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Use and meaning teachers assign to the integration of the MICA 3.0 kit for teaching climate change

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Introduction: Teaching climate change requires teachers to have the educational resources that will facilitate teaching this content and visualize how a global problem has various local implications. In Chile, the capacity for environmental data collection and use at the school level remains limited, hindering evidence-based and context-aware climate education.

Methods: This study follows a Design-Based Research (DBR) approach and comprises three main phases: (1) the participatory design of an environmental monitoring station based on the needs identified by in-service teachers for teaching climate change; (2) the development and implementation of a professional development course to support teachers in the appropriation of the technological resource; and (3) the analysis of learning experiences designed by teachers who integrated the technology into their pedagogical practices.

Results: Teachers successfully designed active learning experiences that incorporated local environmental data. These experiences promoted the development of scientific skills and 21st-century competencies, contextualized within local territories and cultures, with the potential of opening new spaces for learning beyond the classroom.

Discussion: The integration of the monitoring station transformed teachers' views of technology, shifting from an instrumental perspective to one linked to key scientific inquiry processes. It also supported the design of active and contextualized learning experiences that promote scientific and 21st-century skills. The relevance and low cost of the resource make it a viable option for scaling, although challenges remain in teacher training related to basic statistics and environmental data management.

KEYWORDS

climate change teaching, techno-educational resources, technological resources kit, IoT technology, continuous training

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1 Introduction

1.1 Use of EMS to promote participatory citizenship

Citizen participation is essential in education and climate change action (Sapiains Arrué et al., 2018). Acknowledging this vital connection, a recent study by the Education Quality Agency in Chile has highlighted the need to improve student participation indicators in educational processes. This approach is especially critical for secondary education students, who must be equipped with knowledge and competencies to Actively participate in decisions that affect their lives and surroundings (Agencia de Calidad de la Educación, 2024). In 2021, Chile signed the Escazú agreement, a meaningful regional commitment that underscores the right to information access, public participation, and justice on environmental issues in Latin America and the Caribbean (Etemire, 2023). This agreement marks a formal recognition of the rights of individuals to influence environmental decisions that affect them directly. When incorporating these principles in education, schools can transform how students perceive and respond to climate change (Sterling, 2021).

Climate change is expressed in various forms in the different territories, each one with its own challenges and opportunities for local action. Education, therefore, needs to adapt to address these variations, integrating climate change teaching transversally in school curriculums (Bieler et al., 2017). This implies not only educating about the causes and effects of climate change but also fostering a practical approach where students can apply what they have learned to projects that will positively impact their communities (Hernandez et al., 2022). Promoting an educational model that fosters active and critical participation of students requires a significant change in teaching and learning methodologies. This approach enriches their academic learning and prepares students to become responsible and proactive citizens in climate change action (Hung, 2022).

The integration of adequate technologies and resources is essential to support this participatory educational model (Haleem et al., 2022). Tools such as Environmental Monitoring Stations (EMS) can be key in this process, providing real data that students can analyze (Tamblay et al., 2024) in an interactive and multi-disciplinary way through projects (Hercog et al., 2023). Technology, therefore, becomes a facilitator of student participation, allowing them to explore evidence-based solutions and participate meaningfully in scientific and political debates about climate change.

The challenge is to build school cultures that integrate technology effectively, avoid the risk of the "technologization" of education, and promote inclusive and participatory environments (Costa et al., 2021). This includes designing pedagogical practices that use technology to promote the participation of all students and social inclusion (Alhassan and Adam, 2021; Chohan and Hu, 2022; Harb and Sidani, 2022). Tools such as EMS can be part of this effort by offering students the opportunity to participate in real research projects that promote the development of abilities related to the study of the environment (Palacios Temprano et al., 2020) that have local and global relevance.

1.2 Challenges and gaps in technology integration

Despite the potential offered by the integration of technological resources for teaching and learning, there is still a digital gap – differences in access to technology and digital abilities – that continues to be a significant obstacle in many communities, limiting the effectiveness of technology-based educational initiatives (Gonzales et al., 2020). This challenge is amplified by socioeconomic differences that can limit access to devices and high-quality internet connectivity (Bonal and González, 2020).

Teacher knowledge and training in technologies are also critical. Many educators are not sufficiently prepared to use advanced technologies in the classroom, which can result in inefficient implementation and lost opportunities for the students (Aditya, 2021; Li, 2021).

The practical implementation of these advanced educational models reveals a significant challenge in current teacher training. Although teachers offer solid experience in specific areas of disciplinary teaching, such as content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK), mainly influenced by years of teaching experience, they face considerable difficulties in technology-related domains (Chai et al., 2020). This deficit is exhibited in technological knowledge (TK), technological pedagogical knowledge (TPK), and the general competence within the technology, pedagogy, and content knowledge (TPCK) framework, which are critical to integrate environmental education technologies and promote citizen participation effectively (Abrahams et al., 2022).

The gap in this technological knowledge suggests an urgent need for professional development programs considering updated technological tools and resources and their practical implementation to promote new digital citizenship abilities (Rahmadi et al., 2020). It is essential to overcome these barriers to evolve pedagogical practices that will respond effectively to the current challenges of climate change and active citizenship.

1.3 Relevance of authentic research and challenges in local educational contexts

Collecting and analyzing local data are emerging as fundamental elements in scientific education, especially in studies related to climate change. This approach allows students and teachers to obtain accurate and relevant information about their immediate environment and promotes authentic research production rooted in their context (Luan et al., 2020). When using technologies such as IoT sensors and open data platforms, educational centers can develop research projects that provide valuable approximations about specific local phenomena, such as climate patterns, air quality, and biodiversity (Tabuenca et al., 2023).

These projects enrich academic learning and contribute to the global scientific knowledge corpus with local studies that can be bought and contrasted with data from other regions. In addition, collecting and analyzing local data prepares students for future careers in science, technology, engineering, and mathematics (STEM), equipping them with the necessary abilities to manage significant volumes of data and perform complex analyses (Abichandani et al., 2022). This research-based education empowers students, transforming them into active researchers of their learning and promoting a better understanding and responsibility over global and local environmental challenges (Nikitina and Ishchenko, 2023).

1.4 IoT technology in schools

The integration of the Internet of Things (IoT) technology in educational centers is revolutionizing how students learn about critical topics such as climate change. Arduino, a free hardware platform that allows the creation of interactive electronic projects, stands out as a fundamental tool in this field (Atanasković et al., 2024; Ga et al., 2021). Using Arduino and other IoT, students can collect and analyze environmental data in real-time, which offers them a practical and tangible understanding of the dynamics of climate change (Ujoodha et al., 2021).

On the other hand, integrating the Internet of Things (IoT) into science education provides an interesting perspective on teaching strategies and approaches. Existing literature has demonstrated that IoT enhances and expands students' experiences engaging with scientific phenomena across different educational levels and age groups (Sari et al., 2022). One of its key characteristics is its curricular integration, which, when aligned with STEM education approaches, enables dynamic, low-cost activities. Additionally, the open-source nature of IoT programming fosters learning opportunities in coding (Abichandani et al., 2022). When applied to real-world, locally relevant problems, IoT has been successfully implemented in data-driven thinking strategies, which, through collaborative work, have contributed to developing problem-solving skills, critical thinking, and leadership (Benita et al., 2021; Saad et al., 2024).

At the curricular level, the integration of IoT in scientific education provides new opportunities to expand students' learning experiences by incorporating it into STEM education (Abichandani et al., 2022). In fact, curricular proposals in Chile advocate for the inclusion of the STEM approach to integrate technology into teaching to foster scientific skills (Ferrada Ferrada et al., 2021). However, the socio-economic events of the past decade have exposed weaknesses in the educational system, where technology has played a secondary role. This identified gap can largely be attributed to the lack of resources, including both hardware and internet access, as well as the costs associated with maintenance at both the school and household levels—factors that reflect the persistent social inequity (Llorens et al., 2021).

Considering the opportunities technology offers and the challenges of both the educational context and the climate change issue in itself, the design of this research considers the development of an EMS as an innovation device for the teaching of climate change, which will become part of rendering the Teaching and Learning Sequences (TLS) operational. Given the background and challenges of the use of IoT by natural science teachers, the question arises: What use and meaning do teachers give to the integration of the MICA 3.0 KIT for teaching about climate change? The goal of this initiative is to develop and implement the EMS according to local, technological, and pedagogical needs in agreement with climate change teaching.

2 Materials and methods

The present investigation is part of a greater project based on building scientific and integrated knowledge. This study seeks to understand the scope, limitations, and implications of science and technology in society, as well as educationally communicating climate change and protecting and conserving the environment at the local level.

The MICA 3.0 kit is composed of 6 maps of Latin American places (Sao Paulo in Brasil, Lima-Callao in Perú, Mexico City in Mexico, Antioquía in Colombia and the maps of the Araucanía and Valparaíso regions in Chile), six applications (same cities) that are activated using augmented reality starting from markers located in the maps, a set of didactic guides for its use at different educational levels and an EMS based on low-cost technology and open software (Figure 1). This element (EMS) is the last one to be incorporated into this project since the maps, applications, and guides have been developed in previous projects.

The purpose of the previous project was focused on the development of technological resources (MICA 2.0 KIT)[1]. The EMS joins this project as an addition to the kit to broaden the possibilities for teachers and provide a more versatile resource that will facilitate the teaching of climate change. Teacher training is also included in order to achieve appropriate technology use.

2.1 Methodology

Given the interventionist nature of this study (Velasco et al., 2021), which seeks the implementation of an EMS focused on the need for technological competence development for science teachers, it is appropriate to carry out a Design-Based Research (DBR) (Padayachee and Howard, 2024). This method places emphasis on an iterative development process of classroom-situated solutions (Juuti and Lavonen, 2012) through iterations in a reflective, adaptative, and collaborative space between the actors involved (Scott et al., 2020). This is, therefore, a qualitative study based on the observation, description, and characterization of episodes as they occur, interpreting the meanings that actors assign to a particular context or activity (Flick, 2014) in a situated manner, acknowledging the unique characteristics and implications in the design of technological solutions for local use through the MICA Kit.

Design based research is a recognized methodology in the development of TLS, given its iterative and cyclic flexibility of which the multiplicity of procedures is acknowledged (Guisasola Aranzabal et al., 2021). In the same way, this methodology provides viability to a situated constructivist approach of TLS thought for participation, considering the local character, the environmental needs, and challenges that are of interest to each school community (Psillos and Kariotoglou, 2016).

The IBD stages consist of a cyclic flow of 3 stages (Figure 2); then, after each implementation milestone, there are spaces for evaluation and reflection about whether the expected objectives were met, which will determine the re-design of the constructed artifact.

1 https://www.etecc.cl/mica/

Table 1 shows how the work process was organized in 3 stages:

Stage 1: Context and design. This stage aimed to identify the technological needs of teachers to teach about climate change, as well as their context conditions. During work sessions with both groups (G1 and G2), disciplinary requirements were collected, such as the need to strengthen their technological and specific CK, for example, descriptive statistics for data use. Then, goals were established about the development of the technological resource and the expected impact on climate change teaching, together with the communities. Finally, teachers' requirements were collected to outline the features of educational technological resources. To facilitate this process, they were shown some examples of possible alternatives based on Arduino, from which the attributes they considered necessary and adequate were selected for their educational context and level.

Once the information from teachers was collected, the electronic design was developed. Then, the technological resource was developed using the agile (Scrum) methodology, which operates based on work sequences and partial deliveries. This methodology conforms to the development of personalized products. It implies the active participation of the client, in this case, the teachers, who use the delivered modules to accept or specify any requirements or incorporate new developments (Morandini et al., 2021). This methodology was selected given the relevance of teacher participation in the validation process. This stage had a duration of 8 months.

Stage 2: Teacher education. With a difference of about a month the technological development, the training course for teachers was developed using the ADDIE Methodology (Morales-González et al., 2014), which considers five stages for the instructional design of training programs: [A]nalysis of the target audience and their characteristics, [D]esign of the route and learning activities, [D]evelopment of activities, resources and learning environments. [I]mplementation of the course with the participants and [E]valuation of the process to determine the need to make adjustments in the next edition. Some of these stages can consider some iteration level until reaching their final version.

This course was implemented in two places in the country, with small groups of teachers: 7 teachers in the G1 and 10 teachers in the G2. At the beginning of the implementation, a semi-structured survey was applied to characterize their professional profile, trajectory, and personal perceptions on three topics: teacher continuing education, climate change, and the integration of new technologies for teaching and learning.

During the implementation of the course, evidence recollection instruments were designed: a teacher characterization questionnaire and a design matrix of learning experiences, whose features are detailed next.

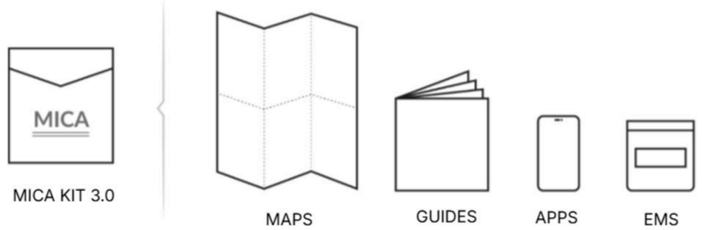

FIGURE 1
Components of the MICA 3.0 Kit (Source: Prepared by authors).

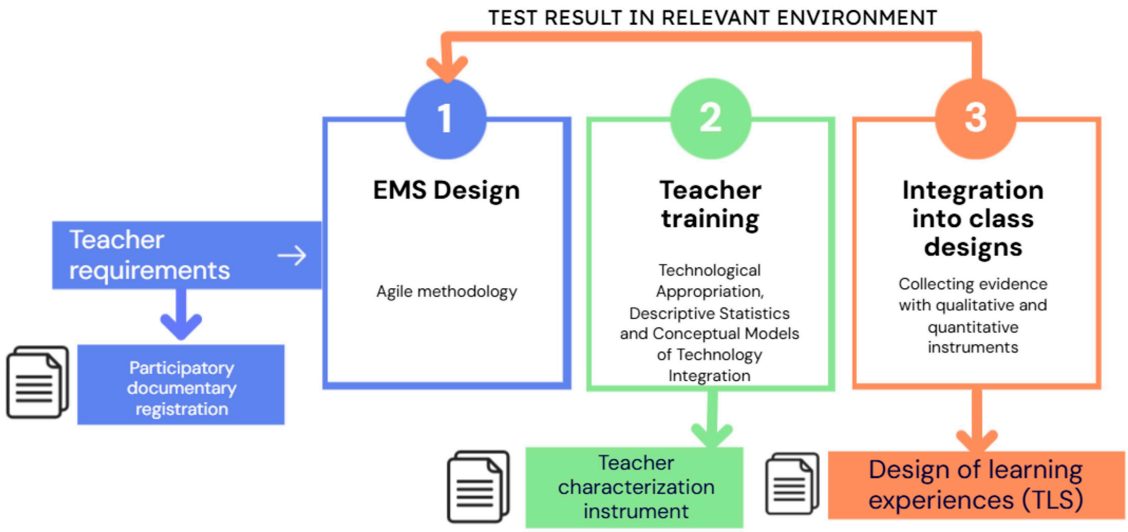

FIGURE 2
Research stages according to the DBR methodology (Source: Prepared by authors).

TABLE 1 DBR process summary.

Stage	Sub-stages	Description
EMS Design	Problem identification	Identification of technological needs of teachers for climate change teaching. Disciplinary and technological requirements are collected, as well as educational context analysis.
	Definition of goals	According to teacher communities, clear goals are established in relation to the development of the technological design and the expected impact on climate change teaching.
	EMS Delimitation characteristics	The teacher community selects the necessary attributes for the monitoring stations for EMS (MICA 3.0 Kit), considering local particularities and educational needs of the corresponding levels.
	Development of technological resources	For the development of the EMS the agile methodology Scrum was used to manage projects through brief and collaborative iterations. Each iteration implies planning, development, review and feedback which ensures the continuous incorporation of improvements based on teacher needs.
Teacher education	Development of training course	The training course for teacher was designed following the ADDIE technology (Davis, 2013), a broadly used model for the creation of educational programs based on IoT (Kaneko et al., 2019). Its implementation in two locations with small groups (7 and 10 teachers) allowed to adapt content to the specific needs of each context and aligned with the proposed objectives.
	Recollection of learning evidence	Design and application of a semi-structured questionnaire to characterize teachers in 6 dimensions (personal data, experience, Current teaching, pilot plans, climate change, and technology use) and a design matrix to evaluate the integration of the MICA 3.0 Kit in climate change research.
Integration of class designs	TLS Local designs	In a process of collaborative construction learning experiences are designed integrating the MICA 3.0 Kit developed and adapted to their specific contexts.
	Discussion space with communities	There are spaces for exchange where teachers share their experiences, reflect about the results and propose improvements.

Stage 3: Integration in class design. As a culmination of the process, teachers designed learning experiences in which the technological resource was included for the teaching of climate change. This design work was done collaboratively between teachers, so from G1, three class designs were received, and in G2, four were collected. At the time of submission of this article, a discussion and a reflective closing activity with G2 teachers had taken place, but the activity with teachers from G1 is still pending.

2.2 Participants and context

The present experience is framed in the execution of the design and implementation process of the MICA KIT in two groups: (G1) with teachers from the Valparaíso region and (G2) with teachers from the Araucanía region in Chile. This is a non-probabilistic sample by convenience, with participants selected by the schools that are part of the project based on the following criteria: interest of the people, time, and authorization to participate in this study during working hours.

In the first instance (seminars), 42 people participated (18 G1 and 24 G2). Table 2 shows the participation and characteristics of the participating groups in the local work instances (virtual and face-to-face):

TABLE 2 Participating groups in the local work instances.

Characteristics	G1 - Valparaíso	G2 - Villarrica
n	7	10
x̄ age	38.5 years (± 3,61)	43.5 years (± 23.3)
Professional training	5 of primary education 2 of secondary education (Cs)	3 of primary education 4 of secondary education 2 Inclusive Education Teachers 1 agronomic engineer participating of TEVT courses
x̄ professional trajectory	16 years (± 14)	19.5 years (± 24.75)
Dedicating	44 h 75%–85% in classrooms	44 h 25% y 65% in classrooms
Courses size	15 a 42 students	15 a 25 students

2.3 Data analysis

The data collected was analyzed using deductive methods for content analysis for the answers in the questionnaire and the design matrix. For this qualitative analysis, the software Atlas. Li (2021) was used, following a rigorous thematic analysis approach, which allowed us to identify significant patterns, emerging trends, as well as challenges and opportunities in the integration of the MICA 3.0 Kit (Lindgren et al., 2020). In particular, the teaching of climate change through the TLS design using this innovation was analyzed, providing a deep understanding of the experiences and perceptions of participants in local contexts. Seeking agreements, the team held weekly meetings to discuss patterns, categories, and trends in data collection. Once agreed, content categorization and general matrix layout were carried out for each group.

2.4 Applied instruments

In order to collect information from participant teachers, two instruments[2] were designed. A semi-structured characterization questionnaire and a design matrix of the learning experience. The purpose of the questionnaire is to describe under what context and participant characteristics the results of this process take place. It's composed of 6 dimensions: personal data (7 questions), teacher training and experience (15 questions), current teaching (7 questions), information about the pilot course (2 questions), climate change (3 questions), and technology use for teaching and learning (3 questions).

On the other hand, the learning experience design matrix allows teachers to record the pedagogical activities to address scientific reasoning processes associated with research on climate change, making use of some of the components of the MICA KIT in the classroom. These instruments were applied to the two groups of participating teachers.

2 Available in the Supplementary annex 1

3 Results

3.1 Teacher requirements

Table 3 shows the requirements collected from the teachers in the seminars.

3.2 EMS design

The EMS is a techno-educational resource based on low-cost technology and open software, whose conceptual-technological solution is shown in Figure 3. This EMS considers the needs identified by teachers (Table 4).

The EMS has two modes of operation:

1. The "station" mode, which captures and sends data every 30 min to the server
2. The "experiment" mode, which captures and sends data every 30 s to the server

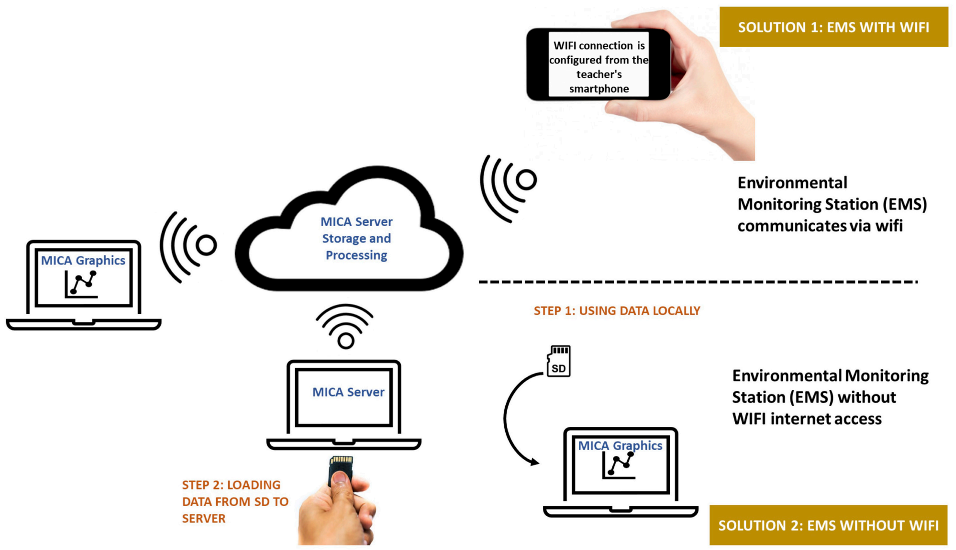

FIGURE 3
Conceptual-technological solution according to teacher requirements (Source: Prepared by author).

TABLE 3 Requirements from teachers for technology resource.

Group	Requirements
G1	- Technology in the service of environmental education and its linkage to local learning - Need to use geospatial technology tools to create maps and integrate environmental history, with the idea of fostering student engagement with their environmental and social surroundings. - Technology should contribute to the visibility of abstract phenomena such as climate change. - Have platforms for teacher training on this topic. - Technology should allow for practical activities and field experiences that foster critical thinking. - Importance of curricular links with socio-environmental and technological issues.
G2	- Need to produce real-time environmental data - Adapting technologies for non-internet contexts - Integrate local knowledge into scientific reasoning, promoting respect and protection of cultures and the environment. - Encourage interdisciplinary work to address socio-environmental problems in a holistic way.

TABLE 4 Characteristics of the EMS.

Sensors	Other Components
• Solar radiation (UV Sensor) • Carbon dioxide concentrations (CO2 Sensor) • Light intensity • Sound intensity • Water quality sensor (based on turbidity	• LCD screen • SD card • Rechargeable battery • GPS • On/off switch • Mode selector button

To ensure the quality and robustness of the technological solution, three types of tests were carried out:

1. Communication test: The obtained data accounts for a 99.77% effectivity (95% expected).
2. Server stress-test:100% of demands attended and stored
3. Information delay tests: This time is typically between 19 and 26 s, which allows us to deliver a manual with information on the latency period.

Finally, the EMS uses a web platform to interact with users, where real-time graphs[3] and "experiment" mode information can be obtained with access protection.

3.3 Teacher characterization instrument

This section comes from the characterization instrument consisting of a single open-response item in three areas, whose responses have been summarized in Table 5, according to the group to which the teachers belong.

3.4 Results of design matrices

The seven design matrices about learning experiences created by teachers were analyzed and systematized in a graph that allows

3 https://www.etecc.cl/ema/

TABLE 5 Teachers' opinions on the 3 areas surveyed.

Value assigned to continuous training attributes	
G1 1- Active methodologies, 2- Practical exercises for teaching pedagogical or disciplinary content that can be transferred to the classroom. 3- Suitability of the training course with their professional background. 4- Governmental recognition to ensure quality.	G2 1- Relevance of the course with respect to the needs of the educational context and your professional career. 2- Assessment of attendance 3- Teaching support through effective communication. 4- Usefulness lies in the theoretical transferability and applicability to the classroom.
Motivations and barriers regarding the use of technology. Teachers' views about their motivations for integrating technology in your classes?, and the main challenges or barriers to this.	
G1 Reasons for integrating technology: 1- Efficiency of class work, 2- Motivation of students, 3- Accessibility of teaching resources, 4- Development of digital competences, 5- Social relevance of technology. Challenges/barriers 1- Lack of technological resources, internet and electricity instability in rural areas. 2- Lack of self-management in the use of technology by students to carry out tasks, 3- Lack of opportunities for improvement and innovation, given the lack of support from school authorities.	G2 Reasons for integrating technology: 1- Relevance and contextualisation of contemporary social work, 2- Student motivation 3- Efficiency and speed in obtaining feedback (online assessment applications), 4- Development of digital skills, 5- Fostering scientific reasoning. Challenges/barriers 1- Lack of resources 2- Digital literacy challenges, 3- Integrative methodologies of technology in education. 4- Lack of managerial support for innovation, 5- Difficulty of teachers in identifying needs. 6- Lack of commitment from parents.
Climate change education. Teachers' views about their reasons to educate on climate change?, and the main challenges or barriers to this.	
G1 Reasons for teaching climate change: 1- Understanding of climate phenomena and anthropogenic effects. 2- Knowledge on technology for project development 3- Development of compliant scientific concepts from local data collection. 4- Making students aware of the effects of their actions. 5- Develop spaces for solving local environmental problems. Challenges/barriers 1- It is necessary to transform practices that affect the environment and that are normalised, such as the environmental influence of advertising in a consumer society. 2- To promote knowledge about the climate and its changes among teachers and students. 3- Promote policies that promote environmental care through initiatives that cover every part of human life.	G2 Reasons for teaching climate change: 1- Understanding of climate phenomena and anthropogenic effects. Challenges/barriers 1- Fostering knowledge about climate and its changes in both teachers and students. 2- Lack of didactic, methodological and participatory updating. 3- Lack of spaces for inquiry through the integration of technology in interdisciplinary problems.

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one to see the route each carries out in terms of seven elements (see example in Figure 4). Said elements correspond to subjects selected by teams of teachers to work on the MICA Kit, educational level, the purpose of the activity under design, spaces inside or out of school in which activities will take place, teaching methodology, and the contribution of the technological resource that teachers expect according to its design. The complete systematization of this first analysis stage is available in Supplementary annex 2.

In the second analysis phase, the information was synthesized based on what we observed that the MICA Kit promotes in the matrices designed by teachers (Figure 5). This synthesis allows the create four categories: (i) objectives aimed at students, this is, the scientific and transversal abilities that teachers consider can be addressed with these resources; (ii) teaching methodologies that teachers select, which in all cases correspond to active methodologies that include students in their learning; (iii) educational spaces and resources that are required to develop activities; and (iv) the connection with the context in which the educational communities are inserted.

In the student abilities category, we see that teachers project both scientific abilities such as observation, creation and hypothesis confirmation, data analysis, and use of scientific instruments; they also project the development of transversal abilities such as creativity, critical thinking, and technological abilities when using software tools and hardware devices for data collection and analysis.

The total number of class designs in the teaching methodologies category included active learning methodologies. Most use inquiry-based learning (5), one project-based learning experience, and one service-based learning.

The educational and context category allows us to group the “effects” of the MICA kit integration in terms of space used for teaching and other technologies included around the Kit. We see that this technology pushes teachers to get out of the classroom. Only two out of seven design matrices center activities exclusively around the classroom; three of them add to the classroom activities outside the school, such as the riverside, parks, or places nearby the school, and the other two are situated both in the classroom and the greenhouses in their own schools. Associated with the school context, other technological resources required to put into practice the designed activities were grouped. Here, we frequently find the use of computers, smartphones, or tablets, software for data analysis (spreadsheet), and some supporting devices such as the projector and audio system.

Finally, in the context relationships category, we observe that all designs contain activities that are in close relationship with the natural and/or cultural environment of educational communities to value and understand the impact of human

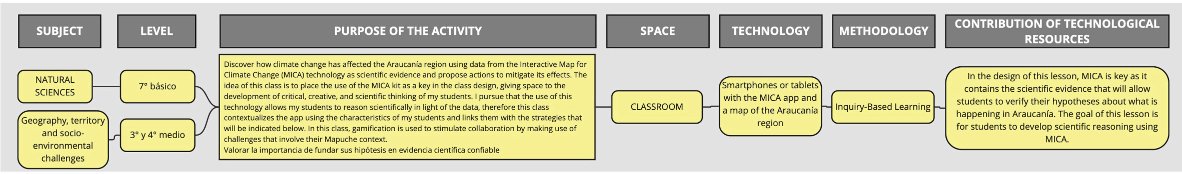

FIGURE 4
Elements considered in the systematization of the design matrices.

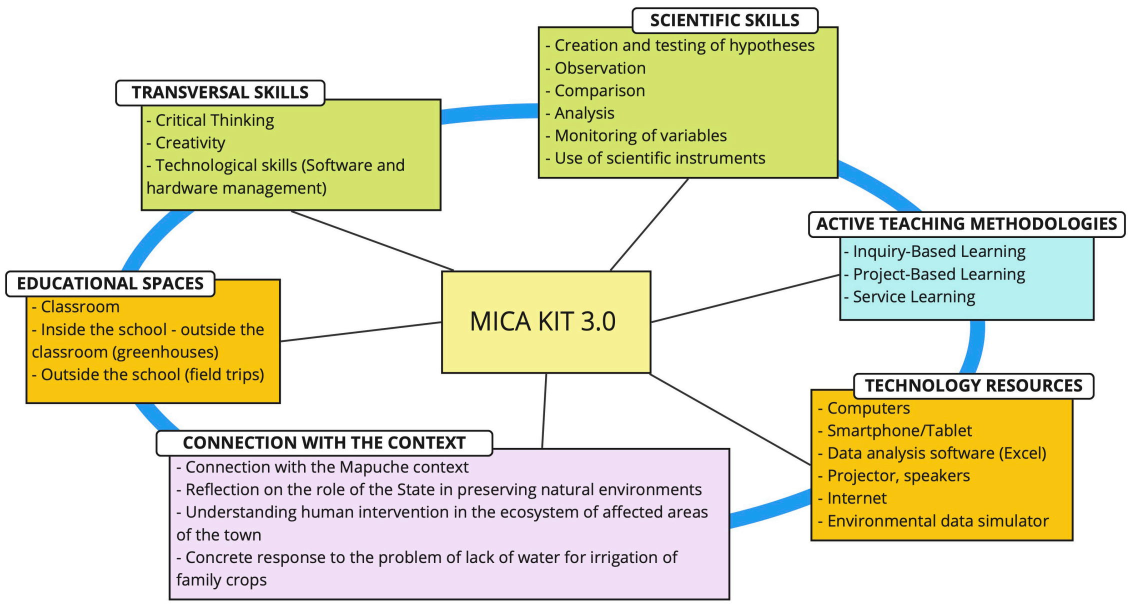

FIGURE 5
Synthesis of aspects promoted by the use of the MICA 3.0 Kit.

actions on the natural surroundings and, in the case of service learning, in addition to understanding a context-situated problem, the generation of solutions that will benefit the families in the educational community.

4 Discussion and conclusion

The results are very promising in relation to the use and meaning that teachers give to the integration of this technological resources kit for climate change teaching. We can find various aspects from which to discuss:

4.1 Regarding the teacher education process

In this area in the design matrices, we have been able to observe the change in meaning that teachers assign to technology: at the beginning of the process, technology is seen as associated with factors such as the increase in motivation, efficiency, and timelines in feedback and 21st-century abilities, all transversal elements in any type of technology integration and described broadly in literature. At the end of the process, it can be observed in the design matrices that teachers integrate technology with very specific processes associated with stages in the scientific process, such as experimentation and data collection and analysis, research of reliable sources, and the creation and contrast of hypotheses from the analyzed data, which suggests that the formative process allows to expand and strengthen not only their technological knowledge (TK) but also to strengthen their pedagogical, technological and content knowledge (TPCK) which was one of the purposes of the design of the course modules (Abrahams et al., 2022; Chai et al., 2020).

Another element that emerges from the formative process is the need to work the contents of basic statistics (descriptive) more in-depth for data management in teachers, along with the use of software that serves this purpose (spreadsheet). The course included a module on data management, but it was insufficient due to the need to start from very basic elements both in contents and spreadsheet use. This remains a challenge that must be addressed in the following implementation, whether it is considering an extended module in this training or considering a certain level of knowledge in descriptive statistics and spreadsheet use as an entrance requisite to begin this course.

4.2 In regard to the development of resources that comprise the kit, we observe that teachers managed to use them and integrate them into their activity design

The EMS designed with IoT components was low-cost; therefore, the kit is very accessible, in line with what is mentioned by Magalhães et al. (2024). Since its origin was connected to teacher requirements, pertinence is adequate. However, because in the following stage, the project is to expand the scope of teachers that can work with the MICA 3.0 KIT, we consider it necessary to apply instruments to evaluate the variables associated with the acceptance of the technology proposed by the UTAUT model (Palos-Sanchez et al., 2019), and in this way develop the support mechanisms and adjustments that are necessary to facilitate its scalability.

4.3 Regarding active learning and the development of 21st Century abilities

In the matrices analysis, we observed that all teacher designs are situated in active learning methodologies and, at the same time, are connected to the development of 21st-century skills in students. These findings are in line with Hercog et al. (2023) and Yilmaz (2021), where we also note that some designs also include more than one subject or educational level, which accounts for the possibility of multi-disciplinary work that the technological resources offer.

From the aforementioned, teachers assign different meanings to technology, as well as the development of 21st-century transversal skills, an scientific abilities, and the opportunity to practice active methodologies connected to the territory by specific content or through their local culture. From the results, we can also see that the uses are diverse since the KIT can be used at primary and secondary education levels, in subjects related to natural sciences and social sciences, or in a combination of both.

5 Limitations

When preparing this communication, the design of the learning experiences stage has been closed, but these have not been implemented with students. Therefore, it is not possible to account for the results and conclusions regarding student learning or participation, which are topics of interest that will be addressed in the next stage.

Another limitation was the small size of the sample, which in the initial stage reached 42 participants, but the in-depth work was carried out with 17 people, given the conditions for piloting this project and the teachers' possibilities to allocate time in their working day to this initiative.

6 Projections

As mentioned at the beginning, this research is part of a larger project, which has set out to design a training pathway for the teaching of climate change aimed at teachers in the Chilean school system. In this context, the results and conclusions obtained in this experience allow us to understand the meanings that teachers assign to the technological resource and to project opportunities and considerations to be taken into account when expanding the coverage of this set of courses that make up the training course[4].

4 https://etecc.cl/cursos

Data availability statement

The original contributions presented in this study are included in this article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the Ethics Committee of Pontificia Universidad Católica de Valparaíso, Ethical clearance number: UFS-HSD2022/1276/22. The studies were conducted in accordance with the local legislation and institutional requirements BIOEPUCV-H 675-2023. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

SP: Formal Analysis, Investigation, Writing – original draft, Writing – review and editing. CC: Formal Analysis, Investigation, Supervision, Writing – review and editing. HV: Conceptualization, Data curation, Formal Analysis, Software, Writing – review and editing. LV: Methodology, Software, Writing – review and editing. JS-P: Formal Analysis, Investigation, Validation, Writing – original draft, Writing – review and editing. AA-M: Project administration, Resources, Supervision, Writing – review and editing. PA: Formal Analysis, Validation, Writing – review and editing. CM: Investigation, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that Gen AI was used in the creation of this manuscript. Artificial Intelligence (AI) tools were utilized to organize and refine the structure of the abstract. These tools supported clarity, coherence, and adherence to academic writing standards, ensuring the abstract effectively communicates the main objectives, methodology, and findings of the study. The content remains the original work and intellectual contribution of the authors.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2025.1537960/full#supplementary-material

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