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MODULAR SCHOOL GARDEN: A PROPOSAL FOR DEVELOPING GARDENS IN SCHOOL ENVIRONMENTS WITH POTENTIAL FOR REPLICATION IN OTHER SPACES

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ABSTRACT
This exploratory study adopted an action-research methodology to assess the feasibility of implementing modular school gardens in Ribeirão Pires, SP, highlighting them as an innovative educational tool to promote healthy eating and sustainability. Using the PDCA cycle, the project involved the active participation of students, teachers, and the local community, providing qualitative insights into the challenges faced and the benefits obtained. Feedback from thirteen students who actively participated in the project was collected and analyzed. These students reported an increase in knowledge about sustainable practices and cultivation techniques. The results indicate that modular gardens facilitate practical knowledge about food production and also demonstrate potential for replication in other educational contexts. The standardization of cultivation procedures, one of the pillars of the project, proved promising, indicating the possibility of expanding the model as part of public policies aimed at environmental and nutritional education. This study suggests that modular school gardens can serve as an effective resource for promoting sustainable self-consumption practices, emphasizing the importance of integrating them as a pedagogical strategy in educational settings.

Keywords: School Garden. Modular Garden Bed. Self-Consumption. Collaborative Network.

HORTA ESCOLAR MODULAR: PROPOSTA DE DESENVOLVIMENTO DE HORTA EM AMBIENTES ESCOLARES COM POTENCIAL PARA REPRODUÇÃO EM OUTROS ESPAÇOS

RESUMO
Este estudo exploratório utilizou a metodologia de pesquisa-ação para avaliar a viabilidade de implementação de hortas escolares modulares em Ribeirão Pires, SP, destacando-as como uma ferramenta educativa inovadora sobre alimentação saudável e sustentabilidade. Utilizando o ciclo PDCA—planejamento, execução, verificação e ajuste—, o projeto envolveu a participação ativa de alunos, professores e a comunidade local, o que proporcionou insights qualitativos sobre os desafios enfrentados e os benefícios obtidos. Os resultados indicam que as hortas modulares não apenas facilitam o conhecimento prático sobre a produção de alimentos, mas também demonstram potencial para replicação em outros

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contextos educacionais. A padronização dos procedimentos de cultivo, uma das chaves do projeto, mostrou-se promissora, indicando a possibilidade de expansão do modelo como parte de políticas públicas voltadas para a educação ambiental e nutricional. Este estudo sugere que as hortas escolares modulares podem servir como um recurso eficaz para promover práticas sustentáveis e o autoconsumo, enfatizando a importância de integrá-las como estratégia pedagógica em ambientes educacionais.

Palavras-chave: Horta Escolar. Canteiro Modular. Autoconsumo. Rede Colaborativa.

HUERTO ESCOLAR MODULAR: UNA PROPUESTA PARA EL DESARROLLO DE HUERTOS EN AMBIENTES ESCOLARES CON POTENCIAL DE RÉPLICA EN OTROS ESPACIOS

RESUMEN
Este estudio exploratorio adoptó una metodología de investigación-acción para evaluar la viabilidad de implementar huertos escolares modulares en Ribeirão Pires, SP, destacándolos como una herramienta educativa innovadora para promover la alimentación saludable y la sostenibilidad. Utilizando el ciclo PDCA, el proyecto contó con la participación activa de estudiantes, docentes y la comunidad local, lo que proporcionó información cualitativa sobre los desafíos enfrentados y los beneficios obtenidos. Se recogieron y analizaron las opiniones de trece estudiantes que participaron activamente en el proyecto. Estos estudiantes reportaron un aumento en su conocimiento sobre prácticas sostenibles y técnicas de cultivo. Los resultados indican que los huertos modulares facilitan el conocimiento práctico sobre la producción de alimentos y también demuestran potencial para replicarse en otros contextos educativos. La estandarización de los procedimientos de cultivo, uno de los pilares del proyecto, resultó prometedora, lo que indica la posibilidad de expandir el modelo como parte de las políticas públicas dirigidas a la educación ambiental y nutricional. Este estudio sugiere que los huertos escolares modulares pueden servir como un recurso eficaz para promover prácticas sostenibles de autoconsumo, enfatizando la importancia de integrarlos como estrategia pedagógica en los entornos educativos.

Palabras clave: Huerto Escolar. Jardinera Modular. Autoconsumo. Red Colaborativa.

1 INTRODUCTION

Food is a fundamental human right as provided for in the Brazilian Constitution. However, in recent years, ensuring healthy, quality, and adequate food for the Brazilian population has faced significant challenges. According to the Federal University of Ouro Preto, the COVID-19 pandemic and the dismantling of public food security policies have worsened the situation, leading to an increase in food insecurity rates in the country, including the reintegration of Brazil into the UN's Hunger Map (UFOP, 2024).

In the school context, the production of gardens has become an increasingly relevant practice as it brings students closer to nature and the food they consume (Coelho et al., 2016). Creating gardens in schools emerges as a promising strategy to provide access to nutritional education, contribute inputs for school meals, promote social engagement, a sense of belonging (Langhi, 2022), and provide a hands-on experience in food cultivation.

Students benefit not only in terms of physical health but also in managing stress and anxiety, common challenges among students (Banu et al., 2023). Sports and other collective activities improve social skills and teamwork while increasing self-confidence, contributing to better academic performance (Dai & Xu, 2022). Overall, physical activity improves student well-being, enhancing mood, self-discipline, and the ability to handle academic pressure (Bondar et al., 2023).

According to (Mann et al. 2022), outdoor activities and nature-specific ones, such as those related to school gardens, have the potential to promote children's and adolescents' learning and development outside the classroom. These activities offer a practical and engaging learning experience that complements formal education and stimulates the development of important skills such as observation, critical thinking, and teamwork.

This study proposes a modular school garden model that can be easily replicated at home, in small public or private spaces. The modular school garden can contribute to strengthening the sustainability goals proposed by the UN by promoting strategies that help organize domestic gardens, considering both self-consumption and knowledge of healthy foods, as well as promoting food security.

Data analysis revealed that the adoption of modular school gardens can be enhanced by technological solutions such as sensors and intelligent automation, enabling gains in sustainability, replicability, and student engagement (de Lima, L.A. et al., 2021); (Liliam Sayuri Sakamoto et al., 2021); (de Lima, L.A. et al., 2023). These results are consistent with studies that employ artificial intelligence technologies for decision-making in complex educational contexts (Davis Alves et al., 2018); (C. Z. Kirilo et al., 2018); (Luiz A. de Lima et al., 2018).

The use of microcontrollers such as Arduino in logic irrigation systems reinforces the role of technology in educational agricultural management (Jonatas Santos de Souza et al., 2021); (De Lima, L.A. et al., 2021). Thus, the garden becomes not only a space for cultivation, but also for scientific experimentation and the development of student autonomy (Vendrametto, O. et al., 2022).

Through the action research methodology, the PDCA cycle was applied collaboratively with students and teachers, proving effective in standardizing cultivation processes and controlling environmental factors (De Lima L.A. et al., 2019); (Nääs et al., 2020); (de Lima, L.A. et al., 2021).

The interface between applied logic, environmental education, and technology was highlighted, especially when addressing aspects of measurement and control (de Lima, L.A. et al., 2023). The feedback collected also indicates an increase in students' critical thinking regarding sustainable consumption and food security (Vendrametto, O. et al., 2022); (de Lima, L.A. et al., 2021).

2 LITERATURE REVIEW

2.1 THE SCHOOL GARDEN AND ITS IMPORTANCE

Creating school gardens can be an important resource for providing students with concepts of production and self-consumption of healthy and fresh foods, directly reaching the population base that can replicate what they learn at home and in the community, in line with the Organic Law of Food and Nutrition Security (LOSAN, 2006) and the National Environmental Education Policy (PNEA, 1999).

The production and promotion of healthy eating and the fight against hunger are global challenges that have drawn the attention of different sectors of society. In the school context, the production of gardens has become an increasingly relevant practice as it brings students closer to nature and the food they consume (Coelho et al., 2016).

According to Cancelier et al. (2020), the school garden serves as a space for adopting healthy habits, not only for students but also for families. Emphasizing the importance of promoting initiatives that value the local food production system, recognizing not only the cultivated foods but also the traditional knowledge and practices focused on this production process, highlights the relevance and implementation of gardens in schools as vectors for multiplying good dietary and social practices (Magalhães & Porte, 2019).

Regarding food, the World Health Organization recommends that children and adolescents consume a diet rich in fruits, vegetables, legumes, whole grains, lean proteins, and low-fat dairy products (WHO, 2019). The Dietary Guidelines for Americans (2020-2025), published by the United States Department of Agriculture, also recommend a balanced diet based on food groups that provide the necessary nutrients for good health (USDA, 2020). Based on the information contained in this guide, Table 1 was constructed, showing the daily nutrient needs according to age group for female and male children and adolescents aged 1 to 18 years.

Table 1

Daily Nutrient Needs for Children and Adolescents up to 18 Years of Age - DRIs 2021.

Age Group	Gender	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)	Vitamin A (mcg RE)	Vitamin C (mg)	Vitamin D (mcg)	Vitamin E (mg alpha-TE)	Calcium (mg)	Iron (mg)	Zinc (mg)
1 to 3 years	Both	1000 to 1400	13	30 to 40	130 to 170	300 to 400	15	15	6 to 7	700	7	3
4 to 8 years	Both	1200 to 2000	19	35 to 50	130 to 220	400 to 650	25	15	9 to 11	1000	10	5
9 to 13 years	Male	1800 to 2600	34	40 to 70	220 to 340	600 to 900	45	15	11 to 15	1300	8	8
9 to 13 years	Female	1600 to 2400	34	35 to 65	220 to 330	600 to 700	45	15	11 to 15	1300	8	8
14 to 18 years	Male	2200 to 3200	52	45 to 100	270 to 430	900 to 1200	75	15	15 to 19	1300	11	11
14 to 18 years	Female	1800 to 2400	46	35 to 70	230 to 360	700 to 900	65	15	11 to 15	1300	15	9

Source: Adapted from Institute of Medicine (IOM) Dietary Reference Intakes (DRIs) (2021).

Supported by data available in the Brazilian Food Composition Table - TBCA (TBCA, 2023) and the daily nutrient needs (DRIs) relationship, it is possible to map vegetable production, identifying the contribution to nutrition and the impact on adolescent health, who can have portions of nutrients supplied by a home (modular) garden.

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2.2 MODULAR SCHOOL GARDEN

The concept of modularity proposed by Baldwin and Clark (2000) can be applied to the garden context to optimize production and resource management. Modules can be combined in different ways to create varied products, allowing greater flexibility in production, facilitating product customization, and improving efficiency and scalability of the production process.

For organizing and maintaining the proposed module, it was necessary to organize a collaborative network (Manzini, 2008) formed by teachers, students, staff, parents, among other actors, called stakeholders (Freeman, 2006). The collaborative network is an alliance of these individuals who work together to achieve common goals by sharing information, resources, and skills (Boschma, 2005).

2.2.1 Garden Module

The garden module proposed in this study is an innovative solution to overcome difficulties related to physical space limitations and uncertainty about what and how to plant. The garden module concept is adaptable and customizable, allowing adjustments regarding size, cultivated products, and available time for management, among other aspects. The idea is to organize planting so that it is possible to have weekly harvests, promoting planned and efficient cultivation.

According to Coelho and Bógus (2016), the implementation of school gardens is associated with increased consumption of fruits and vegetables and improved ability to identify them among children and young people. These educational initiatives promote an education that transcends the mere transmission of scientific information about nutrition, contributing to the construction of a meaningful relationship with food production and the recovery of healthy eating practices. Pourias et al. (2017) and Kortright and Wakefield (2020) also emphasize the role of school gardens in environmental education and promoting healthy eating habits.

For the development of the garden module, the work of the Brazilian Agricultural Research Corporation (EMBRAPA, 2012) was used as a reference, which offers guidelines on implementing modular gardens and cultivation and management techniques. Additionally, international studies, such as those by Calvet-Mir et al. (2016) and Specht et al. (2019), discuss the benefits of urban gardens in promoting sustainability and improving quality of life in cities.

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The module in this context has an academic rather than commercial objective. It is intended for self-consumption and should be understood as adopting standards to regulate the proportions of various parts of a vegetable and legume bed relative to the area to be cultivated, the products, and their nutritional components. The number of people to be served and their preferences are taken into account. The research that originated this article adopted a family of four people for study purposes.

Regarding the products to be cultivated, there are flexible options according to the classification of vegetables, as shown in Table 2, with choices that meet the user's desires or needs and their families. Components may be associated with seasonings, plants with medicinal properties, or as complements to menus.

Table 2

Classification of Vegetables

Category	Examples of Vegetables	Planting Season
Leaves	Lettuce, Spinach, Arugula	Spring, Fall
Roots	Carrot, Beet, Radish	Spring, Summer, Fall
Tubers	Potato, Cassava	Spring, Summer
Legumes	Tomato, Bell Pepper, Zucchini	Spring, Summer
Onions & Bulbs	Onion, Garlic, Leek	Fall, Winter
Crucifers	Broccoli, Cauliflower, Cabbage	Fall, Winter
Leaves	Lettuce, Spinach, Arugula	Spring, Fall

Source: Adapted from EMBRAPA (2023).

The products cultivated in a modular garden should complement, not replace, regular meals and their respective nutrients. It is an excellent source for promoting healthy eating but not a complete nutrient source.

2.2.2 Module Dimensioning

The dimensioning of the garden module is essential to meet the dietary needs of a family. For this study, we considered a family of four people, with a recommended intake of fruits, vegetables, and legumes of approximately 16 kg per day, based on the recommendation of 400g per person (DRIs, 2021).

To calculate the garden's dimensions, it is important to consider the production of vegetables per square meter, which varies according to various factors such as the type of vegetable, as shown in Table 3. Climatic conditions and management techniques will help plan the number of beds needed to meet the family's nutritional needs.

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Table 3

Spacing and Number of Plants per Square Meter for Vegetables

Vegetable	Spacing (cm)	Number of Plants per m²	Average Production per Plant (grams)	Vegetable	Spacing (cm)
Lettuce	25 x 25	16	200 g cycle of 40-60 days	Lettuce	25 x 25
Kale	70 x 70	2	Perennial production	Kale	70 x 70
Arugula	20 x 20	25	150 g cycle of 35-60 days	Arugula	20 x 20
Chives	10 x 10	100	Perennial production	Chives	10 x 10

Source: Adapted from EMBRAPA (2023).

Table 3 presents an estimate of the number of plants per m², as there is no standardized calculation to determine the exact amount of vegetables per m², depending on various factors such as vegetable type, plant size, and cultivation method. Techniques like vertical or hydroponic cultivation can allow a greater number of plants per square meter and different sizes.

The garden's planning should meet the family's daily vegetable consumption needs. Matos (2002) suggests that each family member should have a garden area of about 10 square meters for cultivation per year. A modular production with daily, weekly, or biweekly harvests should be planned.

To estimate the cost of this modular garden, the main inputs for vegetable cultivation, such as seeds, fertilizers, irrigation, and depending on soil conditions, may require the purchase of vegetable soil, compost, lime, and other inputs before planting. A homemade solution for fertilization can be families using composters for some of the organic waste and having condensed material and leachate as fertilizers and eventual pest control.

2.2.3 Potential for Replication of Modular School Gardens in the Region

The metropolitan region of ABCDM consists of seven cities in the state of São Paulo: Santo André, São Bernardo do Campo, São Caetano do Sul, Diadema, Mauá, Ribeirão Pires, and Rio Grande da Serra. According to data from the 2020 School Census, this region has about 780 basic education schools, including municipal, state, and private schools. These schools serve a total of more than 380,000 students distributed across different educational stages, from early childhood education to high school (INEP, 2022).

The municipality of Ribeirão Pires was chosen for the implementation of the first modular school garden. With an estimated population of 125,000 inhabitants (IBGE, 2021) and according to data from the 2020 School Census, there are 85 schools in the city, including

31 state schools, 33 municipal schools, and 21 private schools (INEP, 2022). These schools serve a total of 14,654 students, distributed as shown in Table 4.

Table 4

Distribution of Schools in Ribeirão Pires

Type of Education	Number of Schools	Number of Students	Total Students (%)
State	31	5,277	36.03%
Municipal	33	7,592	51.84%
Private	21	1,785	12.14%
Total	85	14,654	100%

Source: School Census (INEP, 2020).

Integrating food cultivation into the school curriculum allows students to see practically how food is produced, from planting to harvesting, reinforcing the value of fresh, natural foods. School gardens serve as living laboratories for environmental education, allowing students to learn about sustainability and resource conservation in a practical way (Domene et al., 2023).

Schools play a vital role in shaping students' well-being beyond academics. The social aspects of garden-related activities promoted in schools can also foster teamwork skills and self-confidence, creating a more positive and comprehensive school experience. Holloway et al. (2023) highlight the importance of school environments in promoting students' health and well-being. In this context, school gardens emerge as vital spaces not only for nutritional education but also as areas of psychological and physical well-being.

2.4 PDCA AND STAKEHOLDERS

The PDCA cycle, which stands for Plan-Do-Check-Act, is recognized as a fundamental iterative methodology for continuous improvement, attributed to Shewhart and widely popularized by Deming (Sokovic, Pavletic, & Pipan, 2010; Johnson, 2002).

Applying the PDCA cycle in creating the modular garden was strategic, beginning with detailed planning, followed by assembly execution. During the project, progress was continuously monitored, and adjustments were made as necessary to promote continuous improvements, enhancing the garden project's efficiency and adaptability.

According to Friedman and Miles (2006), stakeholder theory and practice are essential for understanding the complex relationships and reciprocal influences between an organization and its various interest groups. For constructing the modular school garden framework, the primary stakeholders considered were students, teachers, staff, parents, and community sponsors.

3 METHODOLOGY

This study conducted exploratory research through action-research and survey methods. Action-research is particularly appropriate for this context as it allows participants—students, teachers, and the school community—not only to interact but also to influence and reflect on their practices and learning environment. This method is dynamic and adaptive, emphasizing change and knowledge generation from practice (Tripp, 2005).

The action-research methodology allowed a collaborative and practical approach to solving identified problems, where participants were actively involved in planning, executing, and evaluating garden activities, enabling real-time data collection and adaptation of strategies as needed (Kemmis, McTaggart, & Nixon, 2014).

The observational nature of the survey provided data collection on stakeholders' opinions through a questionnaire with open and closed questions and a Likert scale. Content analysis was used to analyze responses, involving a series of analytical procedures from material preparation to result interpretation (Bardin, 2011). These procedures include pre-analysis, material exploration, and results treatment, inference, and interpretation.

3.1 METHODOLOGICAL PROCEDURES

The study began with a second-year technical business administration class integrated with high school in the integrative project course at the beginning of 2022. The group of 20 students aged 16 to 17 attended weekly sessions on the importance of good nutrition, producing part of their own food, soil preparation, composting techniques, and proper tool use.

There were six weekly meetings where tutors, partners of LEBEM, a civil society organization located on the border of Ribeirão Pires and Mauá, explained permaculture concepts, organic vegetable production, and composting in detail to the students (LEBEM, 2022).

The space chosen for the module is at the back of the school. The 50-square-meter area was cleaned and prepared by a team of teachers and students. Seven symmetrical rectangular beds were built, ranging from 0.7 meters wide to 2.9 meters long, making rational use of the area. The space between the beds is 30 to 40 cm, considering the need for

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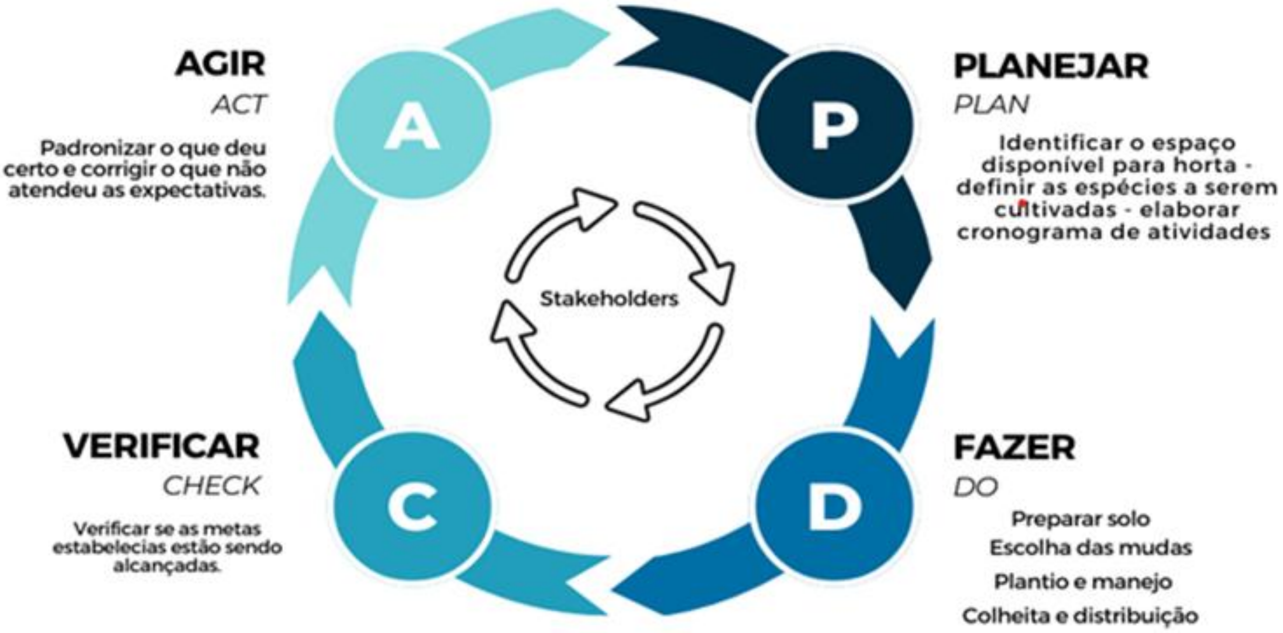
management during the production cycle. The chosen vegetables were short-cycle (40-60 days) between seedling planting and harvesting, including lettuce, kale, arugula, chives, cilantro, and parsley.

Figure 1 shows the operational framework created to implement the modular garden using the PDCA method and promote systematic cultivation. The illustrative model incorporates four fundamental stages—Plan, Do, Check, and Act—each designed to enhance the cultivation process's efficiency.

Figure 1

Process for Creating the Module



Source: The authors (2024).

Active stakeholder participation is essential to ensure the model's effectiveness and continuous improvement, enabling adaptive and dynamic management of the school garden. Team formation was a key component in the PDCA process applied to the modular garden context at every stage, from planning to harvest.

- Plan: In this phase, stakeholders are identified and involved in the planning process, which may include teachers, students, community members, urban agriculture experts, volunteers, and potential consumers of garden products. The participatory model ensures that planning considers a variety of needs, knowledge, and expectations, resulting in a more robust and inclusive plan.

- Do: During implementation, stakeholders are responsible for cultivating and managing the garden, contributing manual labor, technical knowledge, and resources. They help translate planning into concrete actions, ensuring execution aligns with what was planned.
- Check: Stakeholders collaborate in evaluating the garden's progress, collecting data, sharing feedback, and participating in meetings to discuss results. Diverse perspectives help ensure a comprehensive assessment of the module's performance in each process.
- Act: Based on collected feedback, stakeholders engage in decision-making to make adjustments and improvements, helping standardize successful processes and develop action plans to address identified gaps or problems.

Including stakeholders throughout the PDCA cycle fosters shared responsibility, ensures multiple perspectives are considered, and supports the project's long-term sustainability.

In 2023, a working group of 20 businesses administration technical students from the school was formed. These students were selected based on their active participation in the project throughout the school year. Of these, 13 students responded to a structured questionnaire that evaluated aspects such as the knowledge gained, the project's relevance in the school, and the application of learned techniques in other contexts.

To investigate students' perceptions of the modular garden project, a mixed-methods approach integrating quantitative and qualitative techniques was adopted. The data collection instrument consisted of a 20-question questionnaire, of which six were closed questions aimed at collecting demographic data and understanding the questionnaire by participants. Eight questions used a ten-point Likert scale to measure learning and project relevance perception (Likert, 1932), and six open-ended questions allowed students to express their experiences and suggest improvements.

Qualitative analysis of the responses was conducted through content analysis methodology, as described by Bardin (2011), allowing systematic categorization and identifying relevant themes. Quantitative analysis of the responses involved statistical calculation to identify patterns and relevant insights (Creswell, 2014; Patton, 2014).

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The data obtained were important for discerning the project's success points and aspects that could be improved for future implementations, as shown in Table 5—Feedback from the orking group.

Table 5

Feedback from the Working Group

Student	Learning (0-10)	Personal Development (0-10)	Food Awareness (0-10)	Market Impact (0-10)	School Relevance (0-10)	Project Experience	Knowledge Gained	Skills Developed	Suggested Improvements	Application Outside School
1	10	10	10	10	10	Unique and profound	Planting, harvesting, nutrition	Communication, emotional intelligence	Enhance food production	Personal routines
2	10	8	10	7	10	New knowledge	Planting, teamwork	Empathy, leadership	More equipment and investment	Job interview
3	10	8	10	10	9	Very educational	Healthy eating	Empathy, communication	Better explanation of activities	Community work, personal routines
4	10	8	8	9	9	Good experiences	Company/project creation	Leadership, critical thinking	Better teamwork	Graduation project, personal use
5	10	9	10	10	10	New and fun	Fertilization, vegetables	Teamwork, communication	More safety and funding	Home garden creation
6	10	10	10	10	10	Comprehensive	Healthy eating	Teamwork, environmental education	Better organization, volunteering	Home garden, community work
7	8	8	8	7	10	Enjoyed participating	Garden care and importance	Critical thinking, teamwork	More financial aid	Graduation project
8	10	10	10	10	10	Revealing	Importance of pesticide-free food	Leadership, focus	More school support, visits to the site	Home garden, community work
9	8	8	6	7	10	Innovative and social	Project development	Emotional intelligence, critical thinking	---	Community work, personal routines
10	6	6	7	8	5	Very important	Planting and garden care	Teamwork, environmental education	Better equipment, more plantations	Graduation project
11	9	8	9	9	8	Gratifying	Use of educational platforms	Communication, critical thinking	Organization, empathy, communication	Graduation project, home garden creation
12	8	9	10	10	10	Multifaceted learning	Project development, use of educational tools	Empathy, communication, proactivity	More organization	Graduation project, community work
13	10	10	10	10	10	Excellent	Cultivation techniques, healthy eating benefits	Empathy, communication, teamwork	Broad dissemination, involvement of all knowledge areas	Home garden creation

Source: The authors (2024).

Content analysis applied to the modular school garden project can be summarized in three main phases:

- Phase I – Pre-analysis: The goal was to directly select materials related to participants' project experiences, involving the selection of student responses collected through questionnaires, applying inclusion criteria to retain responses offering insights into knowledge gained, skills developed, and practical applications, and excluding those that were not pertinent or substantial.
- Phase II – Material Exploration: The focus of this stage was to analyze and code responses to identify the main themes and subthemes characterizing participants' experiences, allowing an understanding of the project's impact on students' perceptions and learnings.

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- Phase III – Results Treatment: This phase aimed to validate and interpret the collected data to formulate conclusions about the project's impact and effectiveness, involving information validation and representativeness analysis of themes concerning the total set of responses, as summarized in Table 6—Content Analysis Summary.

Table 6
Content Analysis Summary

Category	Details
Project Experience	Educational, Important, Fun, Comprehensive
Knowledge Gained	Planting, Healthy Eating, Cultivation Techniques
Skills Developed	Teamwork, Communication, Leadership
Suggested Improvements	More Equipment, More Safety, Better Organization
Application Outside School	Home Garden, Community Work

Source: The authors (2024).

When comparing the initial project goals with the results obtained from participants' responses, the importance of implementing the garden in the school unit is evident. The data also show how to direct future lines of investigation or additional project development exploring specific aspects such as suggested improvements and project application outside school.

Quantitative data collected during the study were analyzed to identify relevant patterns, focusing on participants' experiences and perceptions, as shown in Table 7—Likert Scale Analysis.

Table 7
Likert Scale Analysis

Category	Mean	Median	Standard Deviation
Learning	8.92	10	1.27
Personal Development	8.54	9	1.44
Food Awareness	9.00	10	1.41
Market Impact	8.92	10	1.27
School Relevance	9.23	10	1.42

Source: The authors (2024).

Quantitative analysis of the data also offers a detailed view of participants' feedback on the project, with high means and medians reaching the maximum scale value, indicating a very positive evaluation.

This methodological approach enabled identifying and solving practical problems related to implementing the garden in the school unit, along with feedback from 13 students who were part of the group that actively participated in immersions to implement the garden module in the school unit in Ribeirão Pires.

4 RESULTS AND DISCUSSION

4.1 MODULAR GARDEN IMPLEMENTATION

The modular garden project showed an increase in environmental knowledge and awareness among the participating students, with students adhering to good consumption and sustainable cultivation practices. The effectiveness of the modular garden as a pedagogical tool is corroborated by previous studies suggesting that integrating these actions in the school environment enhances active learning and promotes ecological awareness among young people (Oliveira & Borba, 2016).

This result aligns with experiential learning theory, which postulates that knowledge is best acquired through direct experience (Kolb, 1984). Thus, the success of the garden module reinforces the need for educational strategies that go beyond conventional teaching methods, encouraging direct interaction with the environment.

4.2 COMMUNITY IMPACT

The project not only brought benefits to participating students but also extended its benefits to the local community, with several teachers applying their lessons with garden support, and students reporting starting home gardens with their families.

The educational impact's extension to the local community suggests a growing appreciation for sustainable self-consumption practices. This phenomenon reflects Putnam's social capital theory (2000), emphasizing how community activities can strengthen social ties and promote collective well-being. Students and their families adopting home gardens indicate an increase in community social capital, demonstrating the potential of school gardens beyond the educational context.

4.3 PROJECT SUSTAINABILITY AND REPLICABILITY

The modular garden model was found to be replicable and adaptable in other schools and contexts, suggesting its feasibility as a sustainable educational strategy.

The replicability and sustainability of the modular garden project align with the principles of education for sustainable development proposed by UNESCO (2017). The project's adaptability to different educational contexts evidences its alignment with global sustainable education goals, seeking to incorporate ecological practices into the school curriculum in an integrated and adaptive manner.

4.4 EDUCATION AND AWARENESS

According to Costa et al. (2019) and Batista et al. (2017), school gardens offer a valuable interdisciplinary space where students develop skills in various areas, reinforcing school menus with fresh, pesticide-free food. This environment promotes a deeper connection between students and the food they consume, increasing awareness of sustainable practices and healthy eating.

Implementing the school garden module not only highlighted the importance of healthy eating but also introduced sustainability practices into the school routine. Events like the sustainable fair expanded the educational impact, involving students, families, and the community.

In this context, the 'Plan' phase of PDCA was essential for structuring educational activities that integrated sustainability concepts into the school's strategic project (PPG). During the 'Do' phase, the school effectively implemented these activities, periodically 'Checking' and 'Adjusting' them to better meet students' needs, increasing the educational impact. This continuous cycle allowed the project to adapt to school and community dynamics, demonstrating the PDCA's effectiveness in promoting sustainable educational practices.

4.5 CHALLENGES AND ADAPTATIONS

Adverse weather conditions negatively impacted planting but provided learnings about plants that best adapt to the local climate, such as kale, cilantro, and chives.

During the 'Do' phase, climatic challenges required revisions and adaptations to the initial planning. Evaluations ('Check') of cultivation conditions provided valuable insights for adjustments ('Act'), focusing on more climate-resistant crops. This process highlighted the importance of flexible and adaptive planning, essential for the resilience and sustainability of school garden projects.

4.6 REPLICATION AND EXPANSION

The project demonstrated that it is possible to replicate the modular garden in other schools and contexts, even with limited space, encouraging the involvement of various stakeholders. The replicability of the garden module was a strategic goal from the 'Plan' phase. The success of the 'Execution' and continuous adjustments based on regular 'Checks' allowed the formulation of an adaptable model that can be implemented in different educational contexts.

Stakeholder engagement in all PDCA phases strengthened understanding of project expansion, highlighting its feasibility and effectiveness in promoting nutritional and environmental education.

4.7 LONG-TERM IMPACT

As discussed by Oliveira and Borba (2016) and corroborated by Dantas et al. (2021), school gardens not only improve the quality of teaching and learning but also promote important values for the formation of conscious and responsible citizens.

Integrating the school garden into school meals as part of the 'Act' phase of PDCA reflects the project's success in creating a sustainable and educational model that transcends the school environment. 'Checking' the project's impact through participant feedback and result analyses allowed identifying long-term benefits, such as improved school meal quality and promoting healthy eating habits, aligning with the UN's sustainable development goals.

4.8 PERCEPTIONS OF SUSTAINABILITY PRACTICES

Of the 13 students who responded to the survey, 92% (12 students) reported a significant increase in their knowledge of sustainable practices after implementing the school garden. On a 0-10 evaluation scale, the average perception of sustainability's importance was 8.9, indicating a high level of awareness. Table 8 shows a summary of the survey results, and the feedback from the participating students was significantly positive, validating the proposal's importance.

Table 8

Survey Results Summary

Category	Quantitative Results	Qualitative Results	Discussion
Perceptions of Sustainability Practices	92% of students (12 of 13) reported a significant increase in knowledge of sustainable practices. Average perception of sustainability importance: 8.9.	"Seeing the plants grow made me understand what it means to consume responsibly." – Participating Student	Direct experience with agriculture changes perceptions of food and sustainability, promoting significant environmental awareness (Costa et al., 2019).

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Impact on Eating and Health Habits	85% of students (11 of 13) reported an increase in vegetable consumption and a reduction in processed food intake.	"I started a small garden in my backyard with my family, and we are eating much more vegetables now." – Participating Student	School gardens catalyze changes in eating patterns, encouraging not only a healthier diet but also replicating these practices at home (Dantas et al., 2021).
Receptivity and Recommendations for Improvements	N/A	Students suggested expanding the garden to include more vegetable varieties and integrating more practical activities related to cultivation.	Student feedback is crucial for the project's continuous evolution, aligning it with students' needs and interests. The importance of an iterative feedback and adjustment model is emphasized to maintain the relevance of pedagogical practices (Batista et al., 2017).

Source: The authors (2024).

These results are consistent with Dantas et al. (2021), who point out school gardens as catalysts for changes in eating patterns. Involving students in direct food cultivation can be a tool to improve healthy eating, demonstrating the potential of school gardens to impact not only the educational environment but also family practices.

5 CONCLUSION

The study on implementing the modular school garden stood out for the practical application of sustainable agriculture in a public school and the creation of a specific PDCA framework for the context of modular gardens. This operational model facilitated project systematization, allowing management that integrated continuous planning, execution, verification, and adjustment.

Using the PDCA cycle in the modular garden project context is an innovative approach that brings quality management principles to the realm of environmental and nutritional education. Integrating this operational model with active stakeholder participation, including students, teachers, and the community, highlighted the project's ability to adapt and expand, reinforcing the potential of modular school gardens as a dynamic and effective learning resource.

The conclusion of the first phase of the modular garden project in the Ribeirão Pires school unit revealed the need to promote food and environmental education among students, reinforcing the importance of consuming fresh food and reducing ultra-processed products.

For future studies, the focus will be on creating strategies to increase community participation and evaluating the garden's long-term impact on students' eating habits and environmental awareness. Some students have already implemented the model at home, demonstrating the project's effectiveness and relevance and indicating its potential impact beyond school walls.

The modular garden project for schools is progressing, and the next step is to expand to municipal schools. This advance will allow more students to learn about sustainable agriculture and apply this knowledge at home. The challenge is to maintain stakeholder engagement and find organic funding solutions for project continuity.

Implementing the project in municipal schools also aims to strengthen environmental and nutritional education in the community, creating a network of educational gardens that can serve as models for other institutions. This expansion is an opportunity to broaden the project's positive impact, engaging even more students and their families in sustainable and healthy practices.

Although the study evidenced positive results, certain inherent execution limitations require critical reflection. Limiting the sample to a single educational institution restricts the generalization of results, and the absence of a prolonged monitoring period prevents robust analysis of the sustainable and long-term effects of the interventions.

Examining the community's role, especially parents, in the educational effectiveness of school gardens would help better understand how community participation can enrich students' learning experiences. With the project's continuation and expansion to other schools, it is expected to broaden the scope and depth of positive impacts on education and the community in general.

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