

Article

An Evaluation of the Experimental Science Teaching Program for Primary Education from the Teachers' Perspective: An Educational Design Research Journey

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Abstract: The concerns about ensuring scientific literacy for all are underpinned by international recommendations from organizations such as the UN and the OECD for science education. They advocate for science education from a contextualized, sequential, systematic, and active perspective on the students' learning process, starting from the early years of schooling. It is based on these pedagogical principles that the research project the "Experimental Science Teaching Program" (PEEC) was founded. This article aims to disseminate an evaluation of the PEEC for primary education, which includes a science teaching curriculum proposal, teaching activities and resources (e.g., digital games), and assessment record instruments for learning. This program was developed using an Educational Design Research methodological approach based on iterative cycles, with the collaboration of a multidisciplinary team (e.g., teachers, researchers, and children). For a final evaluation of the PEEC components, we consulted the ten participating teachers through a questionnaire survey one year after the end of their official collaboration. The main results highlight the relevance and appropriateness of the proposals presented for the targeted age group and the assumptions and objectives of science education in terms of the curriculum, teaching resources, and digital assessment games. Teachers also mentioned continuing to use the PEEC resources after their participation in this study. These results underscore the need to expand and promote projects of this nature to contribute to more practical science education in Portugal and, consequently, to increase children's levels of scientific literacy.

Keywords: science teaching; educational design research; educational resources; primary education



Citation: Silva, P.C.; Rodrigues, A.V.; Vicente, P.N. An Evaluation of the Experimental Science Teaching Program for Primary Education from the Teachers' Perspective: An Educational Design Research Journey. *Educ. Sci.* **2024**, *14*, 782. <https://doi.org/10.3390/educsci14070782>

Academic Editors: José Benito Vázquez Dorrío, Araceli Queiruga-Dios, Manuel Filipe P. C. M. Costa and Miguel Ángel Queiruga Dios

Received: 5 June 2024
Revised: 8 July 2024
Accepted: 12 July 2024
Published: 17 July 2024



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1. Introduction

A scientifically literate society presupposes the making of informed, conscious, and well-founded decisions, aimed at ensuring environmental integrity, achieving economic viability, and attaining full democracy. Despite the lack of consensus on the definition and assessment of "scientific literacy", it is universally sought. As early as 1847, the phrase "Science for all" was proclaimed [1], but it is theorized that the term "scientific literacy" first emerged in the mid-1950s, when the scientific community in the United States recognized the importance of granting the entire society access to scientific knowledge [2]. This paradigm shift has attributed a new purpose to science education for everyone and from the earliest years, which was previously exclusive to those inclined and desiring to pursue a scientific career. Thus, the primary goal of science education became preparing societies for constant transformations, unpredictable challenges, and inevitable adaptations in the face of scientific and technological evolution, essential for achieving the 17 Sustainable Development Goals of the 2030 Agenda [3]. The traditional transmissive practices, once satisfactory for their purposes, no longer serve today's needs. The Inquiry-Based Science

Education (IBSE) approach is one of the methods that meet the general aspirations for an active, contextualized, sequential, and progressive science education capable of fostering scientific skills. This approach, inspired by scientific work methods, promotes students' involvement in age-appropriate practical science activities [4,5].

In Portugal, the first subject encompassing natural sciences for primary education (ages 6–10) appeared in 1968 under the name “Geographic-Natural Sciences”. In 1979, it was renamed “Physical and Social Environment” and changed to “Study of the Environment” in 1991, a name that persists today. It is a subject that, admittedly, integrates areas of natural sciences (physics, chemistry, and geology) and social sciences (geography and history), realized in a curriculum that encompasses various learning objectives. This curricular document incorporates less than 50% of natural science learnings, with a predominance of knowledge over investigative skills and attitudes and values, with few explicit guidelines for science teaching [6].

Science education in the early years is a field of teaching, training, and research that, although consolidated, is relatively recent in Portugal [7]. The curricular devaluation and disrepute in weekly class hours appear as obstacles to the universal appreciation of the area [7].

In 2006, minimum weekly teaching times were defined for the curricular areas of primary education, 8 h of Portuguese, 7 h of mathematics, and 5 h of Environmental Studies, half of which are in experimental science teaching, marking its compulsory nature for the first time. In 2018, the weekly hours were redefined, and the Environmental Studies subject was reduced to three weekly hours. This entrenched devaluation is revitalized and accentuated by the relegation of the science teachers themselves, especially compared to mathematics and Portuguese teachers [8]. The disparity in class hours is particularly concerning when one of the constraints to performing more science activities is the perceived lack of time [9,10]. Therefore, a change that makes the time spent on these areas equal [11] and autonomous, as seen in countries like Ireland, Canada, the United States, Spain, and Australia, is urgently needed.

The Portuguese scenario worsens when the practices of teachers are strongly influenced by their training, beliefs, conceptions, and knowledge. These become one of the determinants of the quality of science teaching [12]. Although the importance of science teaching is legitimized by the teachers from the teaching cycle [13,14], their still naive conceptions seem congruent with essentially traditional practices [8] with still inadequate scientific knowledge [13,15–17]. These conceptions so affect the practices of teachers that practical activities in this teaching cycle in Portugal still occur sporadically [13,14,18–21]. In addition to the insufficient periodicity of the activities, they seem to be decontextualized and not conducive to promoting scientific skills in children [22]. The scarce diversity of activities, limited use of group work, and reliance on textbooks as the chosen resource [10,23] are indications of predominantly transmissive practices characterized by the complacent attitude of children towards their learning process. Thus, the teaching of sciences in primary school in Portugal is far from the desired standard. The difficulties of teachers in transforming their practices are increasingly evident [14], mainly due to the lack of quality educational resources appropriate for the age level of the students and lack of training [8–10,12,13].

The ideological clash between international guidelines for science education (e.g., the IBSE perspective and Science, Technology, and Society—STS orientation) and what is being implemented in primary schools in Portugal can constitute obstacles and difficulties that impact children's learning. The participation of students in international studies such as Trends in International Mathematics and Science Study (TIMSS) and the Programme for International Student Assessment (PISA) shows still unsatisfactory results. Regarding the performance of 4th-grade students in TIMSS [24] from the first participation (1995) to the second (2011), there was a significant increase of 52 points (from 452 to 522 points) (Figure 1). However, in the last two participation cycles (2015 and 2019), the average

scores have decreased (508 points and 504 points, respectively), getting closer to the TIMSS average (500 points), contrary to other countries' trends.

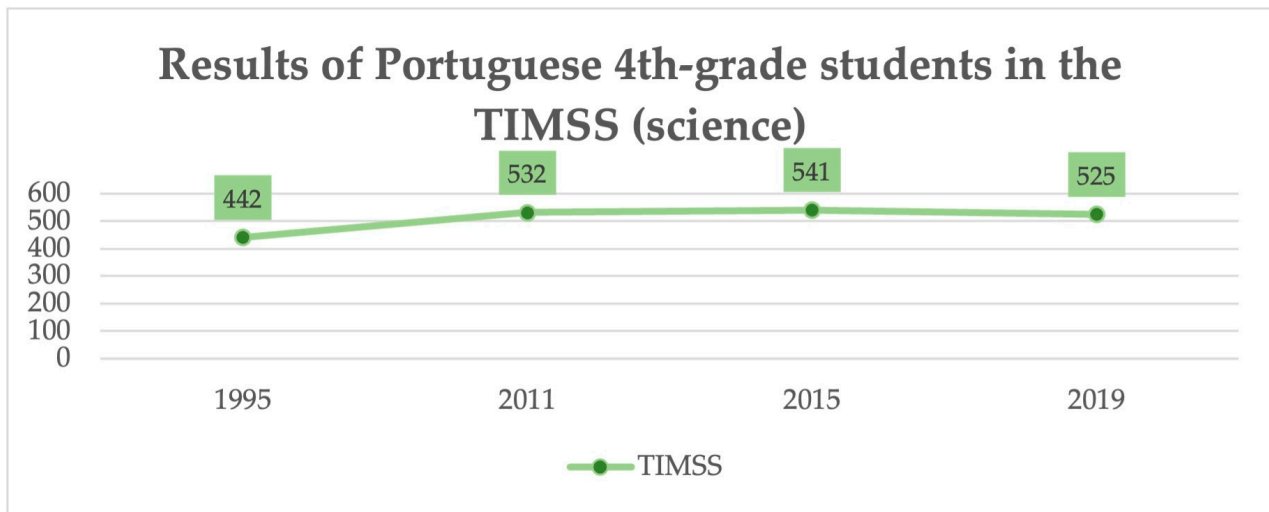


Figure 1. Results of Portuguese 4th-grade students in TIMSS in the science domain.

Respectively, in PISA (Figure 2) [25], for 15-year-old students, in the first four participations from 2000 to 2009, there was an increase of 34 points (from 459 points to 493 points). In 2012, there was a slight deviation from this trend (with 489 points), but it recovered in the 2015 participation, where they reached 501 points, for the first time surpassing the OECD average (489 points). From 2018 until the latest participation up to 2022, scores decreased again, reaching 484 points. The Eurydice report, 'Increasing Achievement and Motivation in Mathematics and Science Learning in Schools', included Portugal among the countries that do not achieve basic levels of scientific literacy [26].

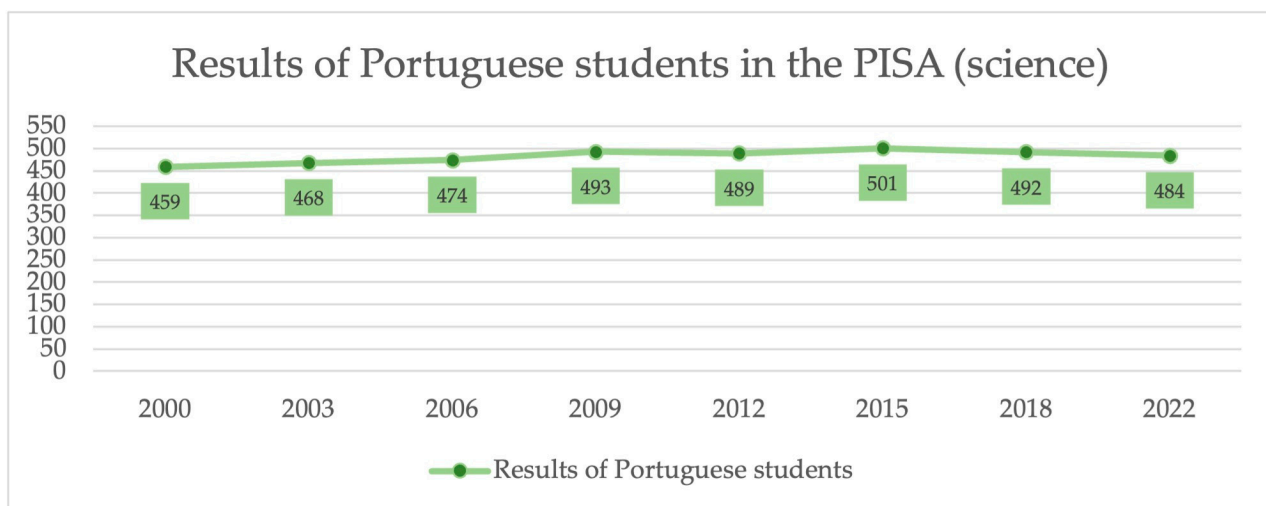


Figure 2. Results of Portuguese students in the PISA in the science domain.

In the national external evaluation (assessment tests) in the 2nd grade, performance results for the years 2017, 2018, 2019, and 2023 [27–30] show that about half of the children (an increase of 45%) showed difficulty, either could not answer as expected or did not respond to science questions, with only around 30% achieving the maximum level in 2022. Knowing that “the group most likely to generate erroneous or incomplete conceptions is that of young children because their experiential world is still confined to a short-lived

space” [31] (p. 113), it is essential to create contexts promoting scientific literacy from the early years, urging for a change in teaching practices in primary education consistent with international and national demands for quality education for all [32].

Over the years, researchers have expressed the need for changes in science education, hoping to change the residual expression of practical science teaching in Portugal. In this sense, they refer to the need for curricular restructuring for the 1st cycle of basic education [11,33,34] and investments in science teaching resources for this cycle [12,34].

The Science Experimental Teaching Training Program (PFEC) and the Digital Science Educational Resources (RED_Ciências) are examples of national intervention and research projects with a high impact on improving teaching practices and increasing children’s scientific literacy. The implementation of the PFEC started in 2006, defining as main actions the training of primary school teachers and equipping schools with the necessary didactic resources for the practical activities proposed in the training. Evaluations from the project demonstrate effectiveness in the professional development of the involved teachers, particularly regarding the appropriation of methodologies, strategies, and activities related to experimental science teaching, as well as for the development of their students’ learning, particularly in terms of scientific skills [35,36]. From this project, a set of didactic guides for eight themes (Dissolution; Light, Shadows, and Images; Sustainability; Electricity; Flotation in liquids; Changes of state; Plants; and the Human body) were made available to support the preparation and exploration of activities in the school context.

Following the development of the PFEC, the RED_Ciências project started in 2019, aiming to conceive/adjust, produce, validate, implement, and evaluate digital educational resources to support experimental science teaching practices for primary school teachers and promote student learning during school and non-school hours. Through a multidisciplinary team, activities and respective resources for the eight themes of the PFEC were developed. A website was created to aggregate various analog (games, record sheets, and assessment activities) and digital resources (videos, posters, games, and video makers) for free. The cyclical process of implementing and validating RED_Ciências resources with teachers and children allowed for the observation of the satisfaction and recognition of the usefulness of these resources by the teacher users as well as their contribution to the development of knowledge, skills, attitudes, and values [37].

The concern regarding the described scenario, the dissatisfaction with its prevalence in Portuguese schools, and inspired by the presented projects, led to the development of the “Programa de Ensino Experimental das Ciências” (PEEC), which is presented here, with the definition of the following research objectives:

To develop (conceive, plan, validate, implement, evaluate) a Program of Experimental Science Teaching for primary education with the following:

- A new proposal for a curriculum project for experimental science teaching with an STS and IBSE orientation;
- Didactic exploration proposals and respective support resources for the implementation of the curriculum project, based on the activities developed throughout the project and the evaluation carried out by class teachers and assisting teachers;
- Activities and assessment registration instruments of learning (knowledge, skills, attitudes, and values) underlying the development of scientific competencies planned for the four years of the 1st cycle of basic education.

The research questions defined for this project are as follows: “How do we systematically promote experimental science teaching in a contextualized manner, with an STS (Science, Technology, and Society) and IBSE (Inquiry-Based Science Education) orientation in primary education?” and “How do we develop an assessment project for and of primary school children’s learning that is coherent with the proposed PEEC (Educational Project for Science Education)?”

This article aims to describe the trajectory and development cycles of the PEEC and present its final evaluation in the voice of collaborating teachers through the Educational Design Research (EDR) methodological approach, justified by the emergence of the problem

and the appropriateness of research purposes and the intervention context, collaborations, and development of the products, as subsequently described.

2. Materials and Methods

2.1. The Educational Design Research Approach

- The Research Design approaches, from which the EDR approach derives, emerged in the 20th century with the aim of ensuring synergies between real problems and academic research carried out in intervention contexts [38–40]. This need for change arises, according to some authors, from the commitment between the utility of generated knowledge and the resulting solutions in research, which were previously considered distant and of little use compared to the problems manifested in real contexts [38,41]. In this sense, this methodology, and its variants, is fundamentally concerned with conducting research based on real problems and ensuring that the presented solutions are truly useful and replicable [42]. The remarkable growth of this approach is expressed by the increasing number of publications and research [43]. In Portugal, doctoral projects adopting these approaches have also been growing [44–50].
- The EDR methodology follows a set of peculiar characteristics that authenticate it, standing out for being the following:
- Pragmatic: the EDR approach is guided by recommendations to generate scientific knowledge for the benefit of solutions to one or more real fracturing problems in educational contexts.
- Grounded: the definition of the problem arises from the synergy of the discursive analysis of the study participants and what is expressed in scientific literacy.
- Iterative: the contours of an iterative investigation imply that the project's evolution occurs through the systematicity of iterative cycles stemming from design, implementation, and evaluation, accompanied by validation and review processes.
- Flexible: it is frequent and acceptable to adapt the initially planned study plan, involving aligning strategies to pursue the stipulated objectives based on emerging insights.
- Interventionist: studies are designed as transformative, proposing effective and replicable changes in real educational contexts.
- Collaborative: Encouraging research with effective collaborations is both an objective and a challenge. From an EDR perspective, this is a requirement, as the success of the research project will inevitably depend on the multidisciplinary team's proficiency in terms of their contributions throughout the research [42,51–53].
- Based on these characteristics, Figure 3 graphically represents the process conducted in this research that was established in three phases with their respective moments and cycles that characterize it and identify it as an EDR project.

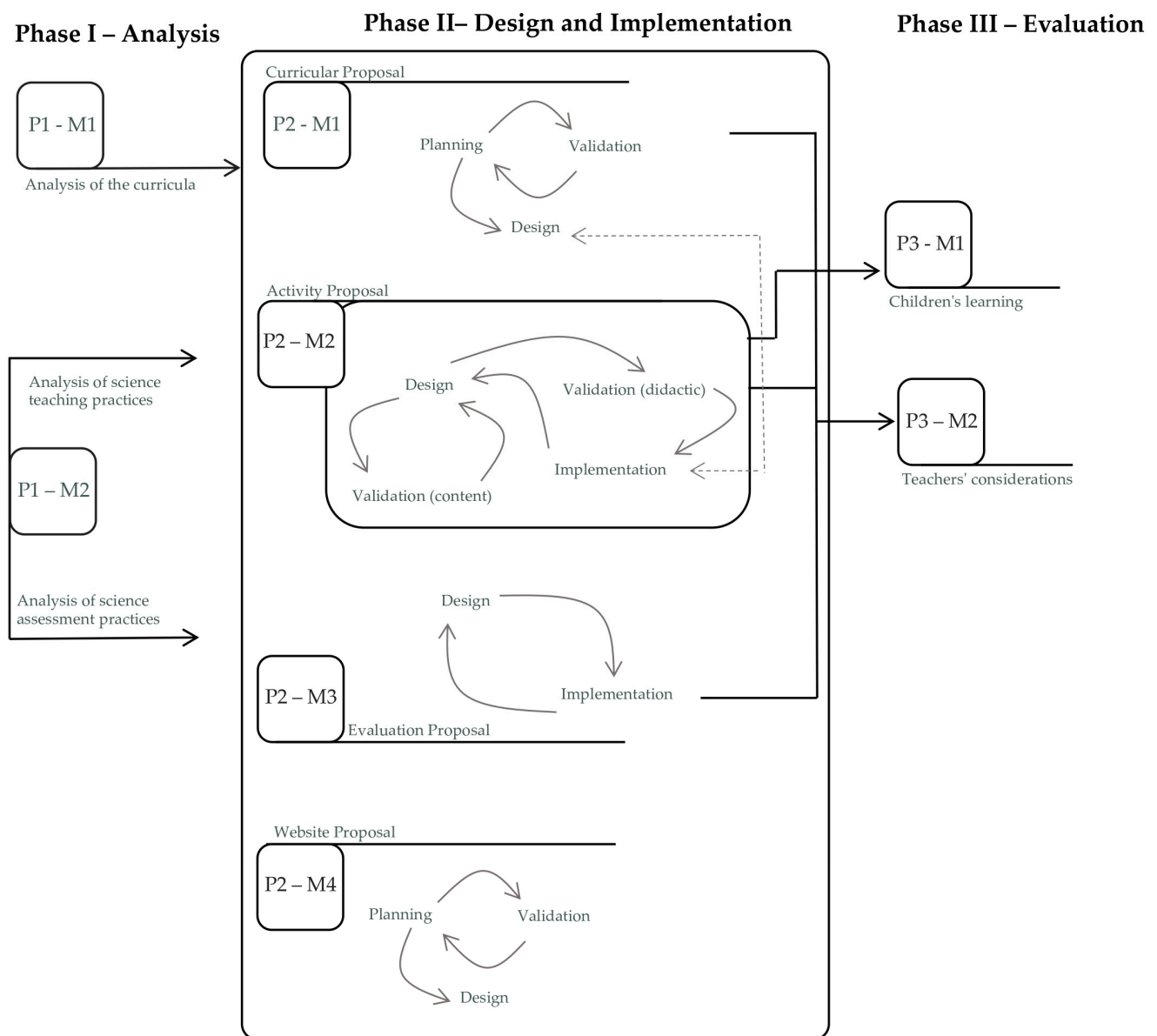


Figure 3. A diagram illustrating the phases and stages in the development of the PEEC project.

Based on the presented scheme, each phase, its respective moments, and tasks that define each one will be described in detail.

Phase I—Analysis or Preliminary Phase

Like any research, the initial phase requires the formulation of research questions and the delineation of the problem to be solved. EDR is no exception, and in Phase I, it follows the norm by identifying and describing the problem [41,42,53,54]. In this particular study, in addition to the state of the art, this phase materialized with reflective analyses, comprising the two moments described in Table 1.

Table 1. Synthetic description of the moments of “Phase I—Analysis”.

Moment	Tasks	Participants	Period	Number of Performance Indicators (<i>n</i>)
P1-M1	<ul style="list-style-type: none"> - Select and systematize the most recent curricular guidelines related to experimental science teaching in primary education; - Analyze the Portuguese primary science curriculum in light of the learning outcomes assessed in TIMSS and PISA; - Comparatively analyze the Portuguese primary science curriculum with other science curricula at this education level. 	Researchers	2019–2020	Scientific article (<i>n</i> = 1); Summary in conference proceedings (<i>n</i> = 2); Poster presentation at a conference (<i>n</i> = 1).
P1-M2	<ul style="list-style-type: none"> - Analyze reports on teaching practices and assessments of primary school teachers in the context of experimental science teaching. 	Researchers	2019–2020	Scientific article (<i>n</i> = 1); Summary in conference proceedings (<i>n</i> = 1).

As described in Table 1, the first moment (PI-M1) consists of the analysis (i) of the school curriculum corresponding to the natural sciences area in the four years of primary education (6–10 years old) in Portugal, in light of the science learnings assessed in the 2019 TIMSS for the 4th grade [55] and (ii) a comparative analysis of the curricula of countries whose results stood out in TIMSS and PISA, namely, England, the United States, Singapore, and Australia [6]. The analysis highlighted evident gaps in terms of the guidelines, orientations, content, and coherence of the science curriculum in Portugal.

The second moment (PI-M2) focused on analyzing reports from the Inspectorate General of Education and Science [22]. It was understood that science teaching practices in primary education observed and evaluated by inspectors were still lacking in contextualization, with little focus on children and a scarcity of promotion of scientific skills. Children’s learning assessments were still a little systematic and overly focused on knowledge.

It is in this exploratory phase that reflection on the current situation of science education in primary education occurs, and a relevant and suitable multidisciplinary team is created to address the challenges encountered. Collaboratively, an action plan is developed for common objectives, namely, to mitigate (i) the identified gaps in the immaturity attributed to science both at the curriculum level and in the time allocated to it in the school year; (ii) the insufficiency of practical activities in this cycle of education as well as the scarcity of active and child-focused strategies; and (iii) the assessment solely based on knowledge. For this purpose, and still in this first phase, it was essential to survey relevant national and international reference literature, guidelines, and support and justifications, a process that accompanied the different tasks of all phases. This phase culminates in the design of the PEEC, as presented subsequently.

Phase II—Design and Implementation

From 2020 to 2023, the PEEC was developed, and it was chosen to implement it in its entirety [54], with the collaboration of scientific validators, primary school teachers, and their respective classes. As indicated in Table 2, this phase emphasized successive iterative cycles between moments of design, validation, implementation, evaluation, and redesign.

Table 2. Synthetic description of the moments of “Phase II—Design and Implementation”.

Moment	Tasks	Participants	Period	Number of Performance Indicators (n)
P2-M1	<ul style="list-style-type: none"> - Design a science curriculum proposal for primary education; - Validate the initial design of the proposal with experts in science didactics, curriculum development, and consulting; - Implement and evaluate the curriculum proposal using PEEC resources with primary school classes; - Redesign the curriculum proposal; - Implement and evaluate the curriculum proposal using PEEC resources with primary school classes; - Finalize the redesign of the PEEC curriculum proposal. 	<p>Researchers; Validators.</p>	2020–2023	<p>Scientific article ($n = 1$); Summary in conference proceedings ($n = 1$).</p>
P2-M2	<ul style="list-style-type: none"> - Design didactic proposals and PEEC resources that are supported by the curriculum proposal; - Validate the didactic resources with experts in the field (e.g., biologists, doctors, and nurses) - Redesign the PEEC didactic proposals; - Validate the PEEC didactic proposals with collaborating teachers; - Redesign the PEEC didactic proposals; - Implement the PEEC didactic proposals with primary school classes; - Finalize the redesign of PEEC resources. 	<p>Researchers; Validators; Primary school teachers; Primary school students.</p>		<p>Scientific article ($n = 1$); Summary in conference proceedings ($n = 1$).</p>
P2-M3	<ul style="list-style-type: none"> - Design digital learning assessment games; - Implement and validate the digital learning assessment games with participating classes; - Redesign the digital learning assessment games; - Implement and validate the digital learning assessment games with participating classes; - Finalize the redesign of the PEEC digital learning assessment games. 	<p>Researchers; Primary school teachers; Primary school students.</p>		<p>Scientific article ($n = 1$); Summary in conference proceedings ($n = 1$).</p>
P2-M4	<ul style="list-style-type: none"> - Design the website; - Validate the website with a programmer; - Redesign the website; - Validate the website with collaborating teachers; - Finalize the website redesign. 	<p>Researchers; Programmer; Primary school students.</p>	2023–2024	<p>Scientific article ($n = 1$).</p>

This phase, as outlined in Table 2, embodies the cyclical, iterative, systematic, collaborative, and formative nature adopted for the conception of the PEEC [54,56]. The design/prototype moment is supported by the search for similar projects and existing knowledge [56]. In this particular case, at each of the listed moments, this research and the relevant selection of studies were carried out, based on the problems detected in the previous phase.

P2-M1—Curricular Proposal: Five foreign science curricula for primary education (the United States, Canada, England, Singapore, and Australia) were selected as pillars for restructuring and inspiration for the development of a curricular proposal [57].

P2-M2—Activity Proposal: A survey of empirical articles on the implementation and evaluation of resources and projects for constructing and providing science resources for primary education was conducted, as well as relevant digital teaching resources for the area in question. The development cycle involved an initial design, successive validations with validators and teachers, an exploration with children, and a final redesign, with a systematic evaluation from the teachers’ perspective [58]. As outputs, 120 science activities were developed with the purpose of making all the respective educational resources available for free, including lesson plans, infographics, and analog games (Figure 4).



Figure 4. PEEC activity resources.

P2-M3—Evaluation Proposal: Attempts were made to understand which digital games are commonly used in science education in primary schools, to identify the particular characteristics that make them educational digital games, and to characterize their use for designing games with assessment activities. The games were explored and appreciated by child users in terms of their preference (between the game and the usual test) and how they felt about their completion at the end of two school years (2020–2021 and 2021–2022). Figure 5 shows some printscreens from one of the digital games developed.

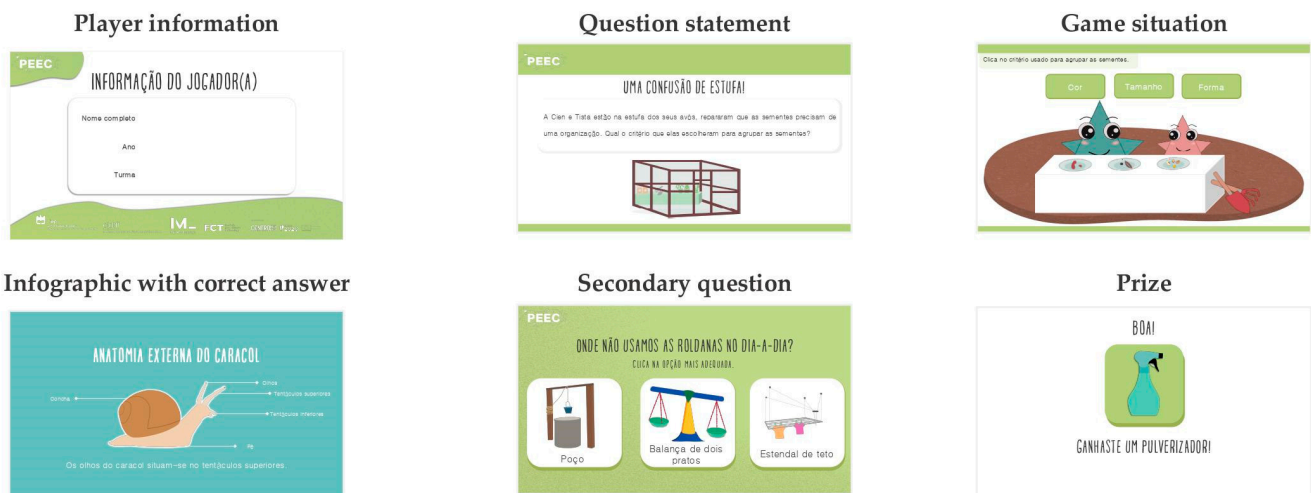


Figure 5. Printscreens from the PEEC assessment game.

P2-M4—Website Proposal: Examples of websites for science educational resources for primary education in Portugal were analyzed, as well as criteria for an accessible website, with input from some teachers regarding its suitability. Figure 6 shows some printscreens from the website.

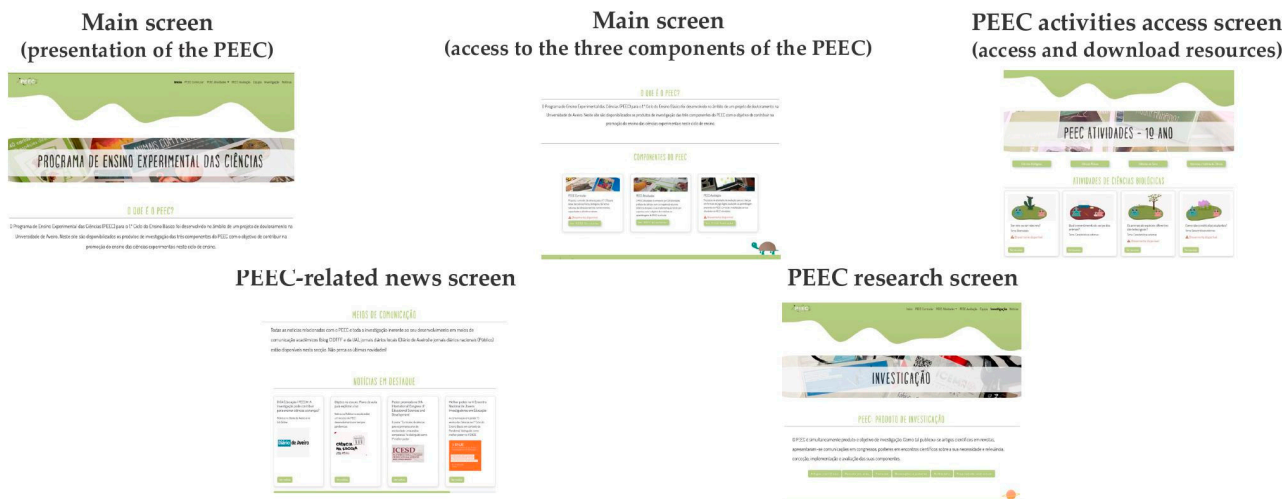


Figure 6. Printscreens from the PEEC assessment game.

This phase highlights the reflective and evaluative nature, of a formative nature, of the EDR until joint solutions are found and consensually desired by all stakeholders regarding the various dimensions of the PEEC. Collaboration was essential in triangulating perspectives at different moments, fueling the cyclical nature of the intervention. Given the absence of standard techniques for data collection [59], we favored listening to the stakeholders either in a written and structured manner (questionnaire survey) or orally in an unstructured way (messaging conversations and phone calls). Initial validation feedback from experts allowed for the improvement of PEEC components before implementation. The usability and effectiveness of teaching resources were evaluated at a later stage, together with teachers, both in a preliminary exploration of resources in activity planning and in the implementation with their classes, and in this case, the data collection process was characterized by being more formal, systematic, and extensive [59].

The third and final phase, evaluation and reflection, allows for a broad summative evaluation of the project. After considering that the research objective was achieved, the project’s effects were assessed, as described in Table 3.

Table 3. Synthetic description of the moments of “Phase III—Evaluation”.

Moment	Tasks	Participants	Period	Number of Performance Indicators (n)
P3-M1	- Investigate the effect of PEEC activities on children’s learning.	Researchers; Primary school teachers; Primary school students.	2022–2023	Scientific article (n = 1); Summary in conference proceedings (n = 1).
P3-M2	- Investigate the perceptions of participating teachers regarding the PEEC.	Researchers; Primary school teachers.	2023	Scientific article (n = 1); Summary in conference proceedings (n = 1).

The first moment of Phase III (P3-M1) aims to investigate the impact that the developed activities had on children’s learning. For this purpose, 149 assessment recording

instruments filled out by participating teachers during the sessions implemented in the academic year 2021–2022, as well as 161 responses obtained from students in the assessment games of the PEEC, were analyzed.

In this article, the second moment of this phase (P3-M2) is presented in detail, which presupposes investigating, after one year of the last implementation (2021–2022), the perception of participating teachers regarding the components of the PEEC. In this regard, we listened to the ten teachers who contributed and participated in the implementation of the PEEC over the two school years. A questionnaire organized into five sections (PEEC Curriculum, PEEC Activities, PEEC Evaluation, and PEEC Implementation; Overall Evaluation) was created, with a total of 24 mandatory closed-ended questions based on a 5-level scale of agreement: Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree. Table 4 presents the questionnaire structure with the research objectives and respective questions.

Responses were received from the ten co-teachers responsible for exploring the science activities throughout this project. In the next section, the analysis of the data and the results derived from the responses of the participating teachers are presented.

Table 4. Objectives and questions of the PEEC evaluation questionnaire.

Group	Research Objectives	Statements/Questions Based on Your Knowledge and Years of Experience as a Primary School Teacher, Please Indicate the Degree of Agreement That Best Reflects Your Opinion Regarding the Following Statements:
PEEC CURRICULUM	Investigate participating teachers’ perceptions of the appropriateness of the learning outcomes advocated in the PEEC curriculum for the intended grade level.	The PEEC curriculum learning outcomes are appropriate for the intended grade level.
	Investigate the relevance that participating teachers attribute to the PEEC curriculum proposal for the development of students’ scientific literacy.	The PEEC curriculum learning outcomes encompass relevant knowledge, skills, and attitudes for promoting students’ scientific literacy.
PEEC ACTIVITIES	Investigate participating teachers’ perceptions of the appropriateness of PEEC activities for the developmental level of children in the intended grade.	PEEC activities are appropriate for the developmental level of children in the intended grade.
	Investigate participating teachers’ perceptions of the adequacy of PEEC activities for mobilizing the intended learning outcomes in terms of knowledge, skills, attitudes, and values.	PEEC activities allow for the mobilization of the learning outcomes outlined in the PEEC curriculum in terms of knowledge.
		PEEC activities allow for the mobilization of the learning outcomes outlined in the PEEC curriculum in terms of skills.
		PEEC activities allow for the mobilization of the learning outcomes outlined in the PEEC curriculum in terms of attitudes and values.
	Investigate participating teachers’ perceptions of the originality of PEEC activities.	PEEC activities and their respective resources are original and innovative.
Investigate participating teachers’ perceptions of the potential of PEEC activities to promote active student engagement.	PEEC activities promote active engagement among children.	
PEEC EVALUATION	Investigate participating teachers’ perceptions of whether the PEEC assessment activities allow for the evaluation of the learning outcomes advocated in the PEEC curriculum.	The assessment activities (evaluation games) allow for the evaluation of the learning outcomes outlined in the PEEC curriculum.
		PEEC digital evaluation games allow children to monitor their learning through the feedback system for each question.
	Investigate participating teachers’ perceptions of the potential of digital games to promote children’s self-monitoring of learning.	PEEC digital evaluation games are coherent and contextualized with what is explored in the school context (PEEC activities). The forms with children’s results sent via email are useful for the teacher. PEEC evaluation games allow for diagnostic, formative, and summative assessment.

Table 4. Cont.

Group	Research Objectives	Statements/Questions Based on Your Knowledge and Years of Experience as a Primary School Teacher, Please Indicate the Degree of Agreement That Best Reflects Your Opinion Regarding the Following Statements:
IMPLEMENTATION OF PEEC	Investigate participating teachers' perceptions of the PEEC's contribution to mobilizing children's learning in terms of knowledge, skills, attitudes, and values.	I believe that PEEC activities contributed to the development of children's knowledge.
		I believe that PEEC activities contributed to the development of children's skills.
PEEC PROJECT	Investigate participating teachers' perceptions of the value they attribute to the PEEC for their science teaching practices.	The PEEC facilitates the systematic and contextualized implementation of practical science activities with my students, and I highly recommend it to other primary school teachers.
	Investigate whether teachers continue to use the PEEC with their classes.	Even though my collaboration in the study has ended, I am still using the PEEC with my class.
	Investigate whether teachers intend to use the PEEC.	I intend to continue using the PEEC in the coming school years.
	Investigate participating teachers' perceptions of the importance of the PEEC for their science teaching practices.	I believe that the PEEC is very important for my science teaching practices.
		I believe that the PEEC is very important for supporting my science teaching practices because it provides activity planning suggestions.
Investigate participating teachers' perceptions of the relevance of teacher training on the PEEC for their science teaching practices.	I believe that the PEEC is very important for supporting my science teaching practices because it provides didactic resources.	
		Teacher training on the PEEC could facilitate the appropriate implementation of practical science activities.

3. Results and Discussion

The results are presented in five sections, corresponding to the organization of the questionnaire survey: PEEC Curriculum, PEEC Activities, PEEC Evaluation, PEEC Implementation, and Overall Evaluation.

3.1. PEEC Curriculum

The considerations made by the teachers regarding the PEEC curriculum, as depicted in Figure 7, indicate the suitability of the learning outcomes defined in the curriculum proposal as potential enhancers of scientific literacy development and the adequacy of these same learning outcomes for the intended grade level.

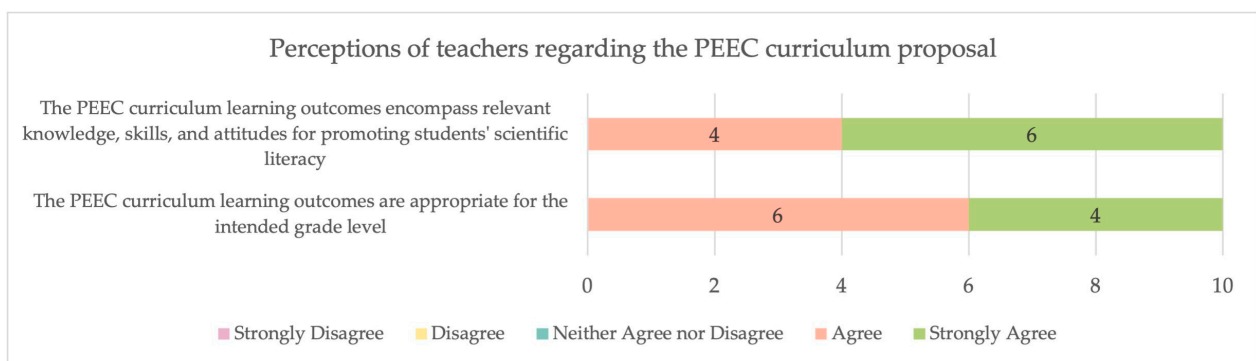


Figure 7. Degree of agreement of teachers on aspects of the PEEC curriculum.

3.2. PEEC Activities

Regarding teachers' considerations about the PEEC activities, as presented in Figure 8, a high degree of agreement can be observed in aspects related to the mobilization of learning in terms of knowledge, skills, and attitudes/values that the PEEC activities aim to mobilize. It is prominently noted that the PEEC activities promote the active engagement of children,

facilitate moments of preparation and exploration of activities, and are considered original and innovative. Less prominently, the appropriateness of PEEC activities for the intended grade level is highlighted. Overall, PEEC activities are conducive to the development of the learning outcomes stipulated in the PEEC curriculum and are appropriate and original, facilitating teachers to prepare activities capable of engaging students actively.

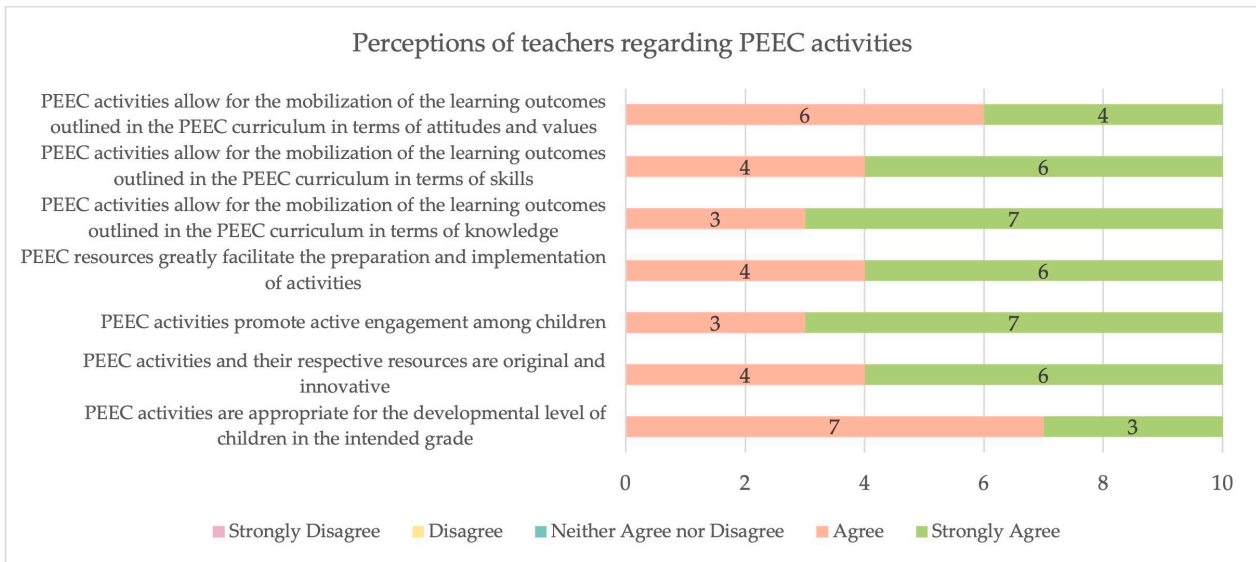


Figure 8. Degree of agreement of teachers on aspects of PEEC activities.

3.3. PEEC Evaluation

Regarding teachers’ perceptions of the PEEC evaluation component, summarized in Figure 9, it was noted that they considered the form automatically sent to their email accounts upon submission of children’s responses in the assessment game relevant. Most agree that assessment games can be used for various assessment modalities (diagnostic, formative, and summative). They also mention that the games are consistent with the other components of the PEEC, both in terms of activities and curriculum. Regarding the feedback system included in the game to enable children to monitor their learning, teachers mostly position themselves at the “agree” level. It can be concluded that digital games designed for science learning assessment purposes are, from the teachers’ perspective, useful and versatile regarding the timing and purpose of application.

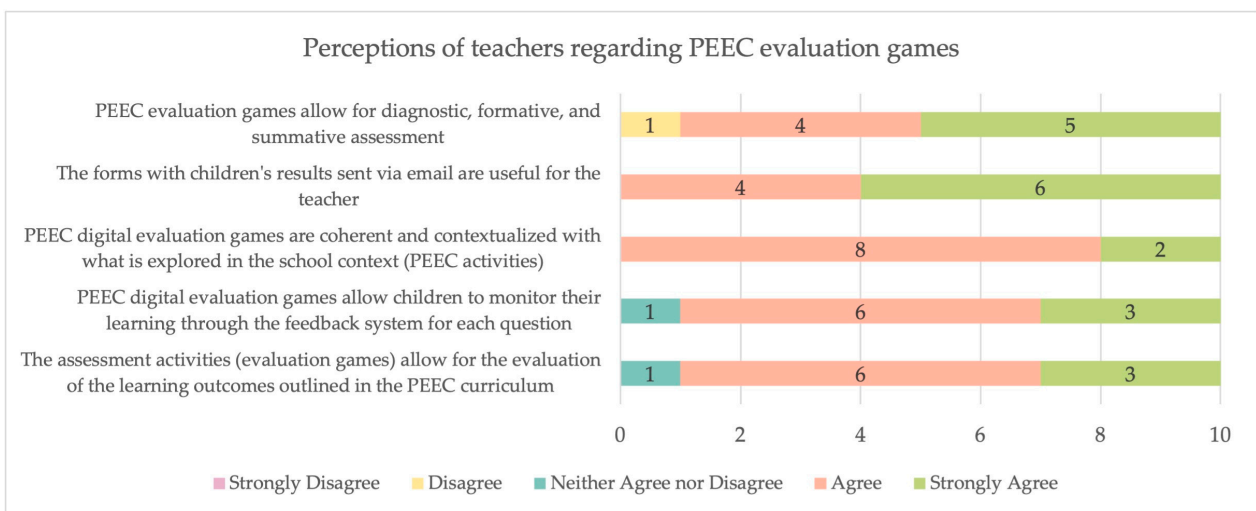


Figure 9. Degree of agreement of teachers on aspects of PEEC assessments.

3.4. Implementation of PEEC

According to the teachers, as depicted in Figure 10, the PEEC activities contributed to the development of children’s learning in terms of knowledge, skills, and attitudes/values.

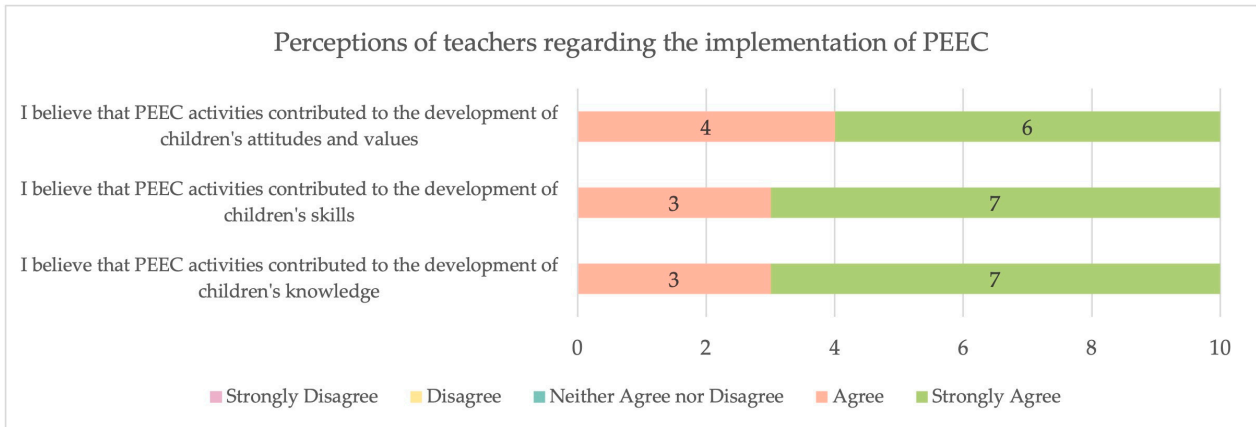


Figure 10. Degree of agreement of teachers on aspects of PEEC implementation.

3.5. PEEC Project

Figure 11 summarizes the data regarding teachers’ considerations of the PEEC project. Their recognition of the importance of the PEEC in providing didactic resources to support their teaching practices and offering activity exploration suggestions that facilitate their intervention is highlighted. They also mention that they have already used PEEC resources after completing their collaboration in this project and intend to use them with their classes in the future and recommend them to other teachers. Most teachers acknowledge the need for continuous training to enhance their practices in science teaching.

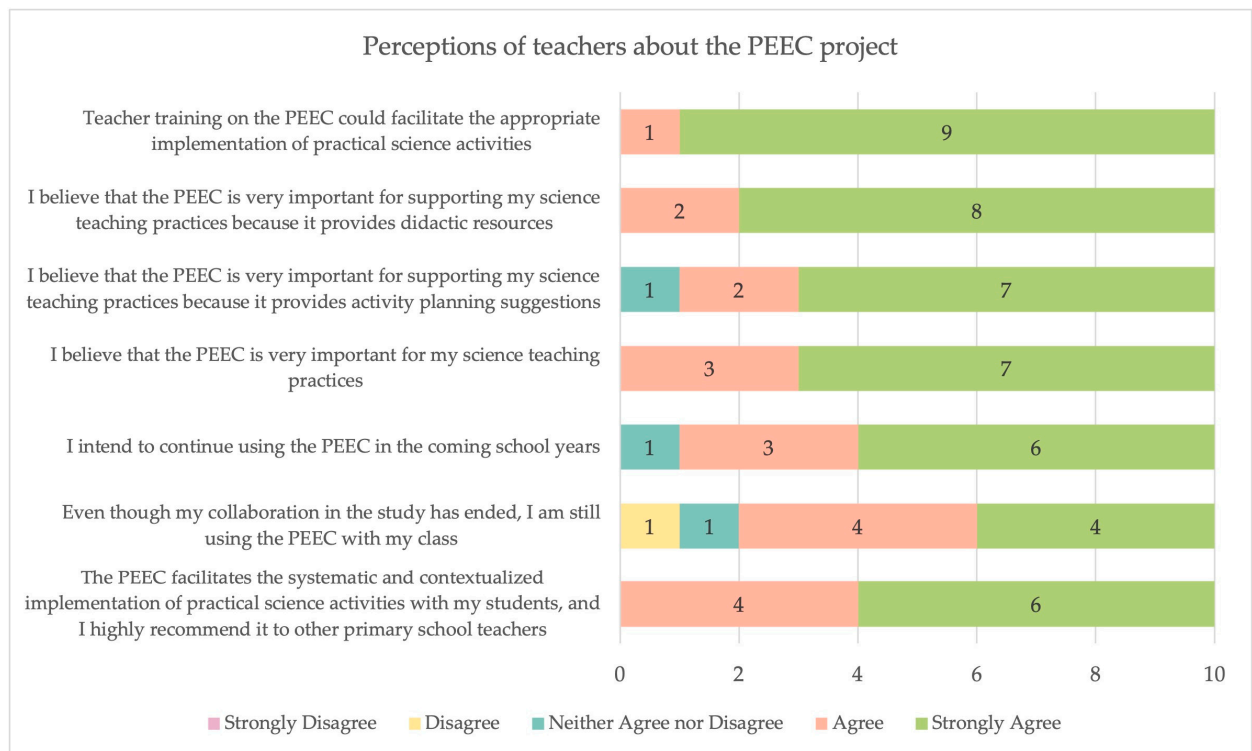


Figure 11. Degree of agreement of teachers on aspects of the PEEC project.

4. Discussion

The results presented stem from the analysis of the responses of the ten collaborating teachers in the cycle of the implementation and evaluation of PEEC resources. We asked the teachers about their perception of the curricular proposal, activities, assessments, implementations of these educational resources, and the PEEC project in general.

The analyses conducted on the Portuguese science curriculum for primary education point out specific deficiencies, considering the learning outcomes assessed in TIMSS [55] and through a comparison of science curricula [6]. Analyses conducted by other authors mention some gaps in health education [60] and low levels of cognitive demand in the learning statements present, hindering children's cognitive progression [61]. This led to the reconfiguration of the curriculum proposal, resulting in a proposal supported by an IBSE perspective and STS orientation. Over two academic years, the curriculum was implemented and evaluated by collaborating teachers. In the final phase, these teachers considered that this proposal is suitable for the intended age group and capable of promoting children's scientific literacy.

Regarding the PEEC activity, an analysis of reports from the Inspectorate General of Education and Science was carried out within the scope of experimental science education, which allowed for the characterization of teachers' practices in primary education, namely, as sporadic, transmissive, and decontextualized [22]. A plan of action was drawn up to combat the difficulties experienced by teachers regarding the lack of quality and suitable resources. In this sense, 120 original activities were developed with didactic resources to support their implementation (lesson plans, contextualization videos, record sheets, infographics, posters, interviews, etc.), which is consistent with the curriculum proposal. Their implementation over two academic years indicated that the resources are appropriate, original, and helpful in preparing and exploring classroom materials with students, and the activities promote science learning in terms of knowledge, skills, and attitudes/values. Two years later, teachers express that the PEEC activities component is original, suitable, and allows for the development of scientific skills and promotion of the active involvement of children.

Regarding the PEEC assessment proposal, some relevant aspects recommended in the scope of science learning assessments [18,34,62,63] are perceived by collaborating teachers as (i) contextualized assessments with real or realistic situations; (ii) science learning assessments should encompass knowledge, skills, and attitudes/values; (iii) varied assessment tools and activities; (iv) a diversity of assessment modalities (diagnostic, formative, and summative); and (v) children's involvement in the process with constructive feedback. The use of digital games as an assessment activity has been increasing [64–67]. Teachers value, similar to the presented results, the immediate feedback [68–70], as well as the storage and tracking of students' responses [71,72].

The results of the effect of PEEC implementation on children's learning corroborate the findings from the analysis of data obtained from children's learning assessment records and responses in the assessment games of the PEEC [73]. Similar studies demonstrate that science activities promote more and better science learning from the early years of schooling [74–79] and that starting early influences and fosters a liking for science [10], legitimizing its relevance, feasibility, and outcomes.

The need for continuous training is recognized by 90% of the participating teachers, decisively constituting one of the concerns and future interventions to improve teachers' practices [80,81]. Resistance to change represents one of the main obstacles to a more holistic education, and this can be countered and overcome with continuous teacher training [82].

The research questions guiding this project focus on two aspects: promoting experimental science teaching in primary education and promoting an assessment for and of learning that is coherent with IBSE and STS teaching practices. Teachers' responses reveal that the curriculum proposals and corresponding activities for their implementation are conducive to developing children's scientific literacy. The ability to conduct two implementation cycles and involve 12 classes each school year allowed for a systematic evaluation of

PEEC resources, which is often cited as a limitation in various studies [79]. Regarding the assessment proposals for and of children's learning, teachers believe these allow for the evaluation of a set of scientific competencies consistent with the curriculum and activity proposals, aiming for more and better learning.

5. Conclusions

In Portugal, teacher training in science education in the early years and research in this area are still recent realities, spanning little more than three decades. This may possibly be one of the reasons why legislative aspects are still in their infancy compared to what is recommended. Projects within the scope of science education of significant breadth have been mentioned, highlighting their duration, team, methodologies, purposes, scope, and products with a common goal: more and better science learning for children. The PEEC project, despite emerging from a doctoral project, also emerges and is envisioned as an initiative with a possible national impact.

As the ERD methodology emanates, real educational context problems were identified with the aim of contributing to their solution through research, simultaneously acting to find workable solutions in real contexts and to generate scientific knowledge. It can be said that curricular, teaching, and learning assessment issues were identified as intervention focuses for the PEEC.

In this article, the evaluation of PEEC from the perspective of collaborating teachers through a questionnaire survey was intended. Through teachers' responses, it was ascertained that the PEEC meets the stipulated purposes in its three dimensions, namely, curricular, activities, and assessments. At the curricular level, teachers consider the suggested learning objectives to be appropriate for the target age group and to be capable of promoting children's scientific literacy. Regarding the proposed activities, from the teachers' perspective, they provide opportunities for the mobilization of learning at the level of knowledge, skills, and attitudes and values. Didactic resources, from the teachers' perspective, are capable of promoting children's engagement and are suitable for their proposed grade level. Moreover, teachers also mention that they are original, innovative, and facilitate the preparation and implementation of activities. Regarding PEEC assessments, specifically the digital game-based assessment activities, teachers consider them to be consistent with the learning objectives proposed in the curriculum as well as in the proposed activities. They value the possibility of receiving results by email and also consider that the game allows students to self-monitor, promoting awareness of their learning through immediate feedback. Overall, teachers attribute high importance to the PEEC for its practices, highlighting the planning and resources provided. Teachers continue and intend to continue using PEEC resources in their classes, and they mention that, despite their collaboration in this project, training could be useful for a better utilization of these resources.

In an EDR investigation like this, it is highlighted that in the final phase of a project of this nature, reflection on the results revolves around three levels [42]. The first concerns "Scientific outputs: Design principles", i.e., general guidelines on how the unfolded EDR research may be applied in the future or decisions for the decision-making of other researchers. The transparent development process was ensured, described in detail through publications in scientific articles and communications at conferences and congresses in the field of various project phases.

The second is "Practical outputs: Designed artifact(s)", i.e., the products resulting from the research, for example, educational resources that promote a solution to the detected educational problem. As results of this research, we highlight the development of the PEEC. A proposal for a primary school science curriculum was created and made available, which is grounded and consistent with current assumptions [57]. Underlying the curriculum proposal, a set of didactic resources consisting of 120 science activities to support teachers' practices was made available. Among these resources, analog games, infographics, videos with recorded interviews, and proposals for registrations in a free and online format stand

out [58]. The last is “Societal outputs: Professional development of participants”, i.e., the implication that the project had on the collaborators. The participating teachers mentioned that their collaboration in the project was enriching in terms of disciplinary and didactic content knowledge. Furthermore, most teachers also mentioned using PEEC resources, which is considered a satisfactory indicator, considering that the scarcity of science practices in primary schools was one of the problems we set out to mitigate.

Thus, the project presented here aims to influence educational policies in Portugal in primary education regarding the reconfiguration of curriculum programs and the provision of PEEC resources to support science teaching for this educational cycle. These resources could also be used in initial and continuous teacher training, considering that they are available for use and are subject to research in those contexts. Given the expressed need by participating teachers for their continuous training, this is one of the future lines we intend to address. In this way, we intend to continue this project and contribute to the right to quality science education from the early years of schooling, promoting the development of scientific literacy for all children.

Author Contributions: Conceptualization, P.C.S. and A.V.R.; methodology, P.C.S., A.V.R. and P.N.V.; validation, P.N.V.; formal analysis, P.C.S., A.V.R. and P.N.V.; investigation, P.C.S.; resources, P.C.S., A.V.R. and P.N.V.; data curation, P.C.S.; writing—original draft preparation, P.C.S., A.V.R. and P.N.V.; writing—review and editing, P.C.S., A.V.R. and P.N.V.; visualization, P.C.S., A.V.R. and P.N.V.; supervision, A.V.R. and P.N.V. All authors have read and agreed to the published version of the manuscript.

Funding: This work is financially supported by: (i) National Funds through FCT—Fundação para a Ciência e a Tecnologia, I.P., under the project UIDB/00194/2020 of I&D CIDTFF (University of Aveiro—Portugal); (ii) Fundação para a Ciência e Tecnologia I.P. with a PhD grant (SFRH/BD/143370/2019), through the European Social Fund and Human Capital Operational Program.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Comissão Permanente para os Assuntos de Investigação (CPAI) of Universidade de Aveiro (protocol code 11-CED/2021, 7 July 2021).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data used for this study are available upon request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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