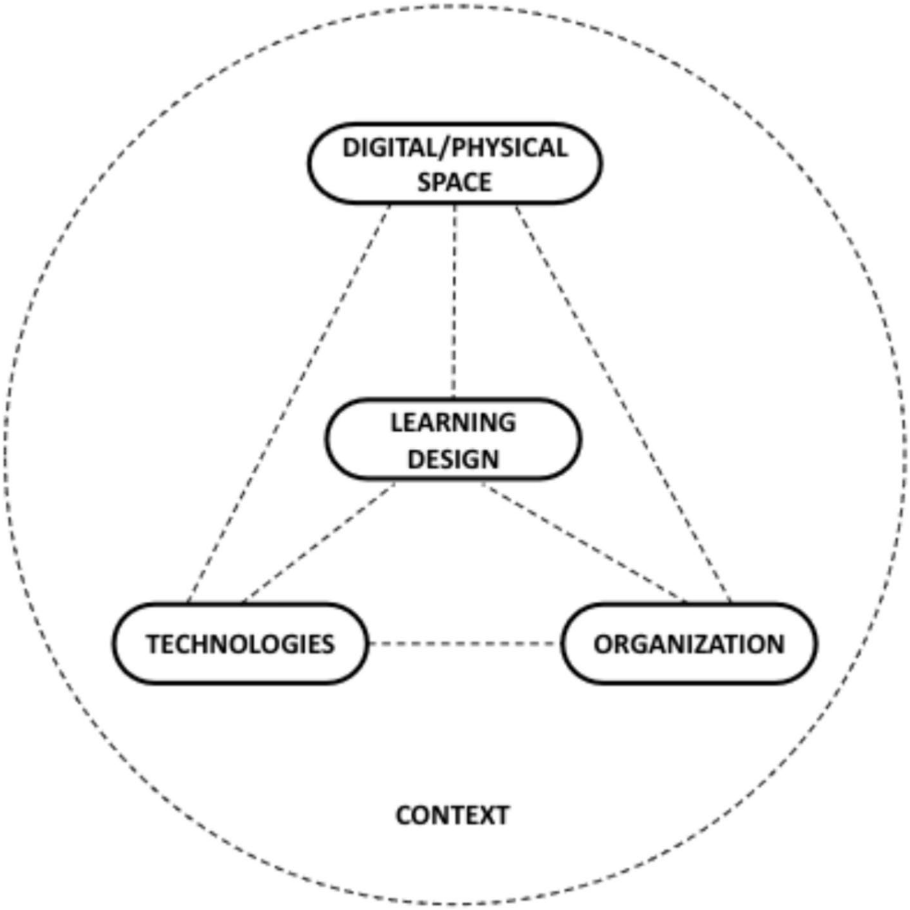

Fig. 1 Designing Teaching and Learning Environments (DTALE) model

spaces, specifying and occupying places are still important to contextualize human activities.

In education, spaces and places can be regarded as contexts that provide opportunities and constraints for learning activities. Traditionally conceptions of 'space' have been narrow, based on physical and built spaces like school buildings and tangible infrastructure (Tondeur et al., 2017). For example, historically school space has typically been divided into classrooms, halls, and offices – objects and people occupy these places. These have been expanded to encompass digital spaces. Digital spaces have been in compulsory schooling for decades, such as students working independently on computers in classrooms in the 90 s and working collaboratively in Google Docs in the 2010s. However, digital spaces have been ignored in educational technology research (Blight & Crook, 2017). How digital technologies are used to create different spaces and what can be done in those spaces is relatively unknown. Therefore, the affordances and limitations, and how spaces can be combined, are still not clear. However, with the advent of increased mobility in learning afforded by digital technologies, there has been a recent movement towards flexible and open learning environments. Here, students can have more agency in choosing and designing their own place within the given space (e.g. Reinius et al., 2021). Therefore, there is some evolution between physical and digital spaces, in shaping different learning experiences.

Theoretically, combinations of physical and digital space can be understood in terms of their relationship to each other in learning design. First, they can be 'redundant', such as comparable places can be found in both spaces and the use of either is a matter of choice. These could be classes that can be taught face-to-face or online, complimentary. They can also be 'comparable' places. which could be found in either physical or digital spaces, but not in both. This could be a homework helpdesk with a real teacher, but is only provided online. They could be 'extended', such as unique places situated in unique spaces, such as an online-only virtual tutor, and it cannot be provided in the physical space. This could also be a soccer field, which is only available in the real space. Therefore, physical and digital spaces can be connected or disconnected in different relationships, depending on the activities and the space they occupy.

In the DTALE model, learning spaces represent physical and digital areas where teachers and students define and seek out places to interact with learning objects, learning-related tools, and each other. While other spaces are possible, such as liminal spaces, flexible, or informal, and formal spaces, these can be considered in terms of integration between physical and digital spaces. Moreover, physical and digital spaces capture much of the configuration found in compulsory school classrooms at this time (Calder & Otrel-Cass, 2021). Depending on the relationships among spaces in redundant, complementary and extended designs, the DTALE model provides a way to reconsider interactions with the other components of schooling.

2.2.2 Technologies

It is then possible to consider what is brought into learning spaces, shaping the learning environment. It is important when thinking about digital technologies, to understand that some digital technologies can create online spaces for work and interaction, such as virtual learning environments and learning management systems (e.g. Canvas) and adaptive learning systems (e.g. Mathletics). These create spaces, largely digital and online, that provide places for digital tools and activities. While other digital technologies are more akin to ‘resources’ that can be brought into learning places – digital or physical. For the purposes of this discussion, we consider here Technologies as the digital technologies that shape, enable and constrain learning spaces. For example, some digital technologies may be infrastructures, such as learning management systems (LMS), which could be considered as ‘extended’ learning spaces. These create quite explicit online-digital learning places, which do not appear in the physical learning space. The possibilities for interactions, tasks and creation within the LMS are then constrained by the design of this type of tool, which is well documented in research (Turnbull et al., 2019; Walker et al., 2016). While a digital technology, such as a shared Google Document can be used flexibly by learners, face-to-face or online, and for a range of tasks. This tool could be found in ‘comparable’ spaces and used in online or physical places for different purposes. Therefore, the affordances of these two types of technologies, and their relationships to space, can be quite different and have different relationships to and affordances in learning places.

By specifically identifying Technologies, it brings focus to their role in learning designs. In modern learning environments, students and teachers routinely work with a variety of digital technologies. As outlined above, these have different relationships to space and different roles in places. When we consider the affordances of digital technologies, how they enable and constrain different activities, their place in learning becomes clearer. For example, digital technologies can range from static to more interactive, from 2D to more immersive (e.g., sharing photos, using virtual or augmented reality), and from desktop to mobile devices and even wearable devices and artificial intelligence (Brown, 2020). While other technologies support networking, facilitate communication, and shape collaboration (Goodyear et al., 2014b). Some of these can be used in a physical classroom, online in class, or online away from the classroom (e.g., blended learning or fully online learning). How these tools are integrated is highly variable, and it depends on the actual functionality and capability of that tool. However, more must be known about their role in learning designs, and the wider learning environment, particularly given their range of uses, interactions and how relationships to space and place are afforded.

Research indicates that digital technology can improve learning outcomes, but, like all teaching tools, it depends on context and how it is used (Goodyear et al., 2014a). For example, effective technology integration differs between disciplines, according to different subject methodologies, pedagogical approaches, and for different students (Schmitz et al., 2023). However, research has also shown that the effectiveness is dependent on whether technology provides an added value for learning by raising the level of the learning activities from passive to active, constructive or even interactive (Sailer et al., 2024). The DTALE model includes Technology as a discrete component to support teachers critical engagement with digital technologies to select and integrate the right tools based on alignments between affordances of those technologies in learning processes, and schools or education systems have in place organisational policies which support access and use.

2.2.3 Organisation

In the DTALE model we also included the more fundamental aspects of school organization. The focus here is on how we structure time and work, such as the structure of “classes”, “subjects”, “grades”, “lessons”, or “employment models”. Already in 1994, Tyack and Tobin (1994) referred to the “grammar” of schooling or “the regular structures and rules that organize the work of instruction” (p. 454). These authors point to, for example, standardized organizational practices in dividing time and space, classifying pupils, allocating them to classrooms, and dividing knowledge into subjects.

At the same time, schools can also be understood as organizations, in that there is a clear leadership and rank in the group, such as principal, deputy principal, head teacher, etc. (Vecchio et al., 2010). Specifically, some see this as a hierarchical bureaucratic organization (Duke, 2018). This means the rules and norms that guide behaviour, and the leadership hierarchy, have limited flexibility. As such, the school as an organization has a significant effect on the shape of learning environments and digital technology use (Howard, 2013). Therefore, schools need to be organized in such a way that they support learning and student experiences (Leithwood & Seashore Louis, 2006).

Many schools, as organizations, have been going through digital transformations, during and since the GOT. Part of digital transformation is organizationally adopting digital technology infrastructures, such as learning management systems and administrative tools, across the school. It has been proven that leadership, in the form of resources, support, and policy to support instructional and pedagogical change, is the most critical factor in successful transformation (e.g., Navridas-Nalda et al., 2020). These elements will have associations with other components in relation to what is available, expectations of learning environments and learning experiences.

2.2.4 Learning Design

Learning design can be defined as "the creative and deliberate act of devising new practices, plans of activity, resources, and tools aimed at achieving particular educational aims in a given context" (Mor & Craft, 2012, p. 86). The core concepts of learning design centre around guidance, representation, and sharing (Dalziel, 2015). Dalziel et al. (2015) detailed how learning design occurs within a teaching cycle where teachers design and plan, engage with students, reflect, and often undertake professional learning. Critical to designing effective learning tasks and environments is understanding the specific needs of the individuals and making appropriate adjustments (Dalziel, 2015; Gravemeijer & Cobb, 2006). Quality learning design is particularly critical in online learning, where students often work independently or are scaffolded to work independently (Lawrie & Wright, 2020). Teachers' integrated learning designs are significantly affected by available digital technologies (what can be included), the learning space (how can it be done), and the organization (what is expected).

The increasing infusion of technology in education has led to the emergence of a number of learning design frameworks that aim to support the effective integration of technologies into learning tasks (see Bower & Vlachopoulous, 2020). Specifically, researchers and educators have looked at constructivist learning designs, where student-centered learning is prioritized (e.g., Kopcha et al., 2020). These designs offer opportunities for personalization, rich interactions, and knowledge building. Research has shown that the use of digital technologies is most effective when integrated within constructive or interactive learning designs (Major et al., 2021; Sailer et al., 2024). However, as stated above, the effectiveness and success of a learning design are not solely dependent on the choice of pedagogy, but also on the availability of adequate scaffolds. The DTALE model provides a way to examine associations among key components, to determine what is needed to support quality learning designs.

2.2.5 Context

The learning context can be defined at many levels, from individual classes (micro) to whole-of-school environments (meso) to a larger education system (macro). The former positioning of context relates to microelements such as individual students and teachers, class compositions, prior knowledge, interests, and motivational dispositions, which have been shown to influence learning (Kauffman, 2015). Context also includes the space or environment where the learning is undertaken, whether a physical, blended, or online space. The meso-level context relates to school-wide social, economic, and environmental aspects. Leadership, collaboration, resourcing, cultural traditions, and environmental conditions interact to affect the school context (Fullan, 2015). The macro context relates to elements such as state or national policies, funding, curriculum, laws, teacher education, professional development, and cultural aspects, which impact the school context (Mavrogordato & White, 2020). Contextual knowledge—from awareness of available technologies to the teacher's knowledge of the school, district, state, or national policies they operate within—is critical for teachers to possess (Mishra, 2019). In this respect, the design of a learning environment should always consider the specific social, physical and cultural characteristics of each school's context (cf. Brianza et al., 2024).

In the following section, we test the applicability of the proposed model through four cases. Each case embodies different spaces, technology, organization, context and learning design goals. Each of the cases provides an opportunity to examine each dimension in more depth and to test relationships within the model.

3 Four Cases Under the Magnifying Glass

The four cases presented here were identified by scholars in the Thematic Working Group 7 at EDUsummIT 2023. The cases represent four international innovative learning environments encompassing a diverse range of contexts, age groups, and educational disciplines. The cases were employed to validate the Designing Teaching And Learning Environments (DTALE) model. They can be considered as a pilot study, where the DTALE model was employed as an analytical model to delve deeper into the cases, and providing a mechanism to explore integration of digital and physical spaces. Each of the four cases presented below offers unique insights reflecting how schools tailor each of the components to their specific contexts. The cases are each presented. They are then further compared and analyzed in the Discussion.

3.1 Portuguese Case: Supporting Athletes Abroad

The first case reports on the innovative approach adopted by Coimbra-Center Schools in Portugal, focusing on the academic and athletic development of high-performance student-athletes from 7 to 12th grade (see Fig. 2).

In this *context,* under the aegis of the Ministry of Education and aligned with Portuguese educational policies, the establishment of Units for High Performance at Schools (UHPS) was initiated. The primary objective of UHPS is to ensure seamless integration and coordination among school administrations, guardians, sports federations, local authorities, and other relevant entities. This *organisation* facilitates the dual career paths

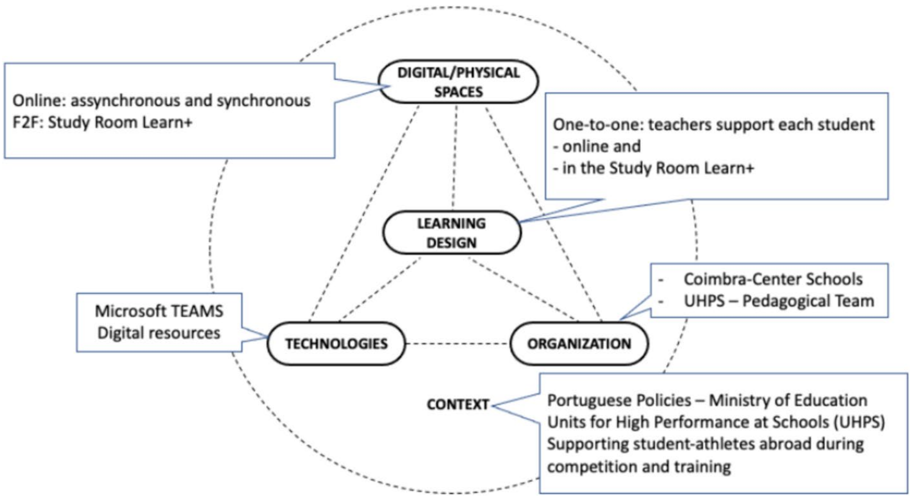

Fig. 2 DTALE model–Portuguese case

of secondary school students/athletes engaged in high-performance sports, including those representing national teams and demonstrating significant sporting potential in specific federated sports. Their sport participation and associated travel makes it difficult for them to consistently adhere to a typical school schedule.

The *learning design* focuses on delivering essential learning experiences for all students requiring specialized assistance. The pedagogical approach centers on student-oriented learning, emphasizing individualized instruction. The supporting pedagogical team includes teachers, Class Council members, school tutors, and psychologists. This team received training in remote teaching methodologies and digital educational *technology* and developed online resources under the supervision of a National Digital Team. The school tutor plays a pivotal role in the daily academic life of student-athletes by:

(a) Crafting personalized learning trajectories based on continuous feedback from educators, including ongoing assessments.
(b) Coordinating with all stakeholders, such as parents, coaches, federations, teachers, and UHPS support staff, alongside national and regional coordinators.
(c) Providing supplementary lessons to address gaps due to absences or specific study needs.
(d) Balancing academic and sports schedules.
(e) Collaborative learning experiences for student-athletes.
(f) Facilitating face-to-face and online learning, designing educational plans, producing innovative digital resources, and collaborating with subject-specific educators.

The team supports student-athletes overseas through various means, including private consultations, collaborative document editing, recording parts of live sessions, and creating video tutorials. On-campus, students-athletes have access to personal learning support in a dedicated *physical space*, the Learn + study room, providing assistance from teachers and psychologists (see Fig. 3). Microsoft TEAMS—the *digital space*—serves as the platform for this initiative, offering both synchronous and asynchronous learning opportunities to

Fig. 3 Supporting students-athletes in the study room Learn+

prevent disruption in education. Technological tools utilized include the TEAMS platform, digital resources, personal devices like smartphones and computers, and routers (provided by the Ministry of Education) to facilitate this comprehensive educational model.

3.2 Swiss Case: Vocational Education with a Mission

The second case is situated at the Bildungszentrum Limmattal in Switzerland (see Fig. 4). The school offers vocational education programs for 1200 learners in the areas of logistics, recycling, and technology.

The school's innovative learning concept, named "N47e8", represents a transformative approach to vocational education and *organization*. This pedagogical approach was designed to aligning with current and future demands of a technology-driven world and

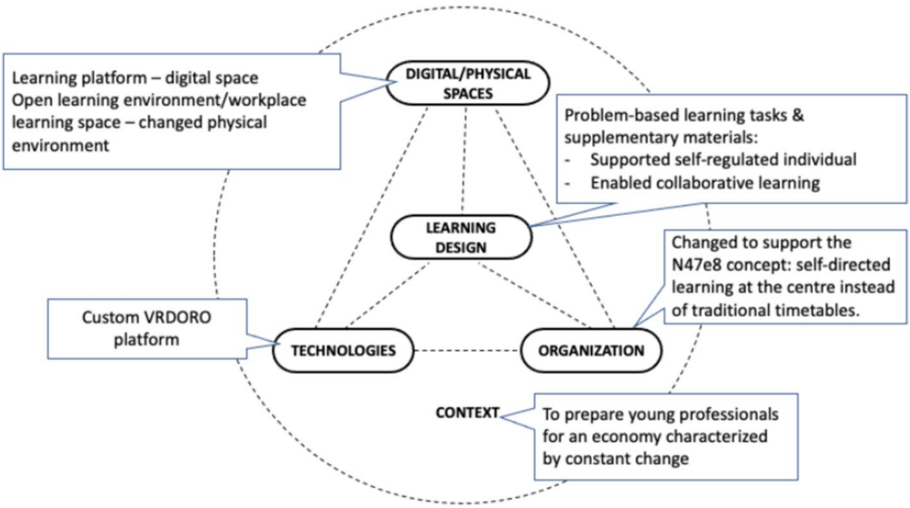

Fig. 4 DTALE model–Swiss case

evolving workplace expectations. The development of this particular approach began with a thorough understanding of the current learning *context*. Recognizing the omnipresence of *technology*, the school emphasized self-directed learning and digital literacy. This shift was also in acknowledgement of the importance of active engagement in problem-solving and self-paced learning as critical competencies for ongoing professional development.

Developing this new teaching and learning mode entailed an intensive year of conceptual work dedicated to *learning design.* The resulting design, driven by the N47e8 approach, asked students to engage independently in a series of "missions"—problem-based learning tasks supplemented by additional information. These sequentially arranged missions culminate in a comprehensive curriculum tailored for vocational learners. This model empowers students with the autonomy to select the missions they wish to undertake and the sequence in which to address them. This learning design facilitates an *organisation* allowing students to seamlessly align their school-based learning activities with practical workplace experiences.

During this developmental phase, a *digital learning space* was custom designed to fulfill the specific requisites of this approach, marking a crucial step in the implementation process. The digital platform (https://vrdoro.com/college) serves as a central hub for organizing learning materials, tasks, and managing learning groups. Its design places a strong emphasis on competence-oriented, problem-based learning tasks. The structure facilitates a learner-paced approach, allowing students to progress according to their individual learning rhythms. Teachers leverage the platform to monitor student progress and assist as needed. This digital space is part of their shift towards a more dynamic, interactive, and learner-centered educational paradigm.

Additionally, there has been a transformative change in the *physical space.* Spaces dedicated to self-directed learning have replaced numerous traditional classrooms, reflecting a shift towards a more autonomous and flexible learning structure. This change is not only functional but also aesthetic, as the school building has undergone a repaint, and the missions are now visually represented as colorful pictograms throughout the facility (see Fig. 5). These pictograms, strategically placed in the school environment, are interactive. Students can scan them with the VRDORO App, which then provides access to the respective missions. This innovative use of digital and physical spaces intertwines to create an engaging, dynamic, and visually stimulating learning environment, further embodying the principles of the N47e8 approach.

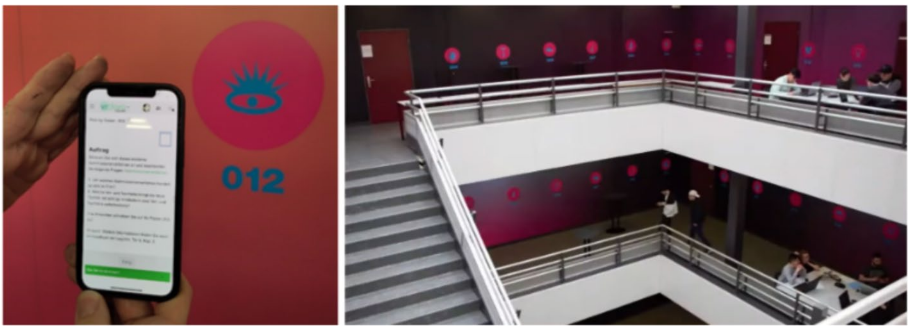

Fig. 5 The integration of self-directed digital and physical learning spaces

3.3 The Dutch Case: Educational Opportunities for Homesitters

The third case centers around an initiative launched in the 2020–2021 academic year by educators from the Agora School, a public school for secondary education in the Netherlands.

The project, *Agora Underground,* was primarily inspired by the insights gained during the shift to remote education necessitated by the COVID-19 pandemic. Recognizing the unique challenges and opportunities presented by this unprecedented *context* (see Fig. 6), the teachers identified two key focus areas. First, the project aimed to utilize *technology* as a means to engage with students who were not attending school often referred to as "home-sitters" or school refusal. By leveraging online coaching, video conferencing, and a virtual learning community, the initiative sought to reintegrate these students into the educational process, offering them a viable alternative to conventional classroom learning. Teachers build trust with their students before encouraging them to participate in activities. Then they focused on students' personal goals and future steps. Second, a significant aspect of this project was its emphasis on customizing educational experiences to meet the specific needs of students who had dropped out of school or were struggling with the traditional education system.

The central goal of the *learning design* was to foster motivation, autonomy, and ownership among students by actively involving them in the creation and organization of their learning community. This student-centered strategy emphasized authentic personalization in multiple dimensions: learning content, the methodologies employed, and the nature of support provided to each learner. Therefore, Agora Underground, established a learning community primarily in a *digital space* using http://gather.town. This innovative platform allowed students to design their own virtual rooms, fostering personalization and creativity beyond traditional classroom settings (Fig. 6). These spaces included personalized rooms, meeting areas, and gaming zones, facilitating diverse interactions.

While focused on digital spaces, Agora Underground's educational model equally values the *physical space* in its holistic approach to learning (see Fig. 7). Mentors conduct home visits to understand and connect with each student's unique context, ensuring that

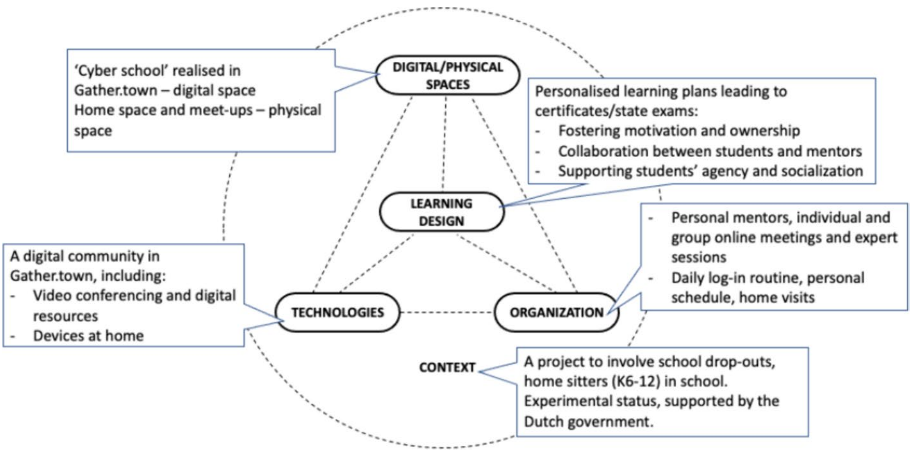

Fig. 6 DTALE model–Dutch case

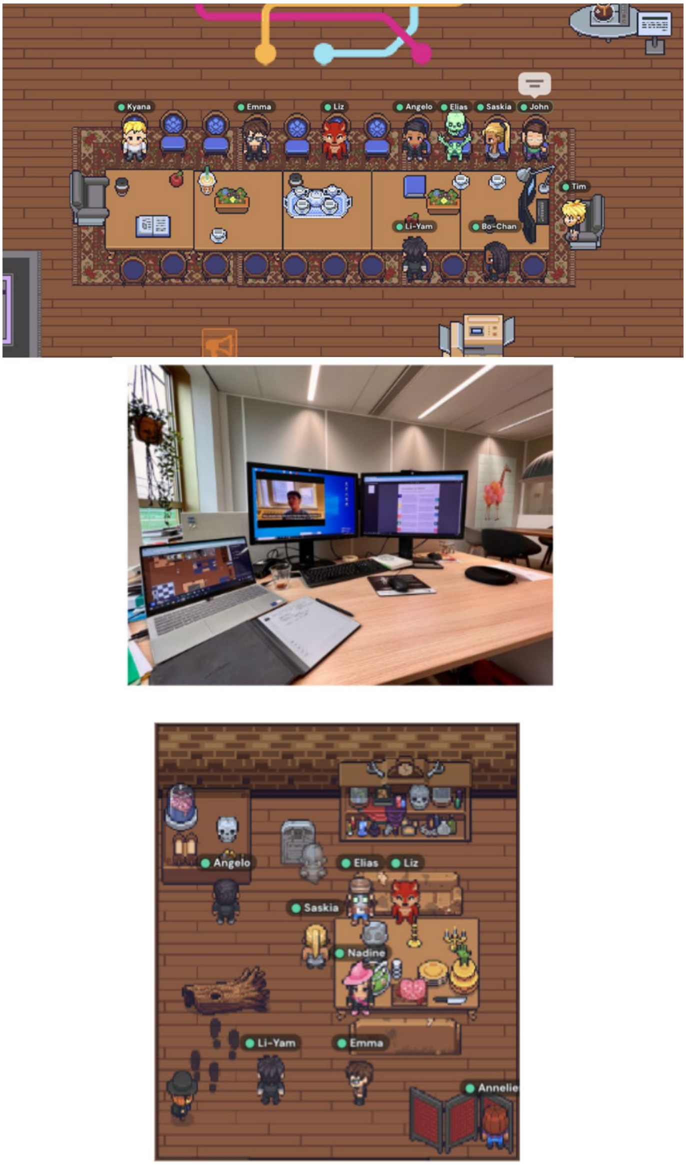

Fig. 7 Top image: daily start in Gather.town. Middle: A physical teacher set-up (at the Agora school) for Agora Underground. Bottom: the digital space for students and teachers, with different rooms and students and mentors as avatars

every learner has a suitable physical space for study. This blended approach integrates digital and physical interactions, creating an inclusive environment that is especially beneficial for students disengaged from conventional education. Central to this model is the use of *technology* in both realms to foster motivation, competence development, and interpersonal relationships. The program has a personalized learning framework, daily virtual check-ins to establish a consistent routine, and a low mentor-to-student ratio for individualized attention. This structure acknowledges the limitations of traditional educational systems and avoids over-standardization to maintain student engagement and cater to diverse learning needs.

3.4 Indian Case: Personal Adaptive Learning

The fourth case study explores a problem in public education in India (see Fig. 8): many children underperform relative to their grade level, leading to a situation termed the "learning crisis" (Pritchett, 2013). For example, grade 4 students often struggle with concepts like measurement and geometry. Public school teachers lack the resources to handle these vast differences in student ability. Their focus is often on completing the current curriculum, leaving unaddressed skill and concept gaps that widen as students' progress through the grades.

In Indian public schools, where class sizes range from 50 to 60 students, implementing differentiated learning is a significant challenge for teachers. Personalized Adaptive Learning (PAL) *technology* addresses this by identifying individual students' concept gaps in large classrooms. For the 1500 students in grades 8 and 9, the PAL system assesses their mathematics levels, tailoring content delivery accordingly. This content is presented as puzzles that scaffold learning and adapt based on student responses, effectively aiding teachers in bridging learning gaps. The system also provides detailed data on student engagement and progress, enabling teachers to create tailored support. Utilizing this data, teachers form student clusters based on ability levels for mathematics lab classes, assigning homework that reinforces concepts and supports learning based on lab performance.

The *learning design* for this initiative dictates teacher and student actions, encompassing interactions in both *physical and digital spaces*. In this context, mathematics lab classes and home environments became key areas for students to engage with PAL technology and enhance their mathematics skills (see Fig. 9). Importantly, while students were physically located in the school or at home, they were working exclusively in a digital space. To facilitate this, schools introduced a dedicated mathematics laboratory class into the timetable, equipped with individual devices and a stable internet connection to support the digital space. This *organisation* of a specialized space within the school premises allowed

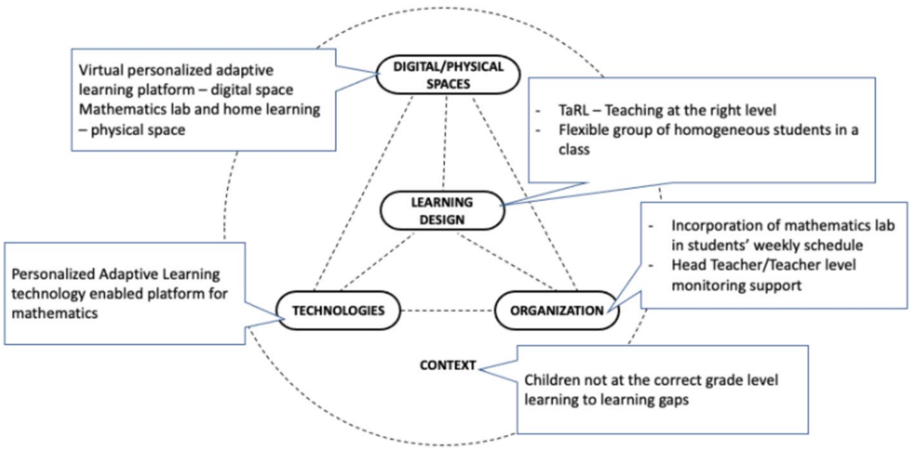

Fig. 8 DTALE model–Indian case

Fig. 9 Students using PAL technology

students to focus on improving their mathematics proficiency, effectively leveraging PAL technology's capabilities.

4 Discussion

The goal of this conceptual paper was to develop and validate a new generic model for designing and evaluating learning environments. The DTALE model was developed based on the literature and expert meetings. In the next step, the model has been validated by applying it to existing cases from four different contexts. By doing so, we explored associations between the learning design, the integration of physical and digital spaces, the application of digital technologies, the organisational structure, and the specific educational context. The following sections outline the most important findings from this validation process and the implications for educational practice and research. It also includes limitations and suggestions for future research.

4.1 A Holistic Approach for Integrating Online and Physical Learning Environments

Based on the literature and the expert meetings, we adapted the Radcliffe et al. (2008) Pedagogy–Space–Technology (PTS) framework by developing a new model by placing learning design in the centre of the model, associated with four components: physical and online spaces, technology, organisation, and the context. Further, the model highlights both physical and digital spaces (e.g. Gourlay, 2021). This provides a useful framework to support understanding and analysis of integrated physical and digital learning environments, which is illustrated in the previous cases. The cases illustrate how the different components in the inner circle influence each other, and they are, in turn, all influenced by the context. This aligns with other studies where pedagogy, space, and technology influence each other (see, e.g., Kali, Sagy, Benichou, Atias, & Levin-Peled, 2019). In that sense, learning environments should be seen as 'designable, constructable and developing' spaces (Herman & Tondeur, 2021) or action spaces (Tondeur et al., 2017). This requires an understanding of the associations among the components in a system (cf. Yurkofsky et al., 2020). Therefore, the focus of this concept paper is on the associations between the different components in different cases, visualised in the DTALE framework (see Figs. 2, 4, 6 and 8).

Radcliffe et al.'s (2008) PST-model addressed Pedagogy first, then Space, and finally Technology. As stated above, the DTALE model places learning design at the center, but also identifies two additional components to consider when designing learning environments: organisation and context. Context was an important component in all four of the cases. According to Blackmore et al. (2011), there is often insufficient recognition of the significance of the context when designing learning environments. Also, Kariippanon et al. (2021) argue that pedagogy-mediated changes to the learning environment shape, and are shaped, by a complex interplay between elements and agents within the educational ecology. This is clearly illustrated by the Portuguese case, which starts with a specific context, focusing on student-athletes to successfully reconcile school activity with the practice of high-performance sports. Consequently, the learning design is focused on differentiated learning, leading to an online space with synchronous and asynchronous learning to supplement and/or replace physical classes. Interestingly, organisation also plays a crucial role in this case, where for instance, a pedagogical team supports each student-athlete online when they are abroad, to a unique schedule, rather than having fixed times and places for instruction. Such findings are particularly important when considering how to develop further and support the future integration of online and physical spaces (cf. ; Ellis & Goodyear, 2016).

One of the main goals of the DTALE framework is to analyze the decision-making process in designing learning environments to understand the integration of physical and digital spaces. Clearly, the immense advancements in technology resulted in rethinking the design of learning environments (Collins & Halverson, 2018). As stated before, several studies prioritise the physical space which can be extended or enhanced with digital tools, rather than recognising the digital space as an equally complex entity with socio-material interactions (Gourlay, 2021), such as in the cases presented above. The Dutch case, for instance, most interaction occurs in the student's digital rooms. This is in combination with the students' physical home space, mainly home visits by mentors to connect with the student and know more about their context. It is important to note that, in this case, the learning design is tailored to the needs, context, and space of each student. According to the literature, students are often placed in a one-size-fits-all learning environment (Kokko & Hirsto, 2021), with the curriculum level, content, and pace determined by the expectation of the average. The Dutch example demonstrates an alternative to this, drawing on an integrated space, to support students struggling with the traditional organization of schooling (Fig. 9).

Clearly, learning design is key to creating effective learning environments. Therefore, it is important to understand the specific needs of the learners and to make appropriate adjustments (McGrath & Fischetti, 2023). Using the DTALE model, it is possible to see how the availability of digital technologies, and the creation of digital spaces and places, supports the specific needs of learners by, for instance, expanding access to education (Portuguese case) or transforming the learning environment (the Dutch case), for personalized adaptive learning (Indian case) or self-directed learning (Swiss case). The key challenge is to make educational institutions more hospitable environments in learning design—to build design capacity among all staff, to help students become more competent participants in processes of designing for learning (Goodyear, 2014a, b). In this respect, the rationale for integrated learning environments lies in their 'use' as driven by the learning design. This brings us to the implications.

4.2 Implications for Educational Practice and Future Research

The DTALE model can be relevant to foster research-informed practice in designing integrated learning environments in K-12 education. Basically, design is problem-solving. In this case, the problem is to create synergy between learning objectives, physical and online spaces, application of technology, organizational aspects, and the educational context. In other words, the DTALE model provides a method to identify, analyze and create synergy between the components. According to previous research (e.g., Gourley, 2021), this is significant in designing learning environments, that is, the integration and conceptualisation of learning designs, physical and digital spaces, technologies, organisation, and context concurrently. An implicit prerequisite in the model is some conception of a learning design or pedagogy, and more specifically the teaching and learning goals. With this premise in mind, the model calls for first considering the learning design (cf. Radcliffe et al., 2008) but simultaneously considering the importance of the other components, as illustrated in the cases. Using the model can help teachers create an overview of and synergy between these components, unpacking the complex relationships and being able to isolate different components for consideration.

The DTALE model is also crucial for informing future research on integrated learning environments. The intention of using the model for research purposes is to create evidence regarding the bigger picture, i.e., the influence of the relationships among physical and digital spaces, digital technologies, organisational structures, and learning designs on teaching and learning processes. The scope of this concept paper permits us to exemplify and illuminate the importance of these components, through international cases. Still, we acknowledge that it has some limitations, and that further research must be carried out to explore the potential of the proposed model fully. In particular, the analyses presented here are post-hoc, the DTALE model did not guide the process of developing each case. Future research, where the DTALE model is used to develop other cases, to deepen the relationships between the components through purposeful design, would be important to understand. To do so, future research, such as case studies, may include the acquisition and analysis of empirical data on relationships among physical, digital, and organisational transitions and corresponding designs of learning experiences (cf. Kokko & Hirsto, 2021).

In this era of rapid change and the introduction of new technology tools, any model needs to be open to allow for the uptake of recent tools such as augmented reality, virtual reality, and all forms of artificial intelligence, in addition to new tools yet unimagined. This may lead to new knowledge of relationships between the DTALE components based on information about using specific teaching and learning methods in digitally integrated learning environments. Future research directions should also explore the model from the perspectives of different stakeholders, such as students, teachers, school leaders and architects. Finally, empirical studies could explore the veracity of the model for different aged students, different disciplines and contexts. This perspective was informed by researchers who have argued for a more holistic approach to research that encompasses the associations between pedagogical, organisational, and contextual characteristics of influence on the design of learning environments (cf. Hermans & Tondeur, 2021).

5 Conclusion

We have proposed a novel conceptual model to consider different components to consider related to integrating digital and physical spaces. The DTALE model provides a framework to guide the use of integrated physical and digital learning spaces. Questioning the intentionality of the learning environment that provokes actions related to the educational use of digital and physical spaces brings us to the purpose of this concept paper, which fuels critical reflection on how the learning environment is currently determined and what is desirable. Ultimately, improving the learning environment will also enhance the quality of the educational activities of the teachers and students. In this concept paper, we especially focused on the construction and validation of digital and physical spaces. The different cases used to validate the DTALE model clearly illustrate that digital technologies can be a driving force in transforming teaching and learning spaces and enabling new pedagogical practices. Although more research is needed to further validate the DTALE model, we hope that the model can be helpful for architects, school leaders and teachers to make informed decisions regarding integrated learning environments.

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