Maker Activity in the Classroom

Solving pedagogical challenges

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Abstract
Contemporary society requires urgent changes in traditional education to engage students and foster innovation, critical thinking, and ethical use of digital technologies. Maker Education, based on Seymour Papert's constructionism, emphasizes knowledge construction through the production of meaningful objects, while promoting the use of technology. However, challenges such as teacher training, curriculum integration, and activities incorporating students' realities and interests hinder its implementation. This article presents a field study conducted in a public school in São Paulo, Brazil, involving a sixth-grade class and six teachers from different disciplines. Initially designed to teach mathematical concepts through an interactive game related to soccer, the project evolved into an interdisciplinary learning experience when a student raised concerns about urban inequality linked to a nearby soccer stadium construction. This shift enabled students to engage critically with real-world issues while aligning with pedagogical objectives as proposed by Paulo Freire. The study shows how integrating Maker Education into the curriculum enhances interdisciplinary and contextualized learning, empowering students to actively understand and address social challenges.

Keywords and Phrases: Constructionism, Maker Education, Project-Based Learning, STEM-rich.

1. Introduction
In today's digital age, traditional educational models require urgent transformation to meet evolving societal needs. Instruction-based teaching often struggles to engage students or equip them with essential 21st-century skills – such as creativity, problem-solving, and the ethical and effective use of digital technologies. According to Kenski (2012), the advancement of digital technologies has profoundly transformed the way people learn, interact, and construct knowledge, requiring education to be reorganized to engage with the practices and challenges of society. To address these challenges, the school curriculum must integrate innovative methodologies while addressing the social, economic, and cultural issues that shape students' daily

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lives. As Paulo Freire (1996) argues, education should be a political act that respects and engages in dialogue with the knowledge built through community practice, allowing the school to be a space for critical reflection on social dynamics and their contradictions.

This educational transformation requires methodologies that integrate theory and practice, promote active learning, and develop essential skills such as critical thinking, problem-solving, and creativity (Perrenoud, 1999; Freire, 1996). In this context, Maker Education emerges, grounded in Seymour Papert's constructionism (1986), emphasizing knowledge construction through the creation of meaningful objects for learners. This approach can also foster an environment conducive to the discussion of sociopolitical issues. Freire (1996, p. 30) highlights that schools should "establish a necessary 'intimacy' between curricular knowledge and students' social experience," creating a bridge between formal knowledge and students' lived realities.

However, the challenges related to the implementation of Maker Education in the school context primarily involve the lack of technical and pedagogical training for teachers, as pointed out by Bevan (2017). Additionally, the connection between maker activities and the school curriculum remains introductory, as indicated by authors such as Blikstein, Valente, and Moura (2020), who emphasize the need to integrate these approaches in a meaningful way, aligned with pedagogical objectives. Another critical issue is the lack of studies investigating students' perspectives in the development of maker activities. Although this aspect is crucial for understanding how these activities connect to students' realities and interests, as argued by authors like Soster (2020), it remains an underexplored area. Given the limited research on the relationship between curriculum and maker practices, the gap regarding students' perspectives becomes even more evident.

The study was carried out with a class of sixth-grade students and involved six teachers: two mathematics teachers, one Portuguese language teacher, one English language teacher, one geography teacher, and one arts teacher. Initially, the two mathematics teachers, after training in the maker space, planned activities aimed at teaching mathematical concepts in a playful and interactive way through a game related to soccer they developed. However, during the use of the game with the students, an observation made by one student about the construction of a soccer stadium near his home brought up social issues related to inequality and urban transformations, expanding the scope of the activity. This shift made the learning experience interdisciplinary and relevant to the students' realities, as proposed by Freire (1975).

This study seeks to answer the following questions: How can teachers maintain pedagogical intentionality while designing engaging activities aligned with curriculum objectives? How can they foster student autonomy and active participation while ensuring connections to students' real-life contexts? Ultimately, this study explores how integrating the school curriculum can foster interdisciplinary and critical learning, empowering students to understand and address real-world issues.

The text is organized as follows: Section 2 presents the theoretical framework. Section 3 describes the work methodology. Section 4 summarizes and discusses the main findings of the work. Finally, section 5 concludes by reflecting upon the work and pointing out suggestions for further research.

2. Theoretical Framework

The study to be described and discussed can be grounded in the contextualized constructionism (Valente, 2003; Valente, 2005), a concept that has been used to support various projects developed in Brazil, such as teacher training, factory worker training, adult ICT literacy, and the One Laptop per Student project (Valente & Blikstein, 2018).

The constructionism proposed by Seymour Papert highlights that learning is more effective when it involves the active creation of tangible products – "Learning is particularly effective when it is embedded in an activity the learner experiences as constructing a meaningful product (for example, a work of art, a functioning machine, a research report, or a computer program)." (Papert, 1986, p. abstract). This idea, widely applied in maker spaces such as Fab Labs and makerspaces, provides opportunities for interdisciplinary integration and learning based on hands-on experiences.

The contextualized aspect is closely related to Paulo Freire's ideas. If the products that students create are connected to their interests and the context in which they live, the likelihood of them understanding the content and engaging in educational activities increases (Freire, 1975). In addition to these ideas, Freire also placed considerable emphasis on generative themes, projects relevant to the community, personal relevance, connection with broader social issues, and sensitivity to local culture (including awareness of the cost of technology) (Freire, 1980).

We live in a society immersed in technologies and digital culture, where rapid changes influence the behavior and expectations of new generations. In the educational field, this scenario reinforces the idea that "Traditional methods, focused on content transmission, often prove inadequate for engaging students who prefer to learn in a practical, interactive, and collaborative manner" (Moura, 2019, p. 248).

Maker spaces and Fab Labs are digital fabrication laboratories equipped with advanced tools such as 3D printers, laser cutters, and CNC milling machines. These spaces enable the creation of various objects and encourage knowledge sharing, fostering creativity, learning, and innovation through collaborative processes. As such, they serve as ideal environments for the development and application of Maker Education, in which "Making can motivate and support learners' purposeful activity, position STEM practices as a powerful cultural tool for engaging in interest-driven activity, and leverage cultural resources and assets with a goal of deepening engagement and learning." (Bevan, 2017, p. 22). Several researchers have suggested that making, when associated with active learning methodologies such as constructionism, can create conditions for students to become creative, critical thinkers, problem solvers, and effective collaborators (Blikstein, 2013; Martinez & Stager, 2013; Halverson & Kimberly, 2014; Bevan, 2017; Yang et al., 2025).

The maker movement established its roots in out-of-school environments, such as museums, science festivals, extracurricular programs, and libraries. The interest in implementing Maker Education in K-12 education began in the early 2010s, particularly in 2013, with the publication of two seminal texts: Dale Dougherty's article *"The Maker Mindset"* (2013) and the textbook *"Invent to Learn"* (Martinez & Stager, 2013). The incorporation of Maker Education into the classroom, according to Bevan (2017), has introduced significant challenges. First, teachers need to navigate logistical and curricular implementation issues. Vossoughi and Bevan (2014) highlight the need for more explicit and detailed analyses of pedagogy in maker spaces. Teachers must understand that centering activities on the student and the production process is essential for the development of constructionism. However, there is a risk that these activities become overly product-focused, dedicating insufficient attention to curricular content (Bevan, 2017).

Maker activities, beyond the final product created by students, should also provide opportunities for disciplinary content to be explored. In this sense, the curriculum should be considered in terms of social interaction with people, materials, and technologies within these spaces. The curriculum activity should not be predetermined and imposed, but rather based on the teacher's pedagogical intent, which is reconstructed through the actions of both students and teachers (Blikstein, Valente & Moura, 2020).

The second challenge is related to preparing teachers to adopt maker practices as a pedagogical approach. Quintana-Ordorika, Garay-Ruiz, and Portillo-Berasaluce (2024) highlight the need for teachers to develop a maker mindset, which involves approaching learning through creation in a playful, collaborative, and experiential manner. To cultivate this mindset, teachers must understand the importance, meaning, and relevance of making things and act based on this understanding. To achieve this, they should be given "the opportunity to gain first-hand experience, possibly in real maker learning environments such as makerspaces, in order to achieve a positive change in their mindset" (Quintana-Ordorika, Garay-Ruiz & Portillo-Berasaluce, 2024, p. 3). Professional development in Maker Education for teachers includes working on teaching and learning strategies, practicing what they preach, and being exposed to technological equipment – not only machines but also the production process itself. In this sense, teachers should receive training on technological tools and pedagogical procedures to be able to design teaching and learning processes aligned with the principles of Maker Education.

The third challenge concerns how to implement these ideas in the classroom. In general, maker activities are organized as projects that learners develop, either using or not using digital fabrication technologies (Vossoughi & Bevan, 2014). Project-based learning (PBL) is considered an instructional method that integrates theory and practice. The hands-on approach creates conditions for learners to be active, giving them the opportunity to develop skills in problem-solving strategies, emotional competencies, and, consequently, to attribute meaning to the concepts being explored in their projects (Zhou, 2023; Biazus & Mahtari, 2022; Almulla, 2020).

In developing projects in the classroom, the pedagogical intent comes from the teacher, while the project itself belongs to the student. The teacher is responsible for proposing the theme to be addressed according to the pedagogical plan, maintaining the learning objectives, keeping students engaged in their goals, and designing assessment strategies for learning (Roessingh & Chambers, 2011). Additionally, the teacher can create educational materials based on maker culture as a viable pathway for transitioning from traditional teaching to maker education. These materials, according to Moura (2019), allow educators to integrate technological tools and collaborative practices into the curriculum while building confidence and familiarity with this new pedagogical perspective.

Students, based on the theme proposed by the teacher, should define their project, preferably considering aspects related to their interests, as well as ensuring its practical and social relevance (Sharipboevna, 2023). Regarding relevance, Freire (1975; 1980) proposed a close relationship between education and social concerns. Through praxis related to the issues of their reality, students gain self-awareness and become active participants in social development rather than subjects of dominant discourses. The goal is for students to be less alienated, capable of facing real challenges, and engaged in genuine critical inquiry and the transformation of reality.

3. Methodology

This work is part of a doctoral research developed as a field study (Gil, 2008), carried out in a public school in the city of São Paulo, Brazil (Moura, 2019). The first author acted as a teacher – invited by the mathematics teacher of the class – to implement a maker-focused teaching activity for a sixth-grade elementary school class of about 30 students, each approximately 12 years old. The school in question does not employ a traditional teaching strategy. Based on the "escola da ponte" model from Portugal, this school operates through project-based-learning.

In addition to the school, the research site included a Fab Lab from the Fab Lab Livre SP program. Both the school and the Fab Lab Livre SP are located within one of the Unified Educational Centers (*Centro Educacional Unificado-CEU*), which are public facilities aimed at education, created by the Municipal Department of Education of São Paulo, and situated in the city's peripheral areas.

The researcher was on-site to develop the activities on 26 occasions over roughly eight months of work: six visits to the classroom and twenty to the Fab Lab Livre SP. In these spaces, the researcher was able to collect and record information about project development, including the planning of the projects in the classroom and the use of digital fabrication machinery at the Fab Lab Livre SP. The researcher also maintained a working relationship with four classroom teachers, holding periodic meetings and participating in discussions about the projects. Altogether, 34 individuals took part in this research.

For data collection, the following resources were used: the researcher's field notes; video recordings and photographs produced in the field; and analyses of both physical and digital materials created by the research participants. These varied types of information allowed for data triangulation, enabling a more accurate understanding of the project's development process.

Finally, guided by the ethical principles of Resolution No. 4871, of October 22, 2001, and by the Code of Ethics of the University of São Paulo, this study conducted its recruitment process through a formal, individual invitation. A Free and Informed Consent Form (TCLE) was used – signed individually, and in the case of minors, signed by their legal guardians.

4. From Teacher Training to the Creation of a Maker Educational Activity

The introduction of the maker movement in the city of São Paulo began with the establishment of the FabLab Livre SP network, comprising 12 spaces, each of which is public and accessible to the entire population of the city. One of the objectives was for these spaces to be used by the community for the development of maker activities, including by educators, enabling teachers and students from public schools to have direct contact with maker-based learning experiences. In one of the training programs promoted by the municipal government, teachers explored the tools and methodologies available in the FabLab that was set up in the same shared space as the school where they worked.

Despite the invitation to develop projects in the FabLab, the teachers were only able to conceive the idea of using the space as technical support for the production of educational materials, still feeling uncertain about digital fabrication technologies (such as laser cutters and 3D printers) as pedagogical tools. Moura (2019) emphasizes that appropriating maker spaces as educational environments requires the integration of technical knowledge with teachers' pedagogical expertise. This integration allows digital technologies to be aligned with educational objectives, fostering student agency in the learning process.

However, for this transformation to occur, it is necessary to overcome the initial tendency to limit the FabLab's use to traditional pedagogical activities, such as the creation of teaching materials, and move toward proposals that encourage greater student autonomy and creativity. It became evident that, upon entering this space, teachers initially sought a comfort zone, a concept discussed by Borba and Penteado (2010), avoiding what the authors call the risk zone – an environment of unpredictability, where pedagogical practices require constant evaluation and adaptation.

4.1 The Teacher's Pedagogical Intentionality and Curriculum Related Activity

The aim of this section is to answer the first research question regarding teachers' pedagogical intentionality by proposing an engaging activity relating to the curriculum objectives.

The FabLab, although initially limited to a support function, can be seen as a gateway to more meaningful pedagogical practices. During the training, two of the teachers, both mathematics instructors, proposed an activity involving the construction of an educational game they had invented. The proposal emerged as a challenge to enhance the game they were already using in the classroom, which had previously been implemented with traditional materials and without technological adaptations. The game, inspired by the format of a soccer championship – a Brazilian passion – aimed to develop concepts of probability, statistics, and fractions through a playful and interactive activity designed for sixth-grade students, around 11 years old.

The choice of soccer as the central theme reflects a pedagogical approach grounded in respect for the students' sociocultural context. Freire (1996, p. 30) emphasizes that teachers should "not only respect students' knowledge, socially constructed through community practice, but also [...] discuss with students the rationale behind some of this knowledge in relation to the teaching of curricular content." In this sense, soccer was strategically used as a bridge between students' daily lives and the abstract concepts of the school curriculum. Freire further questions "Why not establish a necessary 'intimacy' between the curricular knowledge essential to students and the social experience they have as individuals?" (Freire, 1996, p. 36).

Inspired by this idea, the two teachers developed an activity in which the class was divided into six groups, each representing a soccer team, either fictional or based on real clubs. The proposal simulated a championship, where teams would compete against each other in rounds organized according to a predefined schedule. The championship format required all teams to face each other twice, alternating between home and away matches. Since there were six teams, each team would necessarily play ten matches (or rounds), as they faced five opponents twice.

The teachers used the FabLab to create a stadium-shaped game board, produced with a laser cutter and a 3D printer, as well as six-sided dice printed in 3D with colored filaments. The dice had three blank faces and three faces with images of soccer balls (one, two, or three balls, representing goals). In the game, the home team would roll three dice, while the visiting team would roll two, reflecting soccer's "home advantage" factor. After each round, the results were recorded in tables containing data such as points, wins, draws, losses, goals scored, and goal difference, serving as the basis for subsequent mathematical exercises. Figure 1, on the left, shows the dice being produced; the center image displays the completed dice; and the right image shows the game board created by the teachers, being used by students during gameplay.

Figure 1: Sequence of photos showing the development of the activity proposed by the teachers. From left to right: dice being printed by the teachers, completed dice, and the game board created by the teachers during gameplay.

The dynamic created by the teachers included a planned interruption of the activity before the final round, allowing students to calculate the probabilities of the upcoming results, aiming to predict the chances of each team winning the championship based on the previously recorded plays. This moment was crucial for the application of the mathematical concepts involved. The students' analysis was transcribed into a mathematical function, indicating the probability of the three possible outcomes: home team victory, draw, or away team victory. After these analyses, the final rounds were played, allowing students to verify which predictions came true.

During the closing discussion, the teachers encouraged reflections on the topic and the activity. In response to one of the questions, a student shared with the class that the construction of a stadium for the 2014 World Cup, near his home, had caused changes in the community's dynamics, including rising rental prices, the closure of small businesses, and increased traffic congestion. As a consequence, his family had to move to another part of the city, escaping this new reality while also benefiting from the appreciation of their property. However, this relocation was not without loss, as they had to leave behind the historical and emotional connections they had built in their former home.

This testimony sparked a broad reflection among the teachers and the class on the social and economic impacts of large-scale urban infrastructure projects on local communities. The student's observation about the increasing cost of living highlighted issues related to the forced displacement of residents and the transformation of social dynamics in affected neighborhoods. Motivated by this discussion, the teachers decided to expand the activity, incorporating the previously explored mathematical concepts into a broader analysis of sociocultural realities, fostering a critical and contextualized debate. As Freire (1996, p. 29) states, "there is no teaching without research and no research without teaching," emphasizing that the educational process must originate from students' concrete experiences and promote a critical analysis of these realities.

Although the activity was developed within a maker context, the game remained within a traditional educational structure, with control over the equipment centralized in the hands of the teachers and limited to their leadership role (Blikstein, 2008; Moura, 2019). Despite its effectiveness in applying mathematical concepts and initially engaging students, the dynamic was not designed to fully leverage the potential of technology in developing critical and creative skills. Moura (2019) reinforces that for maker education to transcend the merely instrumental use of technologies, it is essential for students to take an active role in the construction and experimentation processes, recognizing them as creative agents of their own learning.

4.2 From Student Interest to the Development of a Maker Educational Activity

The second research question is related to how teachers can enable a learning situation in which the students can be autonomous and active, while ensuring connections to their real-life contexts? As the two mathematics teachers became more confident in working with digital fabrication equipment and already introduced to the maker culture approach, they decided, based on the student's testimony and their peers' interest in the topic, to introduce a new challenge, allowing students to choose what they wanted to explore about the subject. The teachers recognized that students bring with them a unique repertoire of experiences, which can – and should – serve as the starting point for any teaching process, ensuring that learning is relevant and meaningful (Freire, 1975). By doing so, the teachers relinquished control over the activity, enabling students to take on a protagonist role and bringing their approach closer to the pedagogical practices advocated in Maker Education (Moura, 2019).

Building on the student's testimony, the teachers asked the groups what aspects of the topic would be interesting to explore. They considered both the students' interests and the possibility of integrating the school curriculum into these new proposals. Mediated by students' life experiences and recognizing the knowledge embedded in their realities, teachers and students engaged in dialogue and decided that each group would create its own soccer club. The groups had to think about various aspects of this creation, including the team's crest, uniform, colors, mascot, and overall visual identity, as well as the challenge of designing and prototyping their own stadium. For the stadium, students needed to consider aspects such as size and capacity, while proposing sustainable and creative solutions for its construction, maintenance, and use.

The teachers noticed the students' enthusiasm for constructing the stadium and decided to propose that they choose a real location within Brazilian territory. The goal was to integrate geography into the project, fostering a multidisciplinary approach.

The suggestion was well received by the students, who took the initiative to invite their school's geography teacher to assist them in selecting the location and providing a justification. The geography teacher seized this opportunity to work on curricular concepts already planned for that stage of learning, such as urban planning, geographical location, accessibility, environmental impact, and the potential benefits or challenges that such a construction would bring to a local community.

As the project evolved, other teachers joined in. The Portuguese language teacher helped students draft a club foundation document, detailing the justification for the emblem and mascot creation while documenting the stadium construction process and the references that inspired it. This activity enriched students' development of writing skills, communication, and presentation abilities. Meanwhile, in the stadium construction phase, the art teacher focused on developing students' artistic skills, encouraging experimentation with materials, aesthetic, functional planning and visual analysis. Additionally, the teacher facilitated reflections on the cultural and historical significance of soccer, analyzing students' choices of mascots and symbols, stimulating creativity and critical thinking while aligning the project with the arts curriculum.

Each group was encouraged to plan, design, and create their materials using the tools available in the Fab Lab Livre SP, applying design, engineering, and sustainability concepts in a practical way. As illustrated in Figure 2, on the left, a computer screen displays the stadium plan; in the center, the arrangement of the stands and seating is shown; and on the right, one of the stadiums produced by a student group.

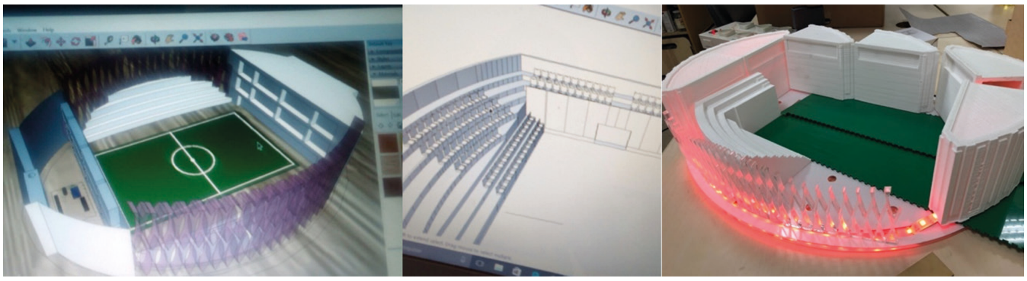

Figure 2: Sequence of photos showing the development of the students' activity. From left to right: stadium plan, stands and seating arrangement, and a stadium produced by one of the student groups.

In addition to the physical prototype, the groups also justified their choices based on technical and social criteria that they established themselves. The students investigated issues such as the economic feasibility of stadium construction, the benefits for tourism and local commerce, and, on the other hand, the potential impacts on traffic and the environment. During this process, they discovered that many multinational companies had their brands associated with sports teams, most of them linked to the English-speaking world. As a result, the English teacher was invited to join the project. With the teacher's support, students decided to present their clubs to "multinational companies," acting as potential investors. Each group prepared a pitch in English, defending the viability and merits of their projects. Additionally, the teacher guided them in pronunciation, fluency, and confidence in speaking, integrating the curriculum with listening comprehension, oral production, vocabulary expansion, and communicative autonomy.

The stadium production, combined with reflections on social and economic issues, allowed students to develop technical, creative, and critical skills in an integrated manner, fostering interdisciplinary learning connected to real-world contexts. The activity also reinforced the integration of maker education with STEM, incorporating elements of arts and other disciplines, such as geography, aligning with the concept of STEM-amplified or STEM-rich, as described by Bevan (2017), promoting the convergence of curricular subjects.

Knowledge construction in this educational environment became a dynamic and interactive process, involving idea exchange, experiences, and perspectives among participants. In collaborative contexts, students became the protagonists of their learning, sharing their experiences and knowledge to enrich collective understanding. This approach allowed learning to transcend individual knowledge acquisition, valuing interdependence among participants and recognizing the transformative role of social interactions in intellectual development (Freire, 1975; 1996).

5. Conclusion

The integration of maker education into the classroom presents significant challenges that must be addressed, as highlighted by various authors (Bevan, 2017; Blikstein, Valente & Moura, 2020; Soster, 2020; Moura, 2019; Quintana-Ordorika, Garay-Ruiz & Portillo-Berasaluce, 2024). Maker education is still not fully incorporated into the classroom, does not yet fully explore disciplinary curricular concepts, and teacher training in this area still needs to be improved and expanded. This study was conducted with the goal of understanding how these challenges can be overcome.

It began with the training of two mathematics teachers, whose initial intention was to learn how to use the maker space to develop support materials for a game they had created to teach statistics. The game was produced using traditional materials as well as tools from the maker space, allowing teachers to gain a partial understanding of the available resources and their potential applications in education.

The use of the game enabled the activity to be expanded, incorporating student interest and connections to real-world social issues, as proposed by Freire (1975; 1996). The activity allowed students to take an active role in the development of the project, creating their own soccer teams and stadiums. This experience illustrates the transformative potential of a pedagogical approach that values active knowledge construction, interdisciplinarity, and the connection with themes relevant to students' realities.

The use of maker methodology with digital fabrication machines in spaces such as Fab Labs enhanced the creation of elements for the soccer teams, providing a rich environment full of possibilities for the application of interdisciplinary concepts and the development of tangible products, as proposed in Papert's constructionism (1986). This experience not only allowed for the development of physical products but also fostered the exploration of curricular concepts, technical skills, creativity, and critical thinking. Additionally, it promoted debates on complex issues such as sustainability, urban planning, economics, and social impact.

Although the field study achieved its objectives, several limitations emerged that can be considered shortcomings. First, the teachers had to divide their time between covering disciplinary content and facilitating maker activities, which were unfamiliar to them. Second, the teachers were still in the process of learning about maker practices and depended on the researcher for guidance in using the tools and constructing the stadium. Third, the Fab Lab Livre SP was located at a distance from the classroom, requiring additional time for participants to move between the two spaces. Finally, the school's existing pedagogical approach was already aligned with maker-based learning, which supported the implementation of the project. In contrast, introducing such a proposal in a more traditional school setting would likely pose significant challenges.

As was mentioned, the project incorporated STEM-rich disciplines, however it has the potential to integrate other subjects, such as history, by discussing the impact of major sporting events in different historical contexts. It could also address themes from the Sustainable Development Goals (SDGs), such as environmental concerns, peace in sports environments, and social inclusion. The key aspect is that maker activities should enhance students' ability to create tangible products, allowing them to become aware of and understand the curricular concepts embedded in their constructions (Blikstein, Valente, & Moura, 2020). For this to happen, teachers must be attentive to the potential for developing activities that align their pedagogical intentions with students' interests and real-life contexts. This requires flexibility in controlling the educational process and encouraging collaboration among teachers from different disciplines, making interdisciplinary projects possible. Such an approach fosters an education in which students become protagonists of their own learning.

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