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DEVELOPMENT ARTICLE

Relational topologies in the learning activity spaces: operationalising a sociomaterial approach

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Abstract

Technology-mediated interactions and datafication are increasingly central in contemporary social dynamics and institutions, including teaching and learning processes. In order to fully understand the complex entanglements of human and non-human actants that emerge in postdigital education, it is essential to imagine new methodological approaches that are sensitive to the multidimensional nature of education—as a socially and materially-situated phenomenon that increasingly takes place across distributed contexts. The overall goal of this paper is to propose and operationalise a new methodological approach for the study of technology in education. It draws on the notion of relational topologies to improve our understanding of educational settings and, ultimately, how learning unfolds. The proposed approach relies on a multi-paradigm enquiry strategy, based on the idea of using "topologies of digital data practices" in combination with the three dimensions that articulate design-for-learning processes according to the Activity-Centred Analysis and Design (ACAD) framework: epistemic, social and set designs. While the article focuses on presenting the elements of the approach from a theoretical perspective, we illustrate its application through the data collected in a small case study that will serve as a testbed. The topologies of relations we present in this article show uses of technology—as described by participants in their own learning experience—that involve different spaces, devices, and personal situations. In doing so, we reveal how humans and non-humans are entangled in hybrid, unstable and generative ways. The article concludes with some remarks on the value of the proposed approach for studying technology in education and its potential to explore the state-of-the-actual in this field, with the ultimate goal of helping inform educational research, practice and decision-making.

Keywords Sociomaterial · Topologies of educational practices · Learning spaces · Learning activity analysis

Introduction

Traditional research methodologies have often proved insufficient for fully understanding the extremely complex dynamics and processes underpinning teaching and learning in technology-mediated situations, as reflected in some recent literature (Castañeda &

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Williamson, 2021; Kimmons & Johnstun, 2019). An excessive focus on rapidly changing technologies that are unthinkingly offered as solutions; the extreme simplicity in proposing paradigmatic perspectives that do not offer holistic views of phenomena; and a constant underestimation of the importance of contexts (personal, social, technological, human) in learning and teaching activity—have given us views that remain overly simplistic.

The absence of educational perspectives and pedagogical approaches beyond technology has been identified as a significant flaw of a traditionally under-theorised field (Biesta et al., 2019; Oliver, 2013; Zawacki-Richter et al., 2019). Therefore, an over-simplifying analysis of education, technology and their intersection has created a field of research and practice that is largely dominated by the views of EdTech companies and "gurus" who seem to have a very clear objective; unfortunately, not an educational one (An & Oliver, 2021; Anderson & Rivera-Vargas, 2020; Selwyn, 2017).

A critical area that urgently needs further attention is the development of inquiry strategies that support robust theory-building efforts, sensitive to the multidimensional nature of education as a social and situated phenomenon. The fuzzy boundaries between technologies and humans in Human–Computer Interaction (HCI) (Frauenberger, 2020) make such an evdeavour particularly challenging. Moreover, the ontological limits of emerging technologies encompass various domains, including natural language processing, social robotics, artificial intelligence, cyber-physical systems, as well as virtual or augmented reality.

To address these challenges, sociomaterial approaches have been proposed, calling for a deep and holistic analysis of data generated from different perspectives (Bieler & McKenzie, 2015; Fenwick & Edwards, 2017). Topological methodologies are one promising approach that allows researchers to explore the form or shape of data practices and how they evolve over time (Decuypere, 2021). However, previous research on technology in education has often overlooked the role of materiality in teaching and learning and failed to recognise the complexity of the more-than-human entanglements that underpin learning activity in practice.

Sociomaterial approaches can provide a more nuanced understanding of the interactions between people, technology, material scenarios, and resources in a learning environment, enabling alternative ways of imagining the curriculum, learning, and knowledge, and new ways to approach pedagogical interventions (Fenwick et al., 2011). The concept of topologies can help both researchers and practitioners to examine these complex entanglements and gain insights into how different actors relate to and mutually influence each other.

This study proposes, and explores the potential of, relational methodologies for understanding teaching and learning spaces, using "topologies of digital data practices" as described by Decuypere (2021). We demonstrate how this approach enables a more complex analysis of educational processes. Our framework includes three topologies for sociomaterial analysis: (1) Influence and activity in the learning space, (2) Multi-spatial learning context, and (3) Entanglements in multi-spatial contexts. We offer new perspectives on educational praxis and aim to develop alternative methodologies for observing and understanding technology-mediated educational processes.

The paper is organized into six sections. The first two sections provide an overview of the theoretical frameworks used in the study. The third section presents a general description of the case study used to put into practice the proposed approach, while the fourth section outlines the procedure for developing the three topologies. The fifth section focuses on the main features and principles of the methodology. The concluding section discusses the limitations of the paper and highlights the added value of the proposed topologies. It explores their potential contribution as components of a methodological approach for studying technology in education from a socio-material perspective, as well as their impact on pedagogical design and educational technology research.

Theoretical frameworks: entanglement theories for understanding educational practices

Sociomaterial theoretical approaches—such as actor-network theory (ANT) (Fenwick & Edwards, 2010), materialist feminism, (Barad, 2003) and posthumanism—view the boundary between human and non-human *actants* (Latour, 1999) as highly blurred. Researchers adopting such perspectives have emphasised the importance of technology and human action mutually shaping each other as part of complex sociomaterial entanglements (Fenwick et al., 2011; Gourlay, 2021; Stiegler, 1998). These theories share three common features: transcending socio-natural and cultural-material dualisms, stemming from established perspectives on human-material relationships, and emphasising that the world is not a passive object in knowledge production (Frauenberger, 2020).

To understand how technology mediates education holistically, it is crucial to capture the complexity of sociomaterial contexts (spaces, resources, social interactions, etc.) through relational approaches (Fenwick & Edwards, 2017).

The ACAD framework provides such a holistic and relational understanding of education and, more specifically, design for learning (Goodyear & Carvalho, 2014). ACAD defines three main aspects that must be analysed when intentionally designing situations for learning: (1) the set design, (2) the epistemic design, and (3) the social design. At the same time, ACAD recognises that learning activity is always emergent and cannot be predefined (see Fig. 1). The relational conditions inherent in these three aspects enable researchers to capture the complexity of crucial processes in a holistic manner

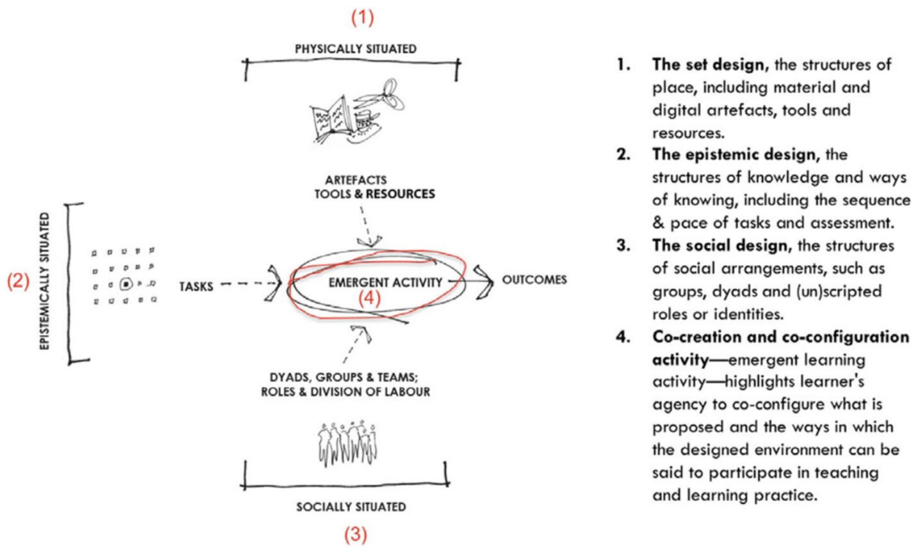


Fig. 1 The Activity Centred Analysis and Design (ACAD) Framework (Carvalho & Yeoman, 2018, p. 1126)

(Goodyear et al., 2021). Therefore, understanding how different elements, which situate learning among these three aspects, can help to better understand the learning situations.

The ACAD framework's relational principles can be operationalised through "topologies of data practices", a methodological framework proposed by Decuypere (2021). This methodological framework aims to enrich analyses of contemporary education processes, in which data practices are a central element. Data practices are "the actions, performances, and the resulting consequences of introducing data-producing technologies in everyday situations" (Decuypere, 2021, p. 67). Thus, the focus is on the actions and consequences of introducing data-producing technologies in everyday situations, rather than just on the technologies themselves. It uses topologies as the basic unit of analysis to study the qualitative qualities of relations between different actors.

Decuypere uses his methodological framework to present four topologies of data practices, as part of a non-one-size-fits-all and adaptable solution to the study data practices: Interface (on), Usage (with), Design (behind) and Ecology (beyond) (see Fig. 2). Each of those topologies addresses data practices from different perspectives and may involve the use of different research methods. In this paper, we draw upon Decuypere's methodological framework to investigate the potential of relational methodologies in understanding teaching and learning spaces.

Decuypere's sociomaterial principles, which underpin our approach, have three key elements: (1) emphasizing actual practices—the **doings**–; (2) a **flat** analysis that doesn't differentiate between 'real' and 'digital'—in this case drawing on the ACAD framework to identify the various actors involved in set design, epistemic design, and social design; and (3) the use of **topologies** as the basic unit of analysis.

Although a sub-branch of geometry, topology has been adapted for use in the social sciences. Unlike traditional geometry, which relies on fixed global coordinates and dynamics to measure and describe objects in space, topology approaches spaces as entities defined by the changing relationships between their points. This view of spaces is generative and useful for social research, especially when analysing educational practices (Decuypere & Simons, 2016, p. 4).

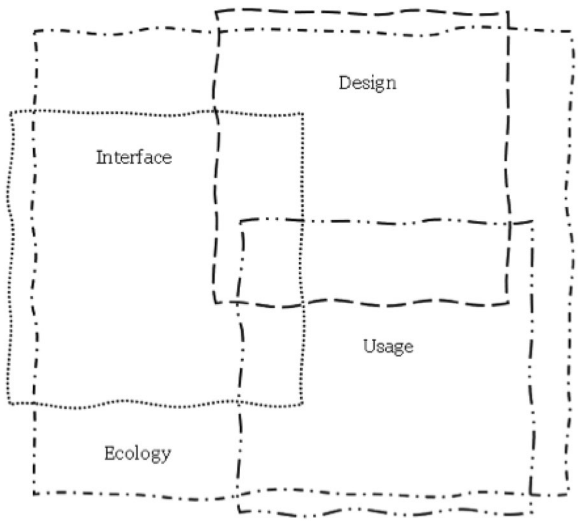


Fig. 2 Four topologies of data practices, together constituting the IUDE-toolbox (Decuypere, 2021, p. 74)

Topologies are useful in educational research as a way of analysing complex systems with non-linear relationships and multiple dimensions. They have been used to examine social networks between students, teachers and others, with measures such as centrality, clustering coefficients and modularity (Yassine et al., 2022). Topologies have also been used to study the flow of information and ideas, as well as to identify key actors in networks (Pierri et al., 2020; Zengin Alp & Gündüz Öğüdücü, 2018). In sociomaterial analyses, topologies have been used to gain insights into educational data practices by examining changes in relationships between different entities (Decuypere, 2021; Decuypere & Simons, 2016; Fenwick & Edwards, 2010, 2017).

Therefore, by adopting topologies as "a methodological lens that shapes how concrete methods can be employed" (Decuypere, p. 71), the approach we propose in this paper offers a pragmatic way of empirically studying digital data practices in education. Topologies are used as the methodological framework that allows us to understand data practices, explore how data practices are constructed and how different data practices relate to each other, and help us operationalise the proposed sociomaterial approach.

The empirical study we present aims to illustrate our proposed methodological approach. It primarily focuses on comprehending a learning design employed within a formal education setting. To achieve this, we examine the structure of an undergraduate course and analyse key elements through the lens of the ACAD framework. Special emphasis is placed on the 'set design' component, which will be thoroughly explained in the next section. By employing this approach, we seek to gain a deeper understanding of the learning experience and the intricate design choices made within the course.

The analysis of learning spaces as part of sociomaterial educational entanglements

In the ACAD literature, learning has been primarily studied in relation to the 'epistemic design' and the 'social design' (Bieler & McKenzie, 2015; Buchem et al., 2011; Elbanna, 2016; Fenwick et al., 2011; Laat et al., 2007 among others). However, less attention has been given to the 'set design', which looks at teaching and learning material conditions (e.g., Yeoman & Wilson, 2019).

Learning spaces have become more important in the light of increasing use of digital resources, new pedagogies, and a shift away from traditional physical classrooms. The concept of learning space has been addressed from a sociomaterial approach as "contingent on a complex and shifting assemblage of human and non-human actors, which extends beyond the immediate concerns of pedagogy to include, among other things, university strategy, government policy, commercialisation and [...] technology" (Lamb et al., 2022, p. 3).

Learning spaces are fundamentally relational environments where learning activities emerge. While teachers—as designers for learning—may preconfigure these spaces, they are ultimately " (re/co)constructed by learners when enacted" (Damşa et al., 2019, p. 2079). The nature of these spaces is contingent upon contextualized infrastructure, encompassing material, digital, social, and pedagogical elements. Such infrastructure facilitates the development of frameworks and ecologies of resources that offer scaffolding within learning spaces and "shape modern experiences of learning" (Ellis & Goodyear, 2018, p. 4).

The Covid-19 pandemic prevented access to the physical campus, revealed the importance of digital platforms and pedagogies as shapers of educational spaces and practices, and highlighted the importance of digital platforms and pedagogies in shaping educational spaces and practices (Wardak et al., 2022). Likewise, it blurred the line between the digital and the analogue (Gourlay, 2021).

The 'set design' has been mainly studied by looking at tools and spaces used in the academic environment (digital and physical tools and spaces), focusing on the elements that educatorsintegrate within the learning design, as well as those aspects controlled by them and their institutions (Gourlay, 2021; Lamb et al., 2022). However, we know little about how students appropriate those tools, and others, into their actual day-to-day learning processes. This includes personal learning spaces and environments, outside of educational institutions, that equally shape students' learning and behaviours in contemporary societies (Oblinger, 2017). The connections between spaces, people, devices, and tools in education remain a mystery to a considerable extent, as the learning process itself does too.

Our methodological approach focuses on "The Space" rather than the set design. This category includes all material and digital elements related to the educational experience of each participant. To understand how these elements influence learning—as situated and emergent—we must analyse their relationships with each other. Actants include physical spaces (e.g., a classroom, the library, a bedroom, a bus), digital platforms and tools (e.g., YouTube, Instagram, Google, edtech platforms), devices (e.g., smartphone, tablet, laptop), interfaces (the connection between the device and the digital tool), the educator, the students, and the institution.

We hypothesise that exploring sociomaterial entanglements (Frauenberger, 2020) in our learning-teaching practices through topologies of digital data practices, as shown in learners' self-reported performance (what students say they do, see Castañeda & Marín, 2023), can positively influence the learning activity. It means enhancing teaching design, acknowledging the relevance of off-campus spaces for learning, and informing institutional planning of digital infrastructures.

This analysis can also enrich students' perspectives on human-material relationships and their reflections on personal technological and learning experiences. Overall, our approach aims to shed light upon the socio-technical contexts of key stakeholders within the academic community, ultimately helping to improve the learning experience.

We propose a methodological approach that uses topologies to better understand the learning activity within educational settings. Additionally, we provide a case study to illustrate this approach in practice. Our discussion builds on the IUDE-toolbox topologies (Decuypere, 2021) while offering more nuanced perspectives. In particular, we analyse the case study data using the Topologies of Digital Data Practices framework to understand the learning activity from various perspectives comprehensively.

In the following section, we detail the procedure and methods we have used as part of a case study that helps us illustrate the methodology in tangible terms for each of the three topologies we propose. Moreover, in the presentation of each topology, we detail how the data was collected and analysed to arrive at the topology.

The RICT case

As previously stated, drawing on a case study in Higher Education, we propose a practical exploration, beyond theory, of how topologies may be applied. This practical application helps us understand the different elements that contribute to the complexity of our research topic, which is understanding teaching and learning experiences through a specific methodological approach. By doing so, researchers can better capture these elements (Mills et al., 2009).

We aim to clarify the epistemological foundations, research questions, contexts, expected results, and contribution of our proposed methodological approach in educational technology by providing an example of its application. However, we do not intend to give a detailed account of the case study that provided the data. The case study helps us illustrate the use of topologies in a sociomaterial approach to technology in education. We provide some contextual information about the experience, but for full details of the pedagogical approach, please see Castañeda & Marin (2023). The data we used in this study were collected in the academic year 2021–2022.

The case study looks at an on-campus pre-service teacher-training course at a Spanish university titled "*Educational Resources and ICT for Primary School*" (RICT from here on). This course is delivered, in English, to students in the first year of their degree, during the spring semester, with 6 credits (as defined by the European Credit Transfer System) and a student workload estimation of 150 h. The course is run by one professor (female with over 15 years of teaching experience in Higher Education, the first author of this paper) over 12 weeks (5 h per week) with no teaching assistants involved.

The course is designed around three large functioning structures that shape the course environment, not only from the social but also from the epistemic viewpoint:

- A formal cooperative learning model (Johnson et al., 2014) works under a strategy of cooperative base groups.
- Task-based learning consists of weekly trialogical learning tasks (Paavola & Hakkarainen, 2014). A theoretical issue defines each task, and students must develop an artefact with a concrete format and under a pre-designed development strategy.
- Pre-established work roles or scripted roles (Dillenbourg, 2002) emphasise the tasks and processes designed for the course and make the target competencies explicit, defined as intended learning outcomes (Strijbos & Weinberger, 2010).

The cohort included 50 students, 35 women (70%) and 15 men (30%), who were organised into eight stable working groups. The study started at week 6 when students had already completed 5 tasks (out of the ten organised in the course). The discussions and data collection took place over 2 weeks, involving different techniques. In this case, no identification or personal data were collected, the anonymised character of data protected participants, and the digital treatment adhered to the ethical requirements of the institution.

Three topologies for exploring and understanding the educational space setting

In this section, we are going to present the three topologies, using the case study to illustrate them in action: (1) 'Topologies of influence and activity in the learning space', (2) 'topologies for the multi-spatial learning context', and (3) 'entanglements in multi-spatial contexts' have been developed in the same process, to iteratively improve our understanding of the spaces where learning activities happen. Therefore, the first topology is the seed of the second one, and so on.

To clarify our process, we will now present the three topologies we developed sequentially. For each topology, we began by identifying the starting question and explaining the reasoning behind the approach, as well as its connection to previously studied topologies. The developing rationale was then combined with the procedures and methods used to map the topologies, complemented with reflections on the insights that each topology offers. Additionally, the presentation of each topology includes details on how the data was collected and analysed.

Topologies of influence and activity in the learning space

Starting question: who introduces the use of tools and resources in the learning activity?

To better understand the space in which the educational experience is situated, we created a topology that falls between the user and interface categories, as classified by Decuypere (2021). This topology also serves as a transitional point from the ACAD framework perspective. It clarifies the relationships between epistemic design (i.e., the task planned by the educator) and set design (i.e., the tools selected by the educator too).

How do these topologies work?

Firstly, we are going to examine the spaces and tools that participants use in their learning experience in the context of the case study. We are going to differentiate between those which were introduced by the teacher (who "requires" students to use them) and those which were brought into the learning process by the students; both those discovered during the course and those based on their pre-existing practices and personal experience. Moreover, we discuss how they use each of them, establishing a clear distinction between the *learning design* (i.e., what students were expected to do) and the *learning activity* (i.e., what actually happened in their engagement with tasks).

The topology procedure

In the case of RICT, we asked students to discuss in groups the main tools they use for their coursework in three different categories: (1) those that are compulsory for the course (required by the professor), (2) those that they discovered while completing the tasks, and (3) those they were already using before the course and decided to integrate in their course's day to day.

Also, using a brainstorming dynamic and a face-to-face discussion facilitated by the teacher, students reflected on their usage of tools for that course (e.g., to read/review content from others, communicate, write long texts, send/create audios, send/create videos, send/create audio pictures, send/create links).

After this, and using an online form, we asked each student individually about how frequently they used those tools (differentiating the three categories) and for what purposes.

Establishing relationships between these two elements, we can build diagrams that show us how students use tools for texting, for example. Figure 3 shows the tools that have been used during the course, including who influence the use of them and how frequently they have been used for writing long texts:

From Fig. 3, we can highlight the importance of those tools selected by RICT students themselves (the personal tools) for collaborative writing tasks: almost half of the

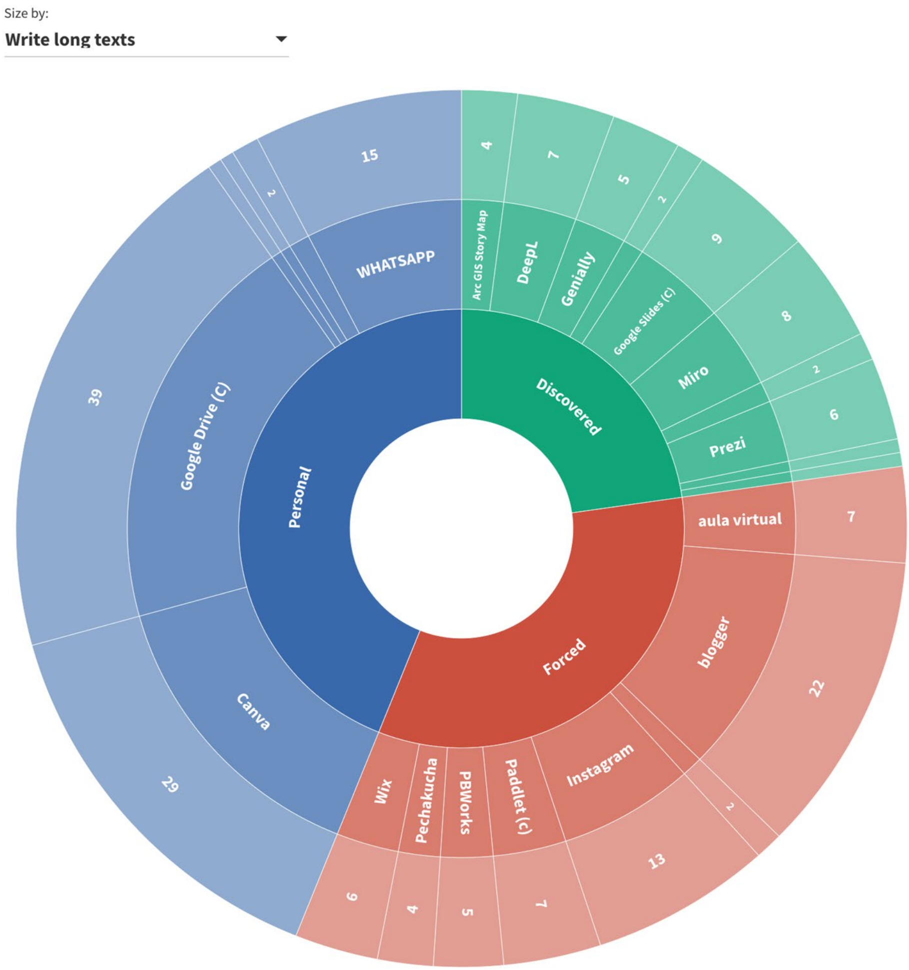


Fig. 3 Tools used for writing long texts by RICT tool students in the course's development. Created with the online tool Flourish (https://flourish.studio/)

writing is done with their own preferred tools. Also, it is interesting to see that they choose tools primarily designed for the creation of visual content (e.g., Canva or Instagram) even to write long texts.

Nevertheless, although this graphic shows some relationships among users and tools, the information offered could be more holistic. Ideally, topologies should cut across all learning activities and consider the practices of students beyond the boundaries of specific modules or courses. Only that way they can fully inform the work of learning designers and educators. Therefore, we have classified different types of uses reported by participants and associated them with different educational uses. For example, building on the PICRAT model, as proposed by Kimmons et al. (2020), we identify passive, interactive and creative uses of particular tools and how they entered the learning activity. Using sunburst charts created for each user, we represented a topology with different visualisations of the relationship between 'tool introducer'/'tool use', regarding the educational purpose as you can see in Fig. 4:

Looking at Fig. 4, we see that the tools discovered by students themselves during the course's tasks are always a minority for every use. The tools that are used as prescribed by the teacher are the most dominant for reading and interacting. Nevertheless, the more creative the use is, the more dominant the personal tools are, that is, those that students bring from previous experiences and established personal practices.

This RICT example also highlightsthat it is essential to be more precise on the uses of tools as appropriated by students in practice. Merging two different types of use in the same category (e.g., "send and create") makes the analysi rather imprecise. Therefore, it would be important to find ways of differentiating both uses orreducing the number of choices.

Topologies for the multi-spatial learning context

Starting question: where is the learning happening? A multispatial context

As it has been previously stated, what Goodyear and Carvalho called "the set design" is the element of the ACAD framework that deals with the educational setting (Goodyear & Carvalho, 2014). This scenario includes spaces, tools and resources, and the most contemporary approaches include the physical and virtual variations of it (Gourlay, 2021). In addition, some of those learning design frameworks included the wider context (Bower & Vlachopoulos, 2018).

Nevertheless, after the several lockdowns experienced worldwide during the Covid-19 pandemic, emergency remote teaching approaches and experiences revealed that the only spaces effectively considered in the learning design were those controlled by the teachers/institution as dedicated "originally" to the learning activity (Czerniewicz, 2020).

Despite this, the other spaces where the learning—and teaching—activity happened during Covid restrictions (particularly the home) were revealed as crucial to understanding how learning activities unfold in reality (Area-Moreira et al., 2021; Bozkurt et al.,

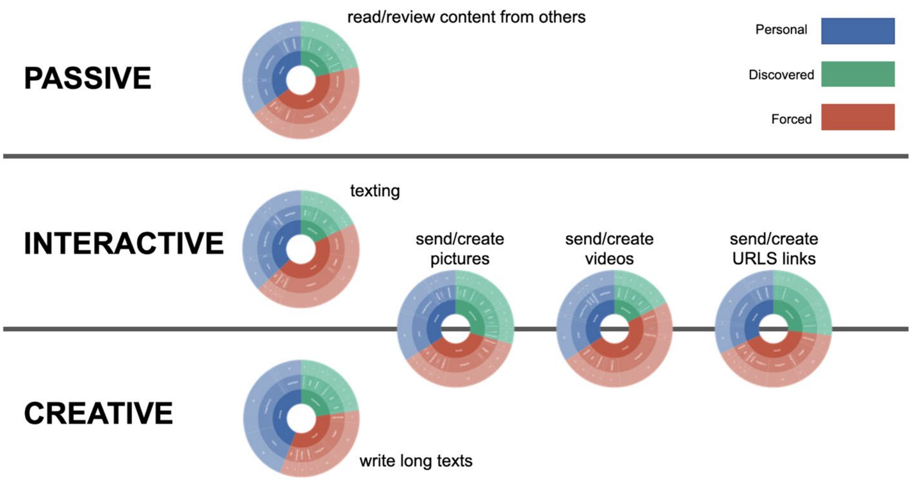


Fig. 4 Topology of RICT influences and activity in the learning space

2020; Jandrić et al., 2020). It is now clear that the learning "scenario" —the set—cannot be confined to the institutional limits, as it naturally surpasses them. Moreover, physical and digital environments coexist and mutually influence each other. Therefore, the analysis and design of the teaching and learning tasks and activities must be done including all those spaces simultaneously and dynamically.

How does this topology work?

We start from the premise that any place where the learning activity is performed can be regarded as an educational space. Following some of the ideas proposed by Wardak et al. (2022), the proposal includes institutional spaces specially dedicated to this experience, but also personal spaces outside the institution or not intentionally designed to host educational experiences.

Topology procedure

Considering this, we argue that almost every space used for education should be included in a matrix—as the one included in Fig. 5—that relates these two dimensions: (1) *space ownership*, that depends on whether the spaces are controlled by the institution or by individuals, and (2) *space intended purpose*, that shows if the space was initially conceived to host learning activities or is otherwise another kind of space "appropriated" for learning despite not being its original use:

Once this matrix is defined, the spaces identified by participants in the educational process as used for the development of the "course activity" should be classified using the different quadrants.

In Fig. 6 we show the spaces identified by students as the main ones for their activity. In one of the class sessions, they were asked to nominate the spaces they used most often while completing the course's tasks. The answers collected on the blackboard via a brainstorming activity were compared among all participants, who then voted to identify the most commonly used spaces. That way, we identified a set of spaces that were most significant for their activity in the course. Later, the researchers manually classified those spaces in the learning context matrix.

This classification of spaces could be used as the basis for exploring the learning context as a multi-spatial scenario, and understanding many questions related to this, such as

Fig. 5 The Multispatial learning context matrix (space ownership and space intended purpose)

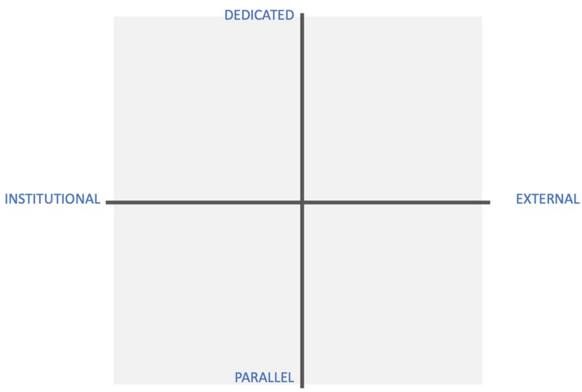
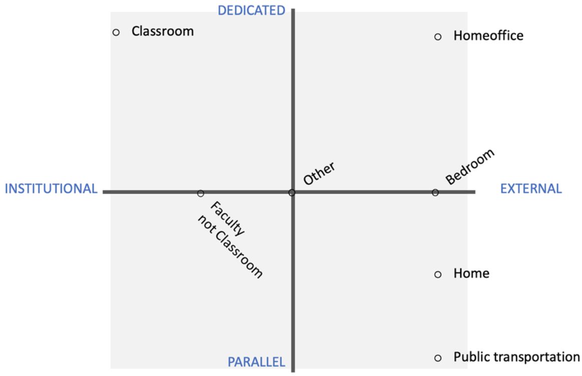


Fig. 6 Multispatial RICT learning Context Matrix. Crucial Spaces for RICT classified in the learning context matrix



how the different spaces interact with each other, how people redefine and re-appropriate spaces for their learning purposes (ownership), or how other elements interact with them or inside them (Raes, 2022). These analyses could be a mixture of *interface* topologies and *ecological* topologies, using Decuypere's classification (2021), and could help to make the vision of the teaching and learning spaces wider.

For example, using the classification of learning spaces already developed for RICT (Fig. 6), we have explored the tools students use for course's tasks and where they are physically present when using the tools (from the bus, from the bedroom, etc.).

Firstly, we asked students to answer how often they use the different tools they reported, from each of the most prominent spaces. We asked them to use an online questionnaire with a 4-level frequency scale (from often to never) that asked for each tool and space (see Fig. 7):

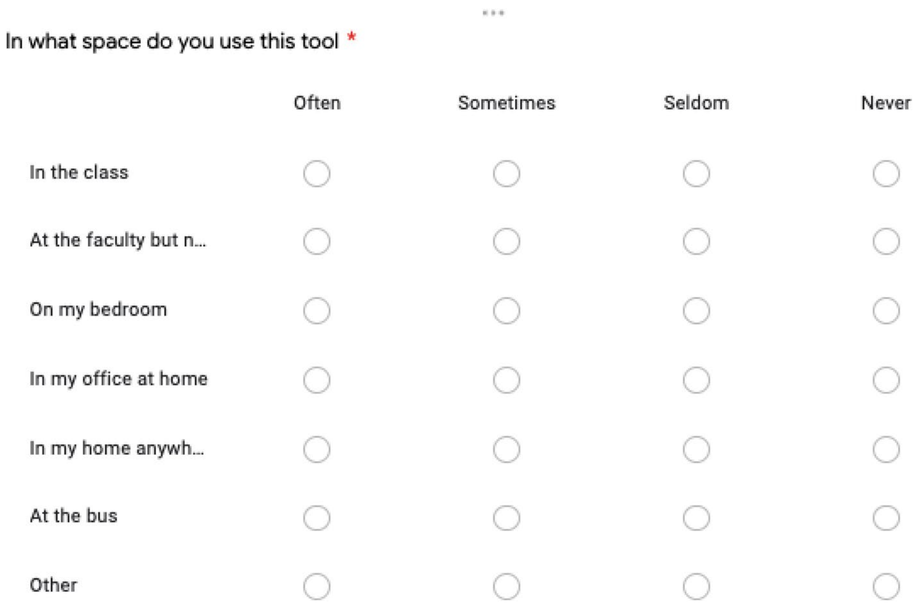


Fig. 7 Question in Google Forms

After this, answers were classified by space and represented using bubble charts that relate the frequency of use with the different tools on each space (bubbles are bigger with bigger frequencies).

The same colour coding was applied to the bubbles associated with each tool and the representation of each space, and after creating all the spaces' visualisations, they were located in the matrix in the analogue place to the space classification, as shown in Fig. 8.

Figure 9 shows the tools that are used the most in each space of the learning scenario. In the case of the RICT data, the figure shows the prevalence of the use of tools for creation (Canva, MIRO, Google Drive) in dedicated spaces, both institutional (the classroom) and personal (the home study room). At the same time, Fig. 9 shows that spaces appropriated for learning tend to attract more use of social networking sites (Instagram) and texting tools (WhatsApp), especially in public transportation (parallel and external space).

Entanglements in multi-spatial contexts

Users, physical and digital spaces, devices and interfaces are all part of the same entanglements. Users choose different devices depending on the characteristics of particular spaces (it is difficult to use a laptop on the bus, for example). The device they use for working influences the interfaces they encounter, which may take the form of dedicated software (e.g., apps or desktop clients) or responsive designs developed to be accessed by a web browser.

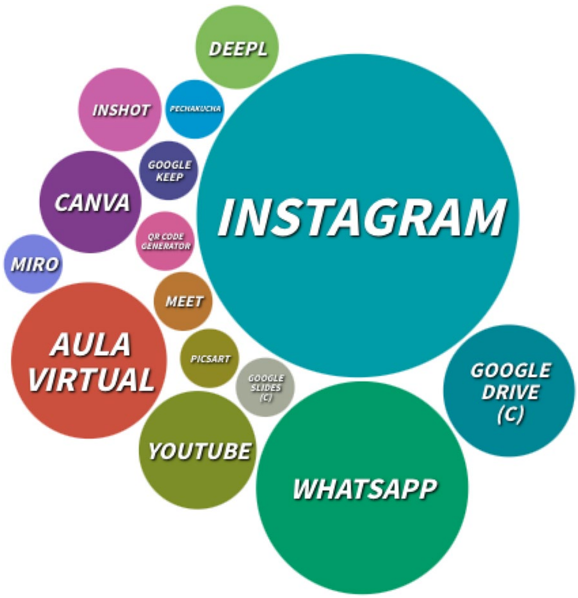


Fig. 8 RICT use of tools in public transportation. Created with the online tool Flourish

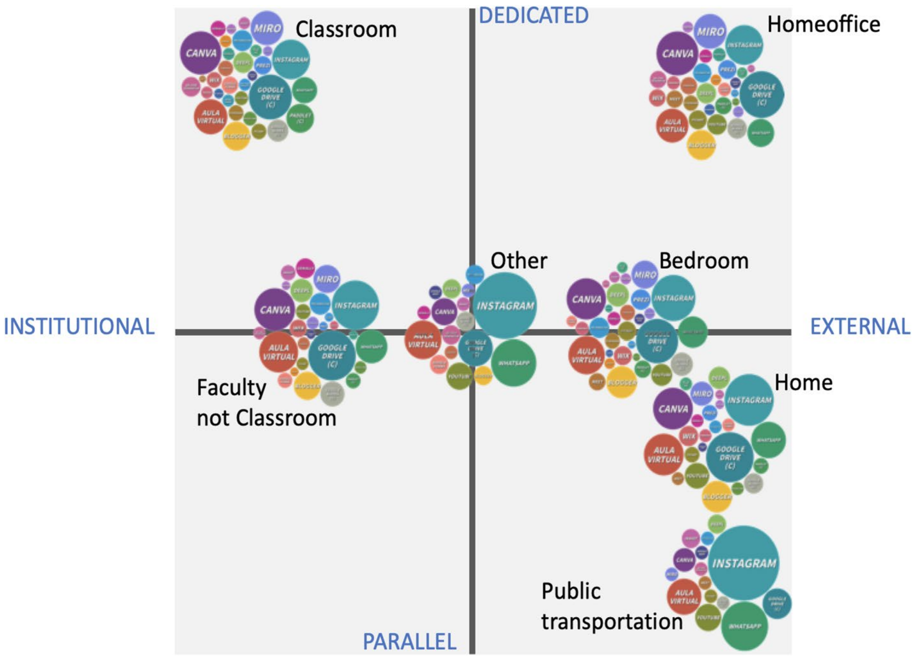
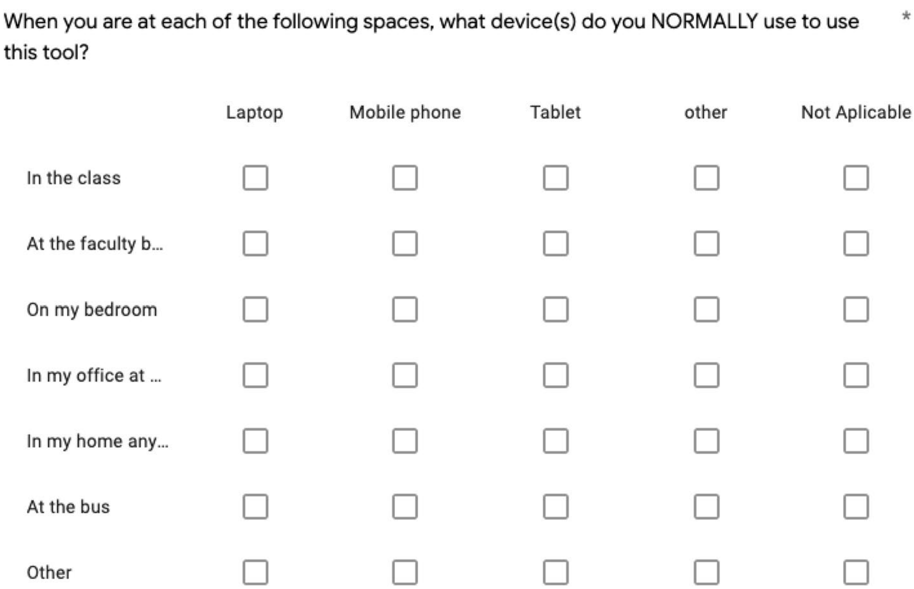


Fig. 9 Topography of tools' uses in the multi-spatial RICT learning context


When you are at each of the following spaces, what device(s) do you NORMALLY use to use this tool? *

	Laptop	Mobile phone	Tablet	other	Not Aplicable
In the class	☐	☐	☐	☐	☐
At the faculty b...	☐	☐	☐	☐	☐
On my bedroom	☐	☐	☐	☐	☐
In my office at ...	☐	☐	☐	☐	☐
In my home any...	☐	☐	☐	☐	☐
At the bus	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

Fig. 10 Item to ask about spaces and devices for each tool

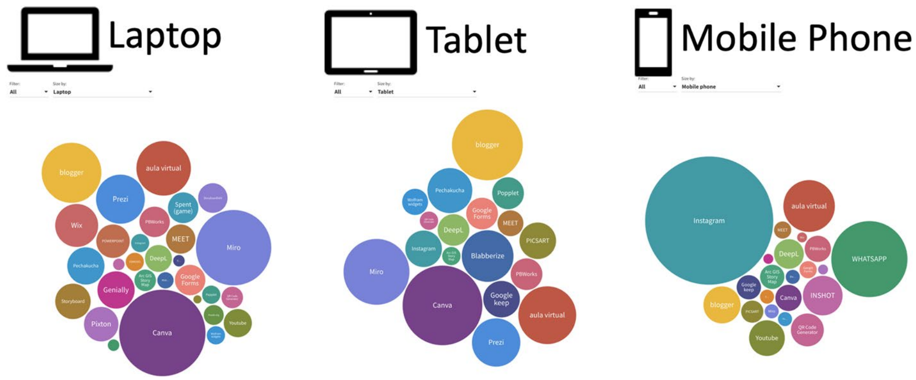


Fig. 11 RICT use of tools and devices

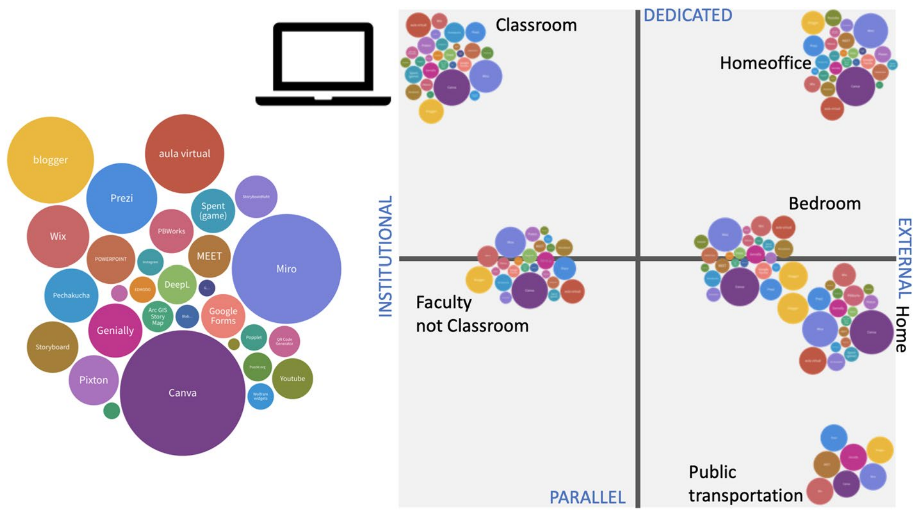


Fig. 12 RICT use of laptops in their multi-spatial learning context

Students were asked to report the device they regularly use to access each tool from each of the spaces. They did so via an online questionnaire, with a grid that relates spaces with devices (see Fig. 10).

With the resulting data (and using the same colour coding as in Figs. 8, 9), we created bubble diagrams to provide an overview of the tools that students use from each type of device (Fig. 11).

Figure 11 shows how the RICT students privilege the use of Instagram and WhatsApp on their mobile phones. CANVA, MIRO and Blogger are preferably used from their laptops and tablets, but the use of the LMS among the three devices is very similar compared to the other tools.

Despite this and considering the multi-spatial intended purpose we have expressed before; we can differentiate how devices influence the use of the apps in different spaces. To do so, we created a bubble diagram for each device in each space, colour-coding the tools. Afterwards, we analyse the general use of the tools in one device by placing every graphic in the RICT multi-spatial learning context matrix (Fig. 5), as it is shown in Fig. 12.

Figure 12 reveals that RICT students used their laptops to create content (with CANVAS, Blogger, and MIRO) in the spaces specifically dedicated to learning (the classroom and their study spaces at home). The bubbles show few differences among spaces regarding the use of laptops, except in the case of public transportation, where the intensity and variety of uses are overall much more limited.

Methodological approach overview

In this article, we introduce the concept of topologies of relation (Decuypere, 2021) as a framework to explore the multifaceted use of technology in educational contexts. We go beyond considering technology solely for its technical functions and instead take into account various factors, including spatial considerations, device usage, and personal circumstances (Gourlay, 2021). Recognizing the intricate connections between humans and non-humans, we acknowledge the complex and dynamic interplay between them (Lupton, 2018). In the following section, we will delve into the key features of our proposed methodological approach, providing a comprehensive overview.

Topology as a methodological lens

In this paper, we consider topologies in the same sense as Decruypere (2021), Decuypere and Simons (2016), i.e., as a methodological lens that shapes how concrete methods understood by the author as concrete instruments or tools, can be employed (Decuypere, 2021). Integrating topologies into research can help us capture the complex multiplicity of education in a post-digital world (Bayne et al., 2014). In this context, "post-digital" refers to a condition where the term "digital" is no longer necessary as computing and data have merged with all facets of reality (Feenberg, 2019; Pepperell & Punt, 2013). Additionally, Saari (2021) asserts that topological reflections can be descriptive and prescriptive at once, and this double perspective could be used in many different ways.

Two paradigms

The proposed methodological approach must be positioned within the epistemological paradigm underlying the research. To do this, it is essential to consider (1) how we understand educational research as a social science and (2) the educational activity we want to explore. Our proposed approach fits into the interpretive (holistic) and socio-critical paradigms (Cohen et al., 2017).

Thus, as the methodological approach we propose in this paper is primarily concerned with understanding practice in context, it refers to the interpretive paradigm and focuses on understanding specific cases and examples by describing and seeking to understand phenomena in context. At the same time, the approach we propose could also transform educational settings and practices; therefore, it points to the socio-critical paradigm that aims to use research as a tool for social transformation (Farrow et al., 2020).

In conclusion, we started from a position of paradigmatic pluralism as the most suitable option in our research since it does not follow exclusively one single paradigm as superior and, at the same time, it does not trivialise the distinctions between paradigms (Kimmons & Johnstun, 2019).

Sociomaterialism as a theoretical approach

As stated in the theoretical framework section, the proposed methodology is based on a sociomaterial vision that sees educational activity as a relational process. We view the sociomaterial as a set of basic assumptions, just like empiricism or pragmatism, that underpin this methodology.

Sociomaterialism is also a way of approaching social phenomena that is key to the chosen paradigm. It is part of the ontological assumptions for the two paradigms used in our research alongside idealism (indirect access, reality subjectively experienced).

However, the paper's goal is not to explain the role of a sociomaterial lens but to use the above principles as a foundation for understanding the approach's main features and possible applications.

Mixed methods

Following the assumption of incommensurability, that the two paradigms are not wholly compatible, the proposed methodology should combine both qualitative and quantitative methods (Creswell & Creswell, 2018; Kimmons, 2022; Teddlie & Yu, 2007).

It means that this research approach utilises both qualitative—which rely on subjective interpretations of rich textual or experiential data—and quantitative—which rely upon objective analyses of measurable data via descriptive or statistical methods—methods, including data collection instruments and techniques, data themselves, and data analysis procedures. This combination allows a richer analysis (Creswell & Creswell, 2018).

Research questions for this approach

After considering the paradigms, theoretical approach, and possible methods underpinning the proposed methodology, it is key to reflect upon suitable research questions that can be addressed.

To put the proposed methodology into action, research questions must align to the goal of understanding pedagogy in practice and teaching practice impact (i.e., through concrete learning activities). The methodology aims to grasp post-digital experiences across multiple layers of sociomateriality, identifying connections from an interpretive perspective that may suggest educational transformations.

Conclusions: uses and contribution of these spatial topologies

This paper presents a methodological approach, for the sociomaterial analysis of teaching and learning spaces, based on three different topologies: (1) Topologies of influence and activity in the learning space, focused on the use of tools; (2) Topologies for the multi-spatial learning context, that reshape learning multi-spaces based on analysing ownership and the original intended purpose of these spaces; and (3) Entanglements in multi-spatial contexts, that explore the multi-spatial spaces defined in the previous one and follows the relationships among them and with interfaces and devices.

We argue that the proposed sociomaterial methodological approaches can significantly contribute to research in educational technology. Topologies are particularly valuable because they can facilitate a thorough examination of various layers within the learning experience and the relationships between human and non-human actants.

In contrast, usual approaches offer more superficial or partial views of the same phenomena, such as attitudes or satisfaction. Topologies also enable a more comprehensive understanding of education in post-digital times, where the distinction between virtual/real, online/offline, and digital/analogue is no longer relevant. This is particularly important when investigating post-digital practices related to teaching and learning (Macgilchrist, 2021).

The three proposed topologies can help us understand the complexity of learning environments for students and teachers. They can also show us the importance of agency in analysing their own learning context and how personal learning environments (PLEs) are influenced by students' decisions, rather than being just the mere result of personalization systems (Dabbagh & Castañeda, 2020). Student agency in the HE context is understood as "access to (and use of) resources for purposeful action in study contexts, i.e. personal, relational (i.e., interactional), and context specific resources to engage in intentional and meaningful action and learning, as experienced or interpreted by students" (Jääskelä et al., 2017, p. 2067). This means that student agency is not just about having the freedom to choose what to learn, but also about having the resources and support necessary to make those choices meaningful and effective. The three topologies can help us to understand how student agency is shaped by the different resources and relationships that students have access to, as well as by the context in which they are learning.

Therefore, it is important to discuss critically the use of tools, metacognitive approaches to the uses of some tools, and also self-directing decisions about how to regulate and decide their learning context (Mercer, 2011). Furthermore, it would be helpful to explore how participants choose the right tools for their learning activity, as well as the space(s) and the social organisation of their work; all of which are critical parts of digital and learning-to-learn competencies.

Topologies can enable a deeper analysis of two key aspects in the study of the role of the participants in teaching and learning processes: ownership and engagement (Dommett, 2018; Hegarty & Thompson, 2019; Raes, 2022). By exploring alternative perspectives on the role of various actors in learning activities, topologies provide valuable insights that contribute to a deeper understanding of the aspects addressed by ACAD. Acting as operational frameworks, topologies capture and examine relationships that may otherwise not be explicitly discussed within the ACAD framework, thereby enriching the perspectives of learning space of designers and analysts. The utilization of topologies could have a significant influence in pedagogical design processes, as demonstrated in our case study. They guide educators in rethinking and redesigning activities, adapting them, modifying knowledge tasks, altering tools, and reconfiguring learning spaces. Furthermore, topologies can suggest proposals to enhance the frameworks from which these interventions are analysed, such as ACAD.

Multidimensional analyses can help universities make informed decisions about infrastructure and technology resources. For example, universities can evaluate the need for resources like plugs and WIFI connections across campuses, classroom furnishings, and mobile-friendly versions of virtual learning environments ("Aula virtual" in the example). They can also determine whether investing in other edtech tools and platforms is necessary (e.g., campus licenses, subscriptions, etc.) (Murphy & Farley, 2017; Seifu, 2020). Equally, if not most important, it could help institutions evaluate and critically analyse the impact of third-party platforms on educational processes (Decuypere, 2019; Williamson, 2021).

Despite their potential benefits, applying topologies can be challenging due to their complex, non-linear, and heterogeneous nature. To use this methodology, specialised software is required to visualise and analyse the multiple data layers and their interconnections. Additionally, implementing topologies requires embracing paradigmatic pluralism and mixed methods, which can take time to implement. Given their complexity, heterogeneity, and non-linearity, it is essential to recognise that topologies are a crucial component of what (Jandrić et al., 2022) refers to as post-digital research.

Ultimately, this paper proposes a novel approach to the study of educational praxis, thereby contributing to the development of alternative methodologies that may enhance our understanding of educational processes as mediated by technology in a post-digital world. It is worth noting that existing research on topologies in educational research has mainly focused on digital tools and platforms (e.g., van de Oudeweetering & Decuypere, 2021), rather than on the learning experience mediated by technology. The proposed approach facilitates the study of topologies of digital data practices in education, offering a detailed strategy to capture the learning experience in a holistic way. In doing so, it has great potential to inform educational research as well as practice. While relying on self-reported data might be perceived as a limitation, we contend that participants' subjective experiences provide valuable insights into learning activities as they unfold in practice.

The study aims to offer new perspectives in a field with a well-established research tradition. Our aspiration is to foster a more nuanced and comprehensive understanding of the complex processes underlying technology-mediated learning activities. As such, it represents a small yet significant contribution to a more extensive discussion on the subject. Our hope is that it not only helps to shed light upon vital research questions in our field, but also contributes to a redefinition of the nature of the questions that are formulated in the field.

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Data availability Due to the nature of this research, the case study participants did not agree for their data to be shared publicly, so supporting data is unavailable.

Declarations

Competing interests The authorship team declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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