

Article

Assessing the Initial Outcomes of a Blended Learning Course for Teachers Facilitating Astronomy Activities for Young Children [†]

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Abstract: Globally, astronomy education is being promoted through curricula. Research indicates that educators need support to fundamentally comprehend and gain knowledge of astronomy as well as pedagogical expertise to organize and facilitate astronomy-related activities in the classroom. In response to this notable demand, we have designed a coherent training program that addresses both the foundational and pedagogical content knowledge necessary to instruct astronomy subjects at the pre-primary and early school levels. This program is constructed in a blended learning format, which combines online and in-person training with practical implementations in the classroom. We trained both professional and student kindergarten teachers, and we used questionnaires and interviews to evaluate and improve our training program. In this article, we present the results of our initial evaluation. We found that the student teachers showed a more significant improvement in their content knowledge, pedagogical content knowledge, and instruction preferences compared to the professional teachers. However, we identified several areas for improvement, which will be addressed in future cycles of the program for further evaluation.

Keywords: astronomy education; preschool education; astronomy content knowledge; pedagogical content knowledge; blended learning; pre-service training; in-service training



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1. Introduction

The training program known as “A Blended learning Approach to Teaching Astronomy to young Children” (ABATAC) was developed to help professional and student teachers develop and deliver astronomy lessons to children in preschool and early school education (years/grades 1, 2, and 3). Here, we present the background and reasoning behind the program, and some of its current results.

Due to its interdisciplinary nature, astronomy is incorporated into STEAM studies (an interdisciplinary approach consisting of science, technology, engineering, art, and math) and improves learning results [1–3]. Learning astronomy in early childhood is vital for developing responsible citizenship, global sustainability principles, skills, knowledge, and attitudes which might enhance children’s accomplishments in the sciences in the short term and over prolonged periods. Astronomy teaches young children observation, classification, prediction, experimentation, and presentation. Finally, in early childhood, children develop their own theory of knowledge as they describe and explain the natural world and develop their own alternative explanations, which are a valid starting point in their scientific explorations [1–4]. Astronomy in early childhood education involves learning about natural occurrences such as the cycle of day and night, moon phases, forces and gravity, light and

shadows, reflections, and more. The ultimate goal of teaching astronomy in early childhood education is to create an inquisitive culture, foster scientific literacy, explore scientific ideas, and ignite curiosity in young children [1]. Thus, educational curricula around the world incorporate teachings about space and the planetary system [5,6]. Additionally, the Greek curriculum for early years education also includes learning objectives and references to this subject matter [7].

While researchers agree that young children can learn about astronomy, it is essential to present scientific information in a way that is appropriate for their age, which requires proper training for educators [4]. This training refers mainly to two dimensions: (a) content knowledge (CK); and (b) didactic approach, which includes pedagogical content knowledge (PCK) [8–10]. PCK, as defined by Shulman [11] (p. 8), is the ability to integrate “content and pedagogy” to understand how specific subjects, problems, or issues should be structured, communicated, adjusted to cater to the varied interests and abilities of learners, and delivered for teaching purposes. Therefore, PCK is crucial for preschool instructors to adjust their educational assistance to match the understanding of children and enhance preschoolers’ scientific knowledge [12].

Various studies reveal that teachers’ lack of knowledge and alternative ideas about the scientific concepts of astronomy (i.e., CK) [13–17] act as a deterrent to its inclusion in their lessons [18–22], and astronomy training can increase teachers’ knowledge of various astronomical phenomena [21]. Research also shows that teachers might not know how to transfer their scientific content knowledge (CK) into school knowledge or an age-appropriate way to encourage children to study physical phenomena (see, for example, [23,24]). This lack of PCK negatively affects their inclination to include innovative approaches such as the STEAM approach in teaching science topics in kindergarten [25–30].

Thus, the ABATAC training program is a systematic effort to provide educators with a complete, comprehensive, and cohesive course for teaching astronomy to young students aged 4–7. While there have been previous attempts to develop teacher training programs, seminars, or educational materials for astronomy lessons, these have been limited in scope and focused on specific astronomy topics (see, for example, [10,31,32]). Studies conclude that to deliver effective astronomy instruction in their classes, teachers need not only good astronomy knowledge but also good knowledge of the most effective teaching approach for each topic [10,33].

ABATAC adopts the idea of learning as a “coherent science content storyline” which strives to move away from the superficial treatment of disconnected science learning activities to provide students with a coherent learning experience of sequenced concepts, ideas, or topics in a manner that “build on one another” ([34] p. 933). In terms of learning activities, the objective is to guide students in recognizing the correlations between questions, evidence, and explanations. On a larger scale, we also turn the learners’ attention to the connections between interconnected concepts and their transferability [35] (such as, for example, studying the phenomenon of day and night alternation in a way that interlocks with their understanding of the concept of pattern). Understanding is more profound, interdisciplinary, and meaningful when concepts are explored in different contexts [36].

In addition, ABATAC adheres to the PCK concept as presented by Gess-Newsome. It includes two “foundational knowledge bases” (CK and PCK), and it encourages teachers to merge them into one knowledge base by organizing cross-curricular activities ([37], p. 13). Thus, the ABATAC program integrates training on both content knowledge (CK) and pedagogical content knowledge (PCK). CK covers fundamental concepts related to stars, planets, satellites, the Moon, our planet, gravity, and small celestial bodies. PCK emphasizes a learner-centered approach to teaching astronomy through inquiry-based learning, the development of spatial thinking, and the understanding of temporal concepts. The program also highlights the importance of alternating between earth-based and space-based perspectives to comprehend the shape, position, and movement of celestial bodies [1].

ABATAC promotes inquiry-based learning (IBL) as the basic learning approach when teaching astronomy to children. It is a student-centered teaching method that emphasizes

active participation, critical thinking, and problem solving through hands-on activities, experiments, and investigations, both individually and in groups, promoting a deeper understanding of scientific processes and fostering a sense of discovery [38]. Furthermore, IBL fosters creativity and critical thinking by encouraging students to handle, use, and analyze information, materials, and ideas, and inspires innovative thinking and problem-solving skills [39,40]. This approach is recommended not only for science education but also for astronomy education, starting from kindergarten and progressing with age-appropriate challenges [6,41–43].

Moreover, as astronomy requires a hybrid approach which combines real-life observations and experiments with special technological tools to study astronomical phenomena that cannot be seen directly [44–46], new digital tools show that virtual environments with a multitude of digital resources and multimodal representations can now be used for astronomy learning [32]. In this respect, blended learning (BL) is an effective method not only for delivering astronomy lessons [47,48] but also for teacher training. Research identifies the need for more studies on how kindergarten, primary, and secondary instructors can benefit from integrating face-to-face seminars with private and collaborative online learning [49–54]. Thus, we developed ABATAC as a BL training program that includes online and in-person training and classroom implementations with support from a team of experts. ABATAC aims to be comprehensive in equipping teachers with the CK, PCK (pedagogical theory), and practical ideas for building a concept-based astronomy curriculum for young children.

The ABATAC training program is divided into three stages. The first stage includes four ABATAC workshops (hereafter, workshops). The second stage involves studying the ABATAC online course (hereafter, the ABATAC course), which is divided into two sections. Section 1 presents basic astronomy CK through multimedia educational materials, diagrams, informational texts, and quizzes. Section 2 introduces the ABATAC program's PCK, which was previously discussed in the workshops. Both the ABATAC course and the workshops contain practical examples and activity ideas for participants to apply their knowledge. The third and final stage is implementing what was learned in the classroom. During this stage, participants are encouraged to keep in touch with the ABATAC program's designers (hereafter, the ABATAC team) for support. The overall duration of the ABATAC training is approximately 18 weeks, with asynchronous and in-person training lasting for 8 weeks, and implementations lasting for 10 weeks with weekly meetings and ongoing support. The first implementation of the ABATAC training program took place during the 2021–22 academic year.

The purpose of this study is to present the primary outcomes of the initial assessment of the ABATAC program. The evaluation was conducted while the program was being implemented and at the end of its first year in order to find out how to optimize its impact. Based on the results, any necessary improvements will be made by following a microcycle of redesigning and testing every new aspect developed in the program [55]. Thus, the following research questions were investigated in this study: 1. What were the primary outcomes of the initial assessment of the ABATAC program? 2. What is the impact of the ABATAC program on the CK and the PCK of preservice (PSTs) and professional teachers (PTs)? 3. What specific aspects of the ABATAC program were the most challenging for the preservice teachers and for professional teachers? 4. What improvements were identified as necessary based on the results of the initial assessment?

2. Materials and Methods

2.1. Research Participants

Our research was conducted in Greece, where children aged 4–6 years are required to attend kindergarten. Thirty kindergarten PTs and forty-six kindergarten PSTs from several regions of Greece participated in the ABATAC training program during the 2021–22 academic year. Due to the novelty of this program and its reliance on funding from a local university, participants were recruited through convenience sampling [56,57]. Our study

required PTs and PSTs to commit to several weeks of study and participate in workshops and the implementation of the program, so it was important to find participants who had a strong interest in astronomy and were willing to actively participate in the program's assessment. An announcement was made for volunteers interested in trying out the new course, which resulted in 30 PTs and 46 PSTs being recruited. The program team recruited 46 PSTs from a pool of 54 enrolled in teaching practice. This ensured that all students received equal supervision from the first researcher.

The Demographic Characteristics of the Sample

As mentioned above, the sample consisted of 76 individuals (46 PSTs and 30 PTs). Tables 1 and 2 show the qualifications and years of professional experience of the sample.

Table 1. The respondents' distribution in terms of qualifications.

Qualifications	Frequency	Percent
"Kindergarten Teacher Degree Equivalency" only	2	2.6
A first degree in education (equivalent to BEd) only	8	10.5
"Kindergarten Teacher School Graduate"	6	7.9
Postgraduate degree	12	15.8
Doctoral degree	2	2.6
Undergraduate student	46	60.6
Total	76	100

Table 2. The professional experience of the sample.

Years of Professional Experience	Frequency	Percent
0	46	60.6
0–5	4	5.4
5–10	4	5.4
10–15	8	10.6
15–20	1	1.4
20–25	11	14.6
25–30	1	1.4
Total	76	

The largest percentage of the sample was female (73, 96.1%) while only 3.9% (3 participants) were male, which is due to the preschool education profession attracting a greater number of females.

According to Table 1, 60.6% of the sample were postgraduate students. Among professional teachers, their qualifications varied and included a first degree in education (equivalent to BEd), postgraduate degrees, "Kindergarten Teacher Degree Equivalency," "Kindergarten Teacher School Graduate," and doctoral studies. All participants with a "Kindergarten Teacher School Graduate" degree, a postgraduate, or a doctoral degree had a first degree in education or a "Kindergarten Teacher Degree Equivalency", which are compulsory prerequisites for Greek kindergarten teachers to be employed.

Regarding professional experience (Table 2), our sample falls into two groups: in the first group were participants with no professional teaching experience, since they were PSTs. In the second group were all other PTs, whose declared professional teaching experience ranged from 0 to 32 years.

2.2. Research Methods and Instruments

Participants' CK and PCK development, as well as their overall evaluation of the ABATAC program, were assessed through questionnaires and an interview. Two questionnaires were used to measure participants' CK and PCK on specific dimensions and sub-dimensions using close-ended questions. Questionnaire 1 (Qr1) was administered three times—before the program (Qr1Admin1), after the ABATAC course (Qr1Admin2), and

after the completion of the entire program (Qr1Admin3). Questionnaire 2 (Qr2) was given after the ABATAC workshops. Questionnaires were distributed using Microsoft Forms.

Participants were interviewed twice after the administration of Qr2 (Int1) and after the third administration of Qr1 (Int2) to clarify their responses and report on their general impression of the ABATAC program. Table 3 shows the arrangement of questionnaires and interviews throughout the ABATAC training program.

Table 3. The arrangement of questionnaires and interviews across different stages of the ABATAC training program.

Stage	Component	Component Content	Supplementary Component Content Running throughout the Duration of the ABATAC Program's Implementation
Before training	Administration 1 of Questionnaire 1 (Qr1Admin1)	Initial assessment of participants' CK and PCK	
The first stage of training (Duration: approx. 4 weeks)	ABATAC workshops	Workshops that introduce the ABATAC program and focus on the rationale for the program, the pedagogical framework, the pedagogical principles, competencies/standards underlying the proposed activities, and the construction of the learning environment	Regular contact with the program team (once a week), discussions, questions and answers, methodological advice
	Administration of Questionnaire 2 (Qr2)	Assessment of participants' PCK and the general difficulty of ABATAC's methodological principles	
After the first stage of training	Open-ended interview (Int1)	Discussion of their overall impression of the training process	
The second stage of training (Duration: approx. 4 weeks)	The ABATAC course	Online course including CK and PCK on the teaching of astronomy	
After the second stage of training	Administration 2 of Questionnaire 1 (Qr1Admin2)	Assessment of participants' CK and PCK	
The third stage of the program: classroom implementation (Duration: approx. 10 weeks)	The ABATAC program's implementation	Lesson planning and implementation by PTs and PSTs	
After classroom implementation	Administration 3 of Questionnaire 1 (Qr1Admin3) Repetition of open-ended interview (Int2)	Overall assessment of participants' CK and PCK Discussion of their overall impression of the program's implementation	

The entire research process was approved by the University's Ethics Committee and the Ministry of Education in Greece, and official permission was granted. The research process also adhered to European Regulation 2016/679 (General Data Protection Regulation (GDPR)). Participants were provided with complete information about the research's scope,

the scope of the publication of our results, their right to withdraw at any time and to request the deletion of their personal data, and the full protection of their anonymity.

To evaluate the impact of ABATAC, we developed our own questionnaires, following an extended literature review and taking into consideration proposals and tools developed by several researchers [58–61] as well as earlier studies on astronomy curriculum for the early years education [1]. The questionnaires were conducted as follows: Five PSTs and five PTs, who were representative of the population but not part of the sample, were asked to fill in the two questionnaires in the presence of one of the researchers. The researcher observed them to note which questions they hesitated to answer or took a long time to answer. After they finished, they were asked to share their experience and identify the questions that intrigued them or were difficult to understand. Furthermore, the researcher discussed any mistakes made in the questions to ensure that this was not due to a misunderstanding. The questions that troubled the respondents were rephrased and tested again with a new pilot group consisting of five PSTs and five PTs who were not part of the original sample.

The questionnaires included questions with closed-ended options, such as single-answer or multiple-choice questions, and multi-item questions rated on a five-point scale. Each of the questions and items included in the questionnaires reflects the content and topics that were covered throughout the duration of the ABATAC program. The first three questions in each questionnaire aimed to collect demographic information about participants, such as their gender, qualifications, and professional teaching experience. Qr1 had 19 CK questions that evaluated respondents' knowledge and comprehension of various phenomena, including gravity, the characteristics and energy of stars, alternation of day and night, alternation of seasons, our planetary system, phases of the moon, orbits of celestial bodies, and the first mission that landed on the moon. It also had two sets of PCK questions. PCK1 used a single multiple-choice question with 22 items to rate the necessity of topics related to the development of spatial thinking (perspective, scale, direction, bird's eye view, 2-D and 3-D geometrical shapes, patterns, regularities, symbols, and space representations such as maps, diagrams, and models of celestial bodies), time perspective, planet identification, orbits of celestial bodies, moon phases, light and shadow, light reflections, and gravity in the astronomy curriculum for young children. It also included references to the importance of external support from parents, specialists, science centers, and planetariums. The rating scale included the following levels: 1. Not at all necessary, 2. Slightly necessary, 3. Moderately necessary, 4. Very necessary, and 5. Highly necessary.

Moreover, Qr1 included a single multiple-choice question named "PCK2" to evaluate the frequency at which respondents were willing to use twelve strategies when implementing astronomy activities, using a 5-point scale. These strategies included presenting new phenomena to children, using images, multimedia resources, and simulations, developing observation techniques, conducting experiments, developing recording skills, using art such as paintings or installations, and allowing students to present their ideas. The respondents were asked to rate how frequently they would use these strategies in their astronomy lessons on a scale of 1 to 5, with 1 = Not at all, 2 = A little, 3 = Sometimes, 4 = Often, and 5 = Very often.

Qr2, which was distributed after the workshops, also contained the PCK2 question. However, the sets of CK and PCK1 questions were not included in Qr2 because the workshops were solely intended to focus on the practical implementation of the IBL and the promotion of children's autonomous inquisitiveness.

Additionally, the ABATAC interviews were conducted to gather further insights and feedback. The ABATAC interviews included the following questions: What is your overall impression of the ABATAC training program? What was your general feeling about teaching astronomy to young children before ABATAC? Has your opinion changed since starting the program? Do you have anything to explain about your responses to the most recent questionnaire? Is there anything about the ABATAC program's implementation that you would like to highlight? Is there anything you would like to mention that was not addressed in the questionnaires or the overall evaluation process?

2.3. Data Analysis

2.3.1. Questionnaire Data Analysis

Data collected in questionnaires were processed using SPSS 21.0. They were coded, entered, and checked for accuracy. Descriptive and inferential statistics were employed. There was only one professional teacher in the sample who did not complete the study for undisclosed reasons. Additionally, there were missing data from one respondent in the PST group in Factors 2, 3, 4, and 5. However, this was a different respondent in each factor. Finally, there was only one PT with missing data in Factor 5 of Qr2. These instances can be treated as random.

2.3.2. Interview Data Analysis

Data collected from the interviews were recorded, fully transcribed, and subjected to “thematic analysis”. First, the data underwent inductive open-ended coding, resulting in various sets of codes. Microsoft OneNote was used to organize the coding process by tagging text and creating hyperlinks for easy navigation. These codes were reviewed multiple times through open and closed coding repetitions, the data were reorganized, and the codes were refined until “internal homogeneity” and “external heterogeneity” were achieved [62–64]. The internal homogeneity ensured that data categorized under each code were cohesive and meaningful, and external heterogeneity ensured that there was sharpness and clarity in the distinctions between the various categories [64]. A process of intercoder agreement was established in which two researchers coded the data. Points of disagreement were discussed with a third, independent reviewer who helped the review team to reach a final consensus [65].

3. Results

3.1. The Impact of ABATAC on the Participants’ Content Knowledge (CK)

Table 4 presents the participants’ scores for Qr1, which was administered three times in each group (PSTs and PTs). There was an increase in the mean of the PSTs between the three administered tests (Qr1Admin1: $M = 9.93$, $SD = 2.84$; Qr1Admin2: $M = 13.04$, $SD = 3.06$; and Qr1Admin3: $M = 13.50$, $SD = 2.83$). The PTs increased their performance between the first and the second administered tests but there was a slight decrease in their performance between the second and the third administered tests (Qr1Admin1: $M = 13.93$, $SD = 2.94$; Qr1Admin2: $M = 16.57$, $SD = 2.10$; and Qr1Admin3: $M = 16.31$, $SD = 2.16$).

Table 4. CK scores for Questionnaire 1, which was administered three times in each group.

Status	Variables	N	Minimum	Maximum	Mean	Std. Deviation
PSTs	Score Qr1Admin1	46	3	17	9.93	2.84
	Score Qr1Admin2	46	6	19	13.04	3.06
	Score Qr1Admin3	46	7	19	13.50	2.83
PTs	Score Qr1Admin1	30	6	19	13.93	2.94
	Score Qr1Admin2	30	11	20	16.57	2.10
	Score Qr1Admin3	29	11	20	16.31	2.16

The differences in the performance of the participants between the three administered tests of Qr1 were determined for each group (PTs and PSTs), and this showed that we cannot reject the hypothesis of normality in all cases at $p > 0.05$ (see Table 5). Thus, a paired samples t -test was performed to detect the significance of the differences in CK scores between the three administered tests of Qr1 in each group (PSTs and PTs) (see Table 6).

Table 5. Shapiro–Wilk tests of normality for the differences in the CK scores for each group.

Variables	Status	Shapiro–Wilk		
		Statistic	df	Sig.
Difference Qr1Admin1-Qr1Admin2	PSTs	0.98	46	0.65
	PTs	0.96	29	0.26
Difference Qr1Admin2-Qr1Admin3	PSTs	0.95	46	0.05
	PTs	0.96	29	0.33
Difference Qr1Admin1-Qr1Admin3	PSTs	0.98	46	0.41
	PTs	0.94	29	0.09

Table 6. Paired samples *t*-test for CK scores for each group.

Paired Sample	Status	Paired Differences		t	df	Sig. (2-Tailed)	Cohen's d
		Mean	Std. Deviation				
Qr1Admin1- Qr1Admin2	PSTs	−3.11	3.18	−6.63	45	0.000	1.05
	PTs	−2.63	2.88	−5.00	29	0.000	1.01
Qr1Admin2- Qr1Admin3	PSTs	−0.46	2.10	−1.48	45	0.146	0.15
	PTs	0.24	2.12	0.61	28	0.544	0.11
Qr1Admin1- Qr1Admin3	PSTs	−3.56	2.66	−9.08	45	0.000	1.26
	PTs	−2.34	3.36	−3.75	28	0.001	0.90

As we can see in Table 6, both groups (the PSTs and PTs) displayed statistically significant performance differences after the first test (Qr1Admin1-Qr1Admin2) and between the first and the final test (Qr1Admin1-Qr1Admin3). More specifically, the PSTs showed a statistically significant improvement in the comparison between the first and second administered tests of Questionnaire 1 (Qr1) ($t(45) = -6.63$, $p < 0.01$, with a large effect size ($d = 1.05$; sensu Cohen, 1988) (all interpretations of the magnitude of effect sizes follow Cohen's (1988) [66] suggestions)) and in the comparison between the first and third administrated tests of Qr1 ($t(45) = -9.08$, $p < 0.01$, with a large effect size ($d = 1.26$)).

In a similar way, the PTs showed statistically significant differences in the comparison between Qr1Admin1 and Qr1Admin2, ($t(29) = -5.00$, $p < 0.01$, with a large effect size ($d = 1.01$)) and the comparison between Qr1Admin1 and Qr1Admin3 ($t(28) = -3.75$, $p < 0.01$, with a large effect size ($d = 0.90$)).

3.2. The Impact of ABATAC Educational Program on the Participants' Pedagogical Content Knowledge I (PCK1)

The development of the participants' PCK was monitored using two questions (PCK1 and PCK2). PCK1 asked respondents to rate the degree of necessity they placed on 22 items using a five-point, Likert-type rating scale (1. Not at all necessary, 2. Slightly necessary, 3. Moderately necessary, 4. Very necessary, 5. Highly necessary). The items referred to the basic topics introduced to the astronomy education curriculum by the ABATAC program, e.g., time and space concepts. The participants were asked to rate these statements at three different phases: before the start of the program, after completing the ABATAC course, and after completing the entire program.

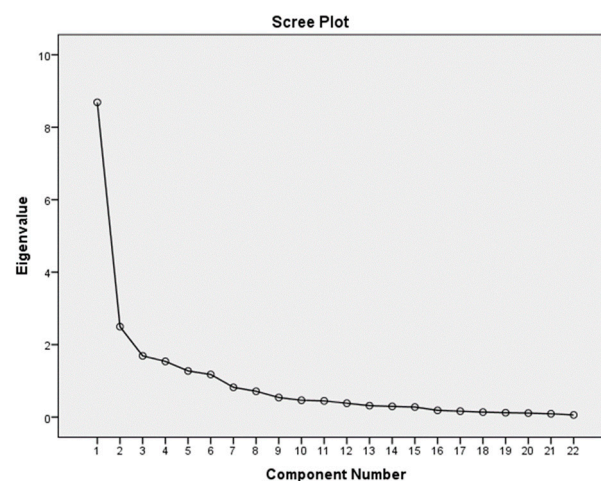
The 22 items of PCK1 were grouped following a factor analysis with a principal component analysis as the method to estimate parameters (Table 7). A normality test was performed, and then paired samples *t*-tests and Wilcoxon rank-sum tests were conducted to determine if there were any significant changes in the mean values of the factors between the different stages of the ABATAC program.

Table 7. Rotated component matrix ^a for PCK1.

Question Item (QIt)	Component		Factor
	1	2	
QIt1	0.548	0.210	Factor 1—Basic concepts
QIt2	0.622	0.177	
QIt3	0.733	0.072	
QIt4	0.578	0.099	
QIt5	0.642	0.250	
QIt6	0.662	0.241	
QIt7	0.611	−0.252	
QIt8	0.657	0.227	
QIt9	0.680	0.293	
QIt10	0.657	0.118	
QIt11	0.824	0.104	
QIt12	0.770	0.005	
QIt13	0.628	−0.218	
QIt14	0.660	−0.140	
QIt15	0.747	−0.211	
QIt16	0.780	0.075	
QIt17	0.779	0.128	
QIt18	0.748	0.112	
QIt19	0.206	0.767	Factor 2—External support
QIt20	−0.015	0.605	
QIt21	0.090	0.749	
QIt22	−0.040	0.698	

Extraction method: Principal component analysis. Rotation method: Varimax with Kaiser normalization. ^a Rotation converged in 3 iterations.

The KMO measure for sample adequacy is equal to 0.81, and the p value in Barlett's test of sphericity is <0.01 , showing that the characteristics of our data allow us to conduct an exploratory factor analysis. To investigate the factor structure, the principal component method with varimax rotation was applied. The results showed an acceptable two-factor solution (first eigenvalue: 8.7; second eigenvalue: 2.5) that explained 51% of the total variance (Figure 1). Factor 1 "Basic concepts" explains 39.5% of the total variance, and Factor 2 "External support" explains 11.4%. The "Basic concepts" factor included the items that referred to the necessity of learning about the planets, time and space concepts, gravity, and light. The "External support" factor included items that referred to the use of external support in the teaching of astronomy.

**Figure 1.** Scree plot of the eigenvalues of principal component analysis for PCK1.

To investigate the reliability of Factors 1 and 2, Cronbach’s alpha coefficient was calculated (Table 8).

Table 8. Reliability Cronbach’s alpha for Factors 1 and 2 in PCK 1.

Factor	Cronbach’s Alpha	N of Items
1	0.931	18
2	0.755	4

The Cronbach’s α coefficients were 0.931 for Factor 1 and 0.755 for Factor 2, indicating an acceptable level of reliability.

As we can see in Table 9, for Factor 1, there is an increase in the mean scores from the first ($M = 3.78, SD = 0.68$) to the second administered tests of Questionnaire 1 ($M = 4.23, SD = 0.45$) but a slight decrease in the mean scores from the second to the third administered tests ($M = 4.15, SD = 0.53$) of the PSTs. Regarding the performance of the PTs, there is a decrease in the mean scores from the first ($M = 4.27, SD = 0.54$) to the second administered tests ($M = 4.20, SD = 0.77$) and a slight increase in the mean scores from the second to the third administered tests of Questionnaire 1 ($M = 4.22, SD = 0.59$).

Table 9. Factor 1 and Factor 2 descriptive statistics for each group.

Factor	Status	Variables	N	Mean	Std. Deviation
Factor 1—Basic Concepts	PSTs	Qr1Admin1	46	3.78	0.68
		Qr1Admin2	46	4.23	0.45
		Qr1Admin3	46	4.15	0.53
	PTs	Qr1Admin1	30	4.27	0.54
		Qr1Admin2	30	4.20	0.77
		Qr1Admin3	29	4.22	0.59
Factor 2—External Support	PSTs	Qr1Admin1	45	4.52	0.53
		Qr1Admin2	46	4.21	0.63
		Qr1Admin3	46	4.37	0.55
	PTs	Qr1Admin1	30	4.05	0.52
		Qr1Admin2	30	4.14	0.65
		Qr1Admin3	29	4.14	0.55

For Factor 2, there is a decrease in the mean scores from the first ($M = 4.52, SD = 0.53$) to the second administered tests ($M = 4.21, SD = 0.63$) and an increase in the mean scores from the second to third administered tests of Questionnaire 1 ($M = 4.37, SD = 0.55$) of the PSTs. The PTs show an increase from the first ($M = 4.05, SD = 0.52$) to the second administered tests ($M = 4.14, SD = 0.65$) and an increase in the mean scores between the second and third administered tests of Questionnaire 1 ($M = 4.14, SD = 0.55$).

As we can see in Table 10, for Factor 1, for the PSTs, the normality assumption was not rejected only for the variable Improvement Qr1Admin1-Qr1Admin3 in both groups (PSTs: $W = 0.95, p > 0.05$; PTs: $W = 0.97, p > 0.05$) according to the Shapiro–Wilk tests; thus, paired samples *t*-test were performed to compare the means of the first and the third administered tests of Questionnaire 1.

Regarding Factor 2 for the PSTs, the improvement was significantly not normally distributed in all the variables (Qr1Admin1-QrAdmin2: $W = 0.88, p < 0.01$; Qr1Admin1-Qr1Admin3: $W = 0.93, p < 0.05$; and Qr1Admin2-Qr1Admin3: $W = 0.93, p < 0.01$) according to the Shapiro–Wilk tests. Thus, the Wilcoxon signed-rank test was performed to compare the means of the different administrated tests of Questionnaire 1. In the PTs, the normality of the distributions of improvement in Factor 2 was not rejected for all the variables (Qr1Admin1-Qr1Admin2: $W = 0.96, p > 0.05$; Qr1Admin1-Qr1Admin3: $W = 0.93, p > 0.05$; and Qr1Admin2-Qr1Admin3: $W = 0.95, p > 0.05$) according to the Shapiro–Wilk tests.

Therefore, a paired samples *t*-test was used to compare the performance of the PTs for the different administrated tests of Questionnaire 1. Table 11 shows the results of the Wilcoxon signed-rank test for the mean scores of the administrated tests without a normal distribution of improvement.

Table 10. Tests of normality for the differences in Factor 1 and 2 of PCK1 between PSTs and PTs.

Factor	Questionnaire/Administration	PSTs/PTs	Shapiro–Wilk		
			Statistic	df	Sig.
Factor 1—Basic Concepts	Improvement Qr1Admin1-Qr1Admin2	PSTs	0.93	46	0.010
		PTs	0.85	29	0.001
	Improvement Qr1Admin1-Qr1Admin3	PSTs	0.95	46	0.063
		PTs	0.97	29	0.545
	Improvement Qr1Admin2-Qr1Admin3	PSTs	0.95	46	0.045
		PTs	0.74	29	0.000
Factor 2—External Support	Improvement Qr1Admin1-Qr1Admin2	PSTs	0.88	45	0.000
		PTs	0.96	29	0.393
	Improvement Qr1Admin1-Qr1Admin3	PSTs	0.94	45	0.026
		PTs	0.93	29	0.073
	Improvement Qr1Admin2-Qr1Admin3	PSTs	0.93	45	0.009
		PTs	0.95	29	0.177

Table 11. Related samples’ Wilcoxon signed-rank tests for Factor 1.

PSTs/PTs	Related Samples	N	Z-Value	<i>p</i>	Cohen’s <i>d</i>
PSTs	Qr1Admin1-Qr1Admin2	46	3.83	0.000	1.37
	Qr1Admin2-Qr1Admin3	46	−1.20	0.231	0.36
PTs	Qr1Admin1-Qr1Admin2	30	0.21	0.838	0.08
	Qr1Admin2-Qr1Admin3	29	−0.72	0.475	0.27

As we can see in Table 12, for Factor 1, only one test showed a statistically significant difference: the comparison of the PSTs’ mean scores in the first and second administrated tests of Questionnaire 1 (QrAdmin1-Q1Admin2), in which $z = 3.83, p < 0.01$, with a large effect size of $d = 1.37$. All the other tests for the PSTs and PTs did not yield statistically significant results.

Table 12. Factor 1 paired samples *t*-tests.

PSTs/PT	Paired Samples	Paired Differences			df	Sig. (2-Tailed)	Cohen’s <i>d</i>
		Mean	Std. Deviation	<i>t</i>			
PSTs	Qr1Admin1-Qr1Admin3	−0.37	0.83	−3.02	45	0.004	0.36
PTs	Qr1Admin1-Qr1Admin3	0.04	0.67	0.37	28	0.714	0.08

The paired samples *t*-test showed a significant difference in mean performance scores between the first and third administrated tests of Questionnaire 1 (Qr1Admin1-Qr1Admin3) in the PSTs ($t(45) = -3.02, p < 0.01, d = 0.36$). However, a comparison of the Factor 1 mean scores between the first and third administrated tests of Questionnaire 1 in the PTs showed a non-statistically significant difference.

In Table 13, we present the Wilcoxon signed-rank tests of the Factor 2 mean scores given for the three administrated tests of Questionnaire 1. The comparison of means showed statistically significant differences between the samples of the first and the second

administrated tests and between the first and the third administrated tests of Questionnaire 1 (in Qr1Admin1-Qr1Admin2 $z = -3.48, p < 0.01$, with a large effect size: $d = 1.21$; in Qr1Admin1-Qr1Admin3 $z = -1.97, p = 0.048 < 0.05$, with an intermediate effect size: $d = 0.62$). The comparison of the mean scores given for the second and the third administrated tests of Questionnaire 1 showed that $z = 1.80 (p = 0.072 < 0.1)$ with an intermediate effect size ($d = 0.55$), indicating a mean difference that is weakly significant.

Table 13. Related samples’ Wilcoxon signed-rank tests for PSTs for Factor 2.

PSTs/PTs	Related Samples	N	Z-Value	p	Cohen’s d
PSTs	Qr1Admin1-Qr1Admin2	45	−3.48	0.001	1.21
	Qr1Admin2-Qr1Admin3	46	1.80	0.072	0.55
	Qr1Admin1-Qr1Admin3	45	−1.97	0.048	0.62

Table 14 shows the results of a comparison of the mean scores between the three administrated tests of Questionnaire 1 for the PTs. None of the comparisons yielded statistically significant improvements.

Table 14. Paired samples test for PTs for Factor 2.

Paired Samples	Paired Differences		t	df	Sig. (2-Tailed)	Cohen’s d
	Mean	Std. Deviation				
Qr1Admin1-Qr1Admin2	−0.09	0.76	−0.66	29	0.516	0.16
Qr1Admin2-Qr1Admin3	−0.02	0.33	−0.42	28	0.676	0.04
Qr1Admin1-Qr1Admin3	−0.09	0.69	−0.67	28	0.508	0.16

In summary, for Factor 1, the PSTs showed an increase in the mean scores observed between the first and the second administrated tests of Questionnaire 1, which was statistically significant, but then, there was a decrease in the performance between the second and the third administrated tests, which was not statistically significant. The overall difference between the first and the third administrated tests was of limited statistical significance. The performance of the PTs dropped slightly between the first and second administrated tests of Questionnaire 1 and then picked up slightly in the third administrated tests, but these differences were not statistically significant.

For Factor 2, the PSTs showed a statistically significant drop between the first and second administrated tests of Questionnaire 1, and then an increased mean score between the second and third administrated tests. Still, there was an overall decline between the first and third administrated tests, which was weakly statistically significant. The PTs increased their performance between the three administrated tests, although this improvement was not statistically significant.

3.3. The Impact of ABATAC Educational Program on the Participants’ Pedagogical Content Knowledge II (PCK2)

PCK2 was a 12-item question using a five-point Likert-type rating scale to evaluate the frequency at which respondents were willing to use the 12 strategies that are essential for a learner-centered and inquiry-based approach to teaching astronomy. PCK2 was a part of both questionnaires (Qr1 and Qr2). So, participants were prompted to rate these statements at four different phases: before the start of the educational program (Qr1Admin1), after completing the workshops (Qr2), upon the completion of the ABATAC course (Qr1Admin2), and after completing the entire educational program (Qr1Admin3). The 12 items of PCK2 were grouped following a factor analysis with a principal component analysis as the method to estimate parameters (see Table 15). Furthermore, a normality test was performed, and paired samples comparisons were conducted to determine if there were any significant differences in participants’ preferences between the ABATAC phases.

Table 15. Factor analysis with rotated component matrix ^a for PCK2.

Question Item (QIt)	Component			Factor
	1	2	3	
QIt5	0.834	0.252	0.029	Factor 3—Processes of inquiry-based learning (IBL)
QIt4	0.789	0.122	0.135	
QIt11	0.637	0.288	−0.095	
QIt3	0.636	0.127	0.391	
QIt7	0.159	0.843	0.138	Factor 4—Promoting autonomy in IBL and artmaking
QIt8	0.323	0.714	0.188	
QIt6	0.288	0.650	0.045	
QIt9	−0.244	0.542	0.452	
QIt10	0.134	0.520	0.208	
QIt12	0.324	0.412	−0.151	
QIt1	−0.035	0.119	0.808	Factor 5—Teacher-directed strategies
QIt2	0.372	0.169	0.768	

Extraction Method: principal component analysis. Rotation Method: varimax with Kaiser normalization. ^a Rotation converged in 8 iterations.

The KMO measure of sample adequacy was equal to 0.78, and the *p* value of Barlett’s test of sphericity was < 0.01, showing that the characteristics of our data allow us to conduct an exploratory factor analysis. To investigate the factor structure, the principal component method with varimax rotation was applied. The results showed an acceptable three-factor solution (first eigenvalue: 4.26, second eigenvalue: 1.58, third eigenvalue: 1.16), which explained 58.4% of the total variance (Figure 2).

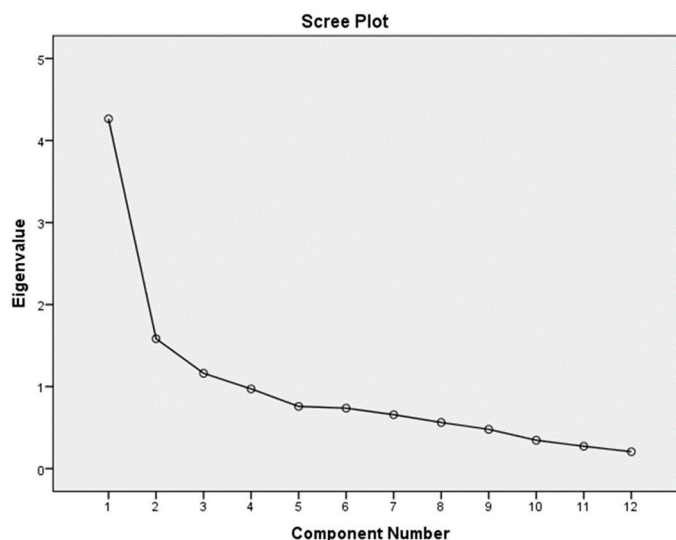


Figure 2. Scree plot of the eigenvalues of principal component analysis for PCK2.

Factor 3, “Processes of Inquiry-Based Learning” (items QIt3, QIt4, QIt5, and QIt11), explains 35.55% of the total variance, Factor 4, “Promoting autonomy in IBL and artmaking” (items QIt6, QIt7, QIt8, QIt9, QIt10, and QIt12), explains 13.2%, and Factor 5, “Teacher-directed strategies” (items QIt1 and QIt2), explains 9.7%. Factor 3, “Processes of Inquiry-Based Learning”, contained items referring to the use of educational resources and the processes of scientific inquiry (observations, experiments, and interpretations of results). Factor 4, “Promoting autonomy in IBL and artmaking”, refers to processes that promote children’s initiative in research and the recording of results, art making, and collaborative activities. Factor 5 refers to more teacher-directed strategies, such as teacher presentations and providing ready-made explanations to the children.

To investigate the reliability of Factors 3, 4, and 5, the Cronbach’s alpha coefficient was calculated.

The Cronbach’s α indexes were 0.773 for Factor 3 and 0.729 for Factor 4, which are acceptable and indicate a high degree of reliability. For Factor 5, the Cronbach’s α index was $0.614 < 0.7$, which is acceptable nonetheless, considering that the factor consists of only two items (see Table 16).

Table 16. Reliability Cronbach’s statistics for Factors 3, 4, and 5 in PCK2.

Factor	Cronbach’s Alpha	No. of Items
3	0.773	4
4	0.729	6
5	0.614	2

As we can see in Table 17, the mean scores increase in Factors 3 and 4 in the PSTs and in Factor 4 in the PTs. In factor 3, the mean scores of the PTs decrease from Qr1Admin1 (M = 4.43, SD = 0.60) to Qr2 (M = 4.52, SD = 0.50), from Qr2 to Qr1Admin2 (M = 4.77, SD = 0.33), and from Qr1Admin2 to Qr1Admin3 (M = 4.75, SD = 0.37).

Table 17. Descriptive statistics for Factors 3, 4, and 5 for each group.

Factor	Status	Variables	N	Mean	Std. Deviation
Factor 3—Processes of inquiry-based learning	PSTs	Qr1Admin1	45	4.45	0.53
		Qr2	46	4.40	0.44
		Qr1Admin2	46	4.69	0.38
		Qr1Admin3	46	4.77	0.34
	PTs	Qr1Admin1	30	4.43	0.60
		Qr2	30	4.52	0.50
		Qr1Admin2	30	4.77	0.33
		Qr1Admin3	29	4.75	0.37
Factor 4—Promoting autonomy in IBL and artmaking	PSTs	Qr1Admin1	45	3.83	0.71
		Qr2	46	4.09	0.53
		Qr1Admin2	46	4.33	0.51
		Qr1Admin3	46	4.50	0.39
	PTs	Qr1Admin1	30	4.05	0.50
		Qr2	30	4.17	0.40
		Qr1Admin2	30	4.29	0.46
		Qr1Admin3	29	4.32	0.40
Factor 5—Teacher-directed strategies	PSTs	Qr1Admin1	45	4.00	0.89
		Qr2	46	3.54	1.04
		Qr1Admin2	46	3.76	0.81
		Qr1Admin3	46	3.67	0.84
	PTs	Qr1Admin1	30	4.13	0.54
		Qr2	29	3.36	1.00
		Qr1Admin2	30	3.40	0.83
		Qr1Admin3	29	3.16	0.91

For Factor 5, the mean scores of both groups (PSTs and PTs) slightly fluctuate. For the PSTs, we observe a decrease in the mean scores from Qr1Admin1 (M = 4.00, SD = 0.89) to Qr2 (M = 3.54, SD = 1.04) and a small increase from Qr2 to Qr1Admin2 (M = 3.76, SD = 0.81). Finally, the mean score drops slightly from Qr1Admin2 to Qr1Admin3 (M = 3.67, SD = 0.84). The PTs show a decrease from Qr1Admin1 (M = 4.13, SD = 0.54) to Qr2 (M = 3.36, SD = 1.00), a slight increase from Qr2 to Qr1Admin2 (M = 3.40, SD = 0.83), and a further decrease from Qr1Admin2 to Qr1Admin3 (M = 3.16, SD = 0.91).

As we can see in Table 18, for the PSTs, the normality of the distributions of differences was rejected for all the variables of Factor 3 and was not rejected ($p > 0.05$) in all the variables of Factor 4 according to the Shapiro–Wilk tests. In Factor 5, the normality of the distributions of differences was rejected for the variables Qr1Admin1-Qr2 ($W = 0.95$, $p < 0.05$) and Qr1Admin2-Qr1Admin3 ($W = 0.88$, $p < 0.01$) but not for the variables Qr2-Qr1Admin2 ($W = 0.97$, $p > 0.05$) or Qr1Admin1-Qr1Admin3 ($W = 0.96$, $p > 0.05$), according to the Shapiro–Wilk tests.

Table 18. Shapiro-Wilk tests of normality for the differences in Factors 3–5 of PCK2 in each group.

Factor	Questionnaire/Administration	PSTs/PTs	Shapiro–Wilk		
			Statistic	df	Sig.
Factor 3—Processes of inquiry-based learning	Difference Qr1Admin1-Qr2	PSTs	0.94	45	0.025
		PTs	0.90	29	0.011
	Difference Qr2-Qr1Admin2	PSTs	0.92	45	0.004
		PTs	0.96	29	0.308
	Difference Qr1Admin2-Qr1Admin3	PSTs	0.86	45	0.000
		PTs	0.81	29	0.000
	Difference Qr1Admin1-Qr1Admin3	PSTs	0.92	45	0.004
		PTs	0.96	29	0.297
Factor 4—Promoting autonomy in IBL and artmaking	Difference Qr1Admin1-Qr2	PSTs	0.97	45	0.315
		PTs	0.97	29	0.615
	Difference Qr2-Qr1Admin2	PSTs	0.97	45	0.310
		PTs	0.96	29	0.347
	Difference Qr1Admin2-Qr1Admin3	PSTs	0.98	45	0.500
		PTs	0.94	29	0.121
	Difference Qr1Admin1-Qr1Admin3	PSTs	0.98	45	0.579
		PTs	0.96	29	0.335
Factor 5—Teacher-directed strategies	Difference Qr1Admin1-Qr2	PSTs	0.95	45	0.039
		PTs	0.95	28	0.242
	Difference Qr2-Qr1Admin2	PSTs	0.97	45	0.243
		PTs	0.95	28	0.199
	Difference Qr1Admin2-Qr1Admin3	PSTs	0.88	45	0.000
		PTs	0.91	28	0.023
	Difference Qr1Admin1-Qr1Admin3	PSTs	0.96	45	0.082
		PTs	0.95	28	0.214

For the PTs, the normality of the distributions of the differences was not rejected ($p > 0.05$) for all the variables of Factor 4. For Factor 3, the normality was rejected for the variables Qr1Admin1-Qr2 ($W = 0.90$, $p < 0.05$) and Qr1Admin2-Qr1Admin3 ($W = 0.81$, $p < 0.01$) and not rejected for the variables Qr2-Qr1Admin2 ($W = 0.96$, $p > 0.05$) and Qr1Admin1-Qr1Admin3 ($W = 0.96$, $p > 0.05$), according to the Shapiro–Wilk tests. For Factor 5, the normality of distributions was not rejected for the variables Qr1Admin1-Qr2 ($W = 0.95$, $p > 0.05$), Qr2-Qr1Admin2 ($W = 0.95$, $p > 0.05$), and Qr1Admin1-Qr1Admin3 ($W = 0.95$, $p > 0.05$), and it was rejected for the variable Qrdmin1A2-Qrdmin1A3 ($W = 0.91$, $p < 0.05$), according to the Shapiro–Wilk tests.

A Wilcoxon signed-rank test was used to compare the means of the variables with non-normal distributions of differences, while a paired samples *t*-test was used to compare the performance of the variables with normal distributions of differences.

In Table 19, we can see that, regarding the PSTs in Factor 3, in a comparison of the related samples of Qr1Admin2-Qr1Admin3, the Wilcoxon signed-rank test showed that $z = 1.73$ ($p = 0.084 < 0.1$) with an intermediate effect size ($d = 0.53$), which indicates that the

difference is weakly statistically significant. Moreover, the comparison of related samples of Qr2-Qr1Admin2 ($z = 3.77, p < 0.01$, with a large effect size: $d = 1.34$), and the related samples of Qr1Admin1-Qr1Admin3 ($z = 3.61, p < 0.01$, with a large effect size: $d = 1.28$) showed statistically significant differences. All other comparisons for the PSTs or PTs did not show statistically significant differences.

Table 19. Related samples’ Wilcoxon signed-rank tests for Factor 3.

PSTs/PTs	Related samples	N	Z-Value	<i>p</i>	Cohen’s <i>d</i>
PSTs	Qr1Admin1-Qr2	45	−0.83	0.408	0.25
	Qr2-Qr1Admin2	46	3.77	0.000	1.34
	Qr1Admin2-Qr1Admin3	46	1.73	0.084	0.53
	Qr1Admin1-Qr1Admin3	45	3.61	0.000	1.28
PTs	Qr1Admin1-Qr2	30	0.52	0.599	0.19
	Qr1Admin2-Qr1Admin3	29	−0.39	−0.695	0.14

Table 20 presents the results of the paired samples *t*-tests that were performed for the Factor 3 variables with a normal distribution in the group of PTs. Both tests revealed a statistically significant difference of the two samples. More specifically, the comparison of the mean scores in the administrated test of Questionnaire 2 with those in the second administrated test of Questionnaire 1 (Qr1Admin2) showed that $t = -2.81$ ($p = 0.009 < 0.01$) with an intermediate effect size ($d = 0.58$), and the comparison between the first (Qr1Admin1) and the third (Qrdmin1A3) administrated tests of Questionnaire 1 showed that $t = -2.61$ with $p = 0.014 < 0.05$, with an intermediate effect size ($d = 0.64$).

Table 20. Paired samples *t*-tests for Factor 3.

PSTs/PTs	Paired Samples	Paired Differences		<i>t</i>	<i>df</i>	Sig. (2-Tailed)	Cohen’s <i>d</i>
		Mean	Std. Deviation				
PTs	Qr2-Qr1Admin2	−0.25	0.49	−2.81	29	0.009	0.58
PTs	Qr1Admin1-Qr1Admin3	−0.33	0.68	−2.61	28	0.0014	0.64

In summary, the PSTs showed an increase in their preference for IBL processes when planning for astronomy activities, and this improvement was statistically significant in most of the comparisons. The PTs showed an increase that was statistically significant between Q2 and Q1A2 and between Q1A1 and Q1A3.

Since the distributions for Factor 4 were significantly normal for all the variables ($p > 0.05$) according to Shapiro–Wilk tests, we performed paired samples *t*-tests on all the variables.

Regarding the PSTs (Table 21), all the paired samples *t*-tests that compared their performance between the questionnaires in Factor 4 showed a statistically significant difference. However, only the Qrr1Admin1-Qr1Admin3 comparison showed a large effect size ($d = 1.14$). The PTs showed an improvement that was not statistically significant between the ABATAC stages, and only the comparison between Qr1Admin1 and Qr1Admin2 showed a statistically significant overall improvement ($t(28) = -2.45, p = 0.021 < 0.05$, with an intermediate effect size: $d = 0.55$). All other *t*-tests yielded results that were not statistically significant.

Table 21. Paired samples *t*-tests in each group for Factor 4.

PSTs/PTs	Paired Samples	Paired Differences		t	df	Sig. (2-Tailed)	Cohen’s d
		Mean	Std. Deviation				
PSTs	Qr1Admin1-Qr2	−0.27	0.73	−2.47	44	0.017	0.43
	Qr2-Qr1Admin2	−0.23	0.62	−2.58	45	0.013	0.45
	Qr1Admin2-Qr1Admin3	−0.17	0.49	−2.36	45	0.023	0.37
	Qr1Admin1-Qr1Admin3	−0.66	0.73	−6.08	44	0.000	1.14
PTs	Qr1Admin1-Qr2	−0.12	0.59	−1.10	29	0.282	0.26
	Qr2-Qr1Admin2	−0.12	0.60	−1.07	29	0.293	0.27
	Qr1Admin2-Qr1Admin3	−0.03	0.41	−0.38	28	0.709	0.07
	Qr1Admin1-Qr1Admin3	−0.25	0.57	−2.45	28	0.021	0.55

Factor 5 refers to teacher-directed instructional strategies, which ought to be subordinate to inquiry-based learning. Consequently, as the ABATAC stages progress, participants should exhibit a diminished inclination towards Factor 5 items. So, for the PSTs, the Wilcoxon signed-rank test showed the following results (see Table 22): the comparison of the mean scores of Qr1Admin1 and Qr2 showed that $z = -2.88$ ($p = 0.005 < 0.01$) with a large effect size ($d = 0.95$), indicating that there was a statistically significant reduction in the respondents’ preferences. There was a further reduction in the comparison of the mean scores between Qr1Admin2 and Qr1Admin3, which was not statistically significant. Similarly, the PTs showed a reduction in their level of preference in the second test of Qr1Admin2 and the third test of Questionnaire 1, which was not statistically significant.

Table 22. Related samples’ Wilcoxon signed-rank tests for Factor 5.

PSTs/PTs	Related Samples	N	Z-Value	<i>p</i>	Cohen’s d
PSTs	Qr1Admin1-Qr2	45	−2.88	0.005	0.95
	Qr1Admin2-Qr1Admin3	46	−1.06	0.291	0.32
PTs	Qr1Admin2-Qr1Admin3	29	−1.42	0.156	0.55

In the paired samples *t*-tests run for Factor 5 (Table 23), we found statistically significant improvements: the PSTs improved in the comparison between Qr1Admin1 and Qr1Admin3, which had a small effect size ($t(44) = 2.25$, $p = 0.029 < 0.05$, $d = 0.41$). The PTs improved in the comparison of mean scores between Qr1Admin1 and Qr2 ($t(28) = 3.69$, $p < 0.01$), with an intermediate effect size ($d = 0.581$), which indicated a statistically significant reduction of their level of preference. A statistically significant improvement was also observed in the comparison of mean scores between Qr1Admin1 and Qr1Admin3 ($t(28) = 5.35$, $p < 0.01$, with a large effect size: $d = 1.27$).

Table 23. Paired samples *t*-tests for Factor 5.

PSTs/PTs	Paired Samples	Paired Differences		t	df	Sig. (2-Tailed)	Cohen’s d
		Mean	Std. Deviation				
PSTs	Qr2-Qr1Admin2	−0.22	1.03	−1.43	45	0.160	0.23
	Qr1Admin1-Qr1Admin3	0.35	1.06	2.25	44	0.029	0.41
PTs	Qr1Admin1-Qr2	0.76	1.11	3.69	28	0.001	0.58
	Qr2-Qr1Admin2	−0.07	1.13	−0.33	28	0.745	0.07
	Qr1Admin1-Qr1Admin3	0.96	0.97	5.35	28	0.000	1.27

In summary, there was a reduction in the mean scores of Factor 5 for the PSTs during the first stage of the ABATAC program, which was statistically significant. In subsequent stages, the mean scores increased slightly, but this difference was not statistically significant.

The overall comparison between Qr1Admin1 and Qr1Admin3 did not yield a statistically significant difference, and this requires further attention. The PTs also displayed a statistically significant reduction in their preference for teacher-directed strategies at the initial stage of ABATAC, but this improvement was unstable in subsequent stages. Finally, the overall improvement observed between Qr1Admin1 and Qr1Admin3 was statistically significant.

The overall analysis of the data collected from the questionnaires shows that that ABATAC had a beneficial effect on educators’ proclivity toward activities that encourage children’s autonomy, coupled with a notable reduction in their preference for a teacher-led approach. Likewise, ABATAC led to an enhancement in the educators’ subject matter and pedagogical content expertise.

3.4. Interview Analysis Results

The thematic analysis of the interview data started with open-ended coding through multiple open and closed coding repetitions. A final set of codes emerged that were grouped in the following major categories: difficulties that the participants (PTs and PSTs) encountered during the implementation of the ABATAC training program, factors that helped the PTs and PSTs implement the ABATAC activities in their classroom, prerequisites for teaching astronomy, and PTs’ and PSTs’ perceptions of teaching macrocosm concepts and phenomena to young children prior to and after the completion of the ABATAC training program.

Table 24 displays the final set of codes and the number of cases, which was obtained at the end of the thematic analysis.

Table 24. Thematic analysis results.

General Code Categories	Sub-Codes	No of Cases PTs Int1 ¹	No of Cases PTs Int2 ²	No of Cases PSTs Int1 ³	No of Cases PSTs Int2 ⁴
Difficulties that the participants encountered during the implementation of the ABATAC program	Lack of time to study the ABATAC course	5	7	2	5
	Navigation of the ABATAC course platform	1	6	2	5
	The amount of information in the ABATAC course	1	9	1	3
	Lack of prior astronomy CK	5	4	12	21
	Lack of teaching experience	0	0	15	7
	Lack of teaching resources	6	4	5	4
	Unfamiliar teaching subject	10	6	16	22
	It requires good preparation	4	3	9	8
	Lack of teaching time in the school schedule	4	10	1	2
	Grasping the ABATAC’s PCK	5	6	4	3
	Adaptation of astronomical concepts and phenomena to children’s cognitive level and interests	2	5	10	22
Factors that helped the PTs implement the ABATAC program	The ABATAC course	8	7	5	13
	The ABATAC workshops	5	2	0	0
	The combination of online course and workshops	10	26	7	9
	The flexibility of inquiry-based approach	4	9	0	2
	The support of the program team	8	11	3	12
	Personal interest in astronomy	7	6	0	2
	Colleagues’ support	3	0	7	5

Table 24. Cont.

General Code Categories	Sub-Codes	No of Cases PTs Int1 ¹	No of Cases PTs Int2 ²	No of Cases PSTs Int1 ³	No of Cases PSTs Int2 ⁴
Prerequisites for teaching astronomy	Good PCK	0	10	1	9
	Good study and preparation of content	2	3	3	10
	Teaching resources (tools, lesson plans, models, etc.)	6	4	5	4
	Training	0	4	0	0
Participants' overall perceptions about teaching macrocosm concepts and phenomena to young children	Teaching concepts and phenomena of the macrocosm to young children is difficult.	12	0	11	0
	Teaching concepts and phenomena of the macrocosm to young children is possible if the teacher prepares appropriately.	0	16	0	18

¹ Number of cases, PTs, Interview 1; ² Number of cases, PTs, Interview 2; ³ Number of cases, PSTs, Interview 1; ⁴ Number of cases, PSTs, Interview 2.

A complete account of the interview qualitative analysis is beyond the scope of the present study due to size limitations. The findings presented above will be discussed alongside the statistical analysis results in the following discussion section. Based on the interview data, it can be inferred that both the PTs and PSTs had altered perceptions regarding the practicality of teaching astronomy in early years curricula.

4. Discussion

The results of the above analysis and our interpretations of them are offered below, which will be useful for the future development of the ABATAC program.

4.1. Improvement in Content Knowledge (CK)

According to the statistical analysis, the PSTs showed a continuous improvement in their CK throughout the duration of the program. This improvement was evident even during classroom implementations, indicating that the PSTs kept acquiring knowledge to gain a better understanding of the physics behind a phenomenon. On the other hand, the PTs showed a mean score reduction between Qr1Admin2 and Qr1Admin3, which was not statistically significant. This suggests that the PTs were able to retain the CK gained from the ABATAC course, and all the ABATAC phases positively impacted the participants' CK. It seems that the ABATAC support team played a vital role in consolidating and retaining the CK gained, as an improvement was evident in the majority of the Q1 administrated tests. Furthermore, in Int2, the participants (11 PTs and 12 PSTs) praised the support they received from the program team, which covered topics related to CK as well.

Moreover, a higher number of PSTs raised concerns about their inadequate background knowledge in astronomy which affected their understanding of the ABATAC program's CK. In Int1, 12 PSTs expressed this concern, which increased to 21 in Int2. On the other hand, only five PTs mentioned this concern in Int1, which decreased to four in Int2. Moreover, the PSTs highlighted that learning and understanding the topics they were supposed to teach in the classroom were the most important prerequisites for astronomy education (10 PSTs as opposed to 3 PTs). This realization was reinforced after the completion of the ABATAC program as more PSTs mentioned it in Int2.

Other research confirms that PSTs possess inadequate conceptual knowledge of fundamental astronomical concepts and that teacher training on a subject increases teachers' self-efficacy when teaching it [30,67–69]. Training programs explore different ways to address this issue [70]. For example, studies have found that when acquiring the necessary knowledge of astronomy, teachers might benefit from authentic and hands-on activities during training [19,71]. Several approaches have been tested for PSTs and proven effec-

tive when correcting their misunderstandings and allowing for a better understanding of the inquiry process in astronomy. These include “refutation modelling” (the modelling and testing of valid and non-valid hypotheses) [72], the “slowmation” (the design of a digital teaching resource, in which PSTs identify an idea’s numerous representations and then break it down into smaller, more manageable pieces) [73], or the “backwards faded scaffolding approach” (in which the trainer gradually grants independence to PSTs) [25]. This research implies that targeted teaching practices and a constructivist approach might help PSTs correct their misunderstandings about astronomy [74]. ABATAC could continue developing CK training, exploring innovative ways to maximize the positive impact on the participants’ CK knowledge base.

4.2. *The Impact of the ABATAC Materials and Methods*

The workshops were considered an important part of the ABATAC program as they allowed the participants to interact with trainers and colleagues, enabling them to find answers to their questions and consolidate their learning. The impact of the ABATAC workshops was evaluated by measuring PCK2, and it was found that there was an impact (though not significant) on the performance of the PSTs for Factor 3 (Processes of IBL). In addition, there was a significant impact on Factor 4 (Promoting children’s autonomy in IBL and artmaking) and Factor 5 (Teacher-directed strategies). The PTs also showed improvement after the workshops, but this was statistically significant only for Factor 5. While previous studies have suggested that engaging in inquiry-based and practical activities can significantly improve teachers’ knowledge and understanding of science and astronomy [34,75], the workshops did not appear to have a significant impact on the PTs and had only a limited impact on the PSTs. Perhaps we should consider this finding alongside the information gathered in the interviews. The PTs highlighted that it was the combination of online and in-person training that helped them implement the ABATAC program (10 PTs mentioned this in Int1 and 26 PTs in Int2). Although Cervato and Kerton [76] found that the BL approach offers an effective way to teach scientific knowledge to PSTs and boost their confidence in teaching science, in our case, fewer PSTs highlighted the BL approach (seven in Int1 which increased to nine in Int2).

Learning opportunities for educators, whether they are PSTs or PTs, may be greatly enhanced via the use of digital resources [32,77]. Even more so, the integration of educational technology with inquiry-based teaching yields notable enhancements in student teachers’ scientific concepts, especially in complex subjects such as astronomy. It is essential to provide PSTs with the opportunity to engage in astronomy activities using educational technology in order to improve their ability to teach scientific topics effectively [32], and research results show that PSTs can benefit from training programs that use technology [78].

The ABATAC course was effective in enhancing the participants’ performance in CK and appeared to have a significant impact on the development of PCK1 and PCK2, particularly for Factor 1 (Basic concepts), Factor 3 (Processes of IBL), and Factor 4 (Promoting autonomy in IBL and artmaking) for the PSTs. The course also had a statistically significant effect on the PTs’ performance for Factor 3. However, the ABATAC course did not have a significant impact on any other aspects of PCK for the PTs or PSTs, and its impact on the PTs was less pronounced. In Int2, only seven PTs highlighted the helpfulness of the ABATAC course, whereas thirteen PSTs referenced it. Upon completing the course, the number of PTs who found it time-consuming increased from five to seven. Similarly, the number of PSTs who felt the same increased from two to five. Moreover, the number of PTs who complained about the course’s information overload rose from one to nine, with the number of PSTs increasing from one to three. Finally, in Int2, six PTs and five PSTs reported that the ABATAC course’s navigation system was not user-friendly. These findings indicate the PTs had more complaints about the online course, concerning its volume and user-friendliness. A possible explanation for this is that the PTs have a hefty workload to handle, which is detrimental to their professional development [79,80]. This

calls for the ABATAC program's creators to conduct a more comprehensive investigation and take further action to improve its navigation [32,81] and ease the workload it entails.

The third ABATAC component included classroom implementations with the support of the ABATAC team. Lesson implementations provide participants with the opportunity to apply what they learnt into practice and thus to integrate and transform their CK and PCK. In our study, the classroom implementations helped the PTs to retain and the PSTs to increase their CK in a statistically significant way. For Factor 2 (external support), they had a negative impact on PST performance, which could be attributed to the challenges they faced when they had support from parents and experts or even educational visits and fieldwork in their practicum. The implementations also showed a significant impact on the PSTs' preference for strategies that increase children's autonomy in IBL and artmaking, which shows that putting these strategies into practice helped them to better understand and appreciate their importance in astronomy education for young children. However, in the classroom implementations, the PSTs showed there was a non-significant drawback to teacher-directed strategies as well. By integrating experiential learning, teacher educators can provide tangible opportunities for PSTs to actively participate in scientific processes and pedagogical approaches, resulting in a more profound comprehension of science and a heightened self-assurance in their capacity to instruct it [19,71,82]. And, according to research, these drawbacks could be a result of people's prevailing beliefs about teaching and learning ([37] p. 14). The PTs also seemed to be positively affected by the implementation experience, and this effect was statistically significant only regarding the reduction in teacher-directed strategies (Factor 5). Whilst BL has been shown to be of great benefit to teaching practices [83], other research confirms that it is by reflection processes [27,84–87] that teachers' practices are significantly improved in science education and early childhood education. Overall, ABATAC could explore ways to incorporate reflective practices into classroom implementations in order to help PTs and PSTs revise outdated beliefs and practices.

4.3. The Improvement in Pedagogical Content Knowledge 1 (PCK1)

Based on the statistical analysis, it appears that the professional teachers (PTs) understand the significance of time and space concepts in astronomy lessons and acknowledge the appropriateness of gravity and light topics for preschool curricula. The PTs' mean scores for Factor 1 are consistently high, above 4.20 in all phases, which is close to the top ranking on the 1–5 rating scale. The minor fluctuations in mean scores across the different administrations of Q1 were not statistically significant. This could be due to the fact that preschool curricula in Greece and other parts of the world emphasize time and space concepts as essential for preschool children in general [88,89]. Furthermore, light, shadow, force, motion, and darkness are some of the most popular subjects in early childhood education [90–92]. Consequently, it is unsurprising that PTs view these topics as essential.

However, during Int1, 10 teachers found the content of ABATAC to be an unfamiliar teaching subject. This number dropped to six teachers in Int2. Moreover, there is limited research on teaching temporal and spatial knowledge, understanding, and skills in early education, particularly in the context of astronomy. Furthermore, existing research indicates that teachers' skills may be underdeveloped, and their knowledge may have deficiencies and they may have alternative ideas [92–94]. Spatial activities are often overlooked, and some preschool teachers feel unprepared to support children's spatial thinking [88,95,96]. Similarly, research indicates that teachers tend to avoid science-related activities [97], and preschool children are more likely to encounter literature, mathematics, and art during their time in kindergarten than topics related to the natural sciences [20,21]. It is also important to consider if participants (PTs) hold alternative ideas, perceptions, or understandings that might not be captured or represented by the closed-ended questions of a questionnaire [14,98,99]. The points above suggest the need for additional research on teachers' comprehension of the significance of "basic concepts" in astronomy education. This can be achieved by utilizing various tools to gain insight into how teachers view the connection

between time and space concepts, as well as topics like light and darkness, in relation to learning about astronomy (a notable example is the use of the discrete choice modeling technique to gather teachers' perceptions on the issue at hand) [100].

It was observed that the PSTs were less aware of the importance of "Basic concepts" in the astronomy curriculum. Initially, their score for Factor 1 showed a statistically significant increase after the completion of the ABATAC course. However, after the classroom implementations, this mean score dropped slightly, although the reduction was not statistically significant. It is also important to note that adapting concepts and phenomena to match children's cognitive levels and interests was one of the major ABATAC challenges faced by the PSTs (10 PSTs mentioned this in Int1 and 22 in Int2). In addition, 16 PSTs in Int1 and 22 in Int2 highlighted that the ABATAC curriculum was unfamiliar to them as a subject. This may suggest the need for further training that will enable PSTs to comprehend and fully appreciate the significance of the aforementioned concepts and topics in astronomy curricula for early years students. Research has identified the need for PSTs to develop their spatial knowledge and skills and to be provided with practical examples to develop the appropriate PCK to teach spatial concepts [101]. Additionally, research indicates that teachers' attitudes and existing beliefs about spatial teaching or any other scientific concept should also be considered [14,94,102]. Therefore, although ABATAC appears to have a positive impact on PSTs' and PTs' awareness of the importance of the given concepts in astronomy education, more research is required to determine how teachers perceive the significance of overarching concepts to astronomy education and the type of support teachers require to enhance their understanding.

Factor 2 refers to the significance of "external support", which is support provided by parents, specialists, and fieldwork that could be carried out in science centers, planetariums, etc. The PSTs showed a statistically significant decline after the completion of the ABATAC course, which then increased slightly after the classroom implementations. The overall decline between the first and final administrated tests of Questionnaire 1 was weakly statistically significant. The PTs showed a slight improvement between the three ABATAC stages, although this improvement was not statistically significant. This shows that the PSTs are less certain about the role of specialists and fieldwork in inquiry-based learning compared to the PTs.

Research indicates that although fieldwork and collaboration with experts are essential in IBL [103–106], teacher educators are still searching for effective ways to improve PSTs' understanding and skills in designing inquiry-based fieldwork [107–109]. It is suggested that enhancing PSTs' ability to organize fieldwork should involve identifying those with low self-efficacy and providing close monitoring and support during their practicum. Improving PCK is also believed to benefit PSTs' attitudes and skills in fieldwork. Finally, more research is needed to explore the interaction between PSTs' efficacy beliefs and their tangible skills [109], as well as classroom implementations to identify PSTs' actual interpretations and understanding of inquiry-based fieldwork and interactions with informal and non-formal education providers.

4.4. Improvement in PCK2

For Factor 3, the PSTs showed a decline in their preference for IBL processes after the ABATAC workshops, but in subsequent stages, their level of preference increased, which was statistically significant. The PTs showed a steady improvement in their mean scores and this increase was statistically significant between the workshops and the completion of the ABATAC course and between the initial and the final assessment through the administration of Questionnaire 1. The ABATAC program resulted in an increase in promoting children's independence in IBL and art making (Factor 4) for both the PSTs and PTs, although these improvements were statistically significant only for the PSTs. The PTs marked a statistically significant difference only between the first and the last administrated tests of Questionnaire 1. Additionally, the ongoing involvement of the ABATAC team provided guidance and clarification on its methodology, which was influential according to 12 PSTs and 11 PTs.

For Factor 5, we observed that both the PSTs and PTs showed a decreased preference for a more teacher-directed approach. This positive change was statistically significant. However, after completing the ABATAC course, we noticed a slight increase in both groups, which was not statistically significant. We believe this could be due to the rich multimedia resources provided by ABATAC, which encouraged the participants to share their newfound knowledge with their students.

In Int2, three PSTs and six PTs mentioned that one of the challenges they encountered was grasping the ABATAC program's PCK. As they explained, this was mainly due to their lack of familiarity with the inquiry-based learning approach. However, the flexibility offered by the IBL approach was a factor that helped two of the PSTs and five of the PTs proceed and get acquainted with this approach. It is worth noting that 10 PTs reported a challenge related to the lack of time to devote to teaching astronomy. This could indicate that although astronomy is included in the curriculum, some teachers may perceive it as an optional add-on rather than a mandatory requirement.

These findings are consistent with the results of other studies, which show that experienced teachers have a greater difficulty embracing and adopting inquiry-based learning due to solidified traditional practices and systemic constraints [27,110,111]. Many educators still emphasize centralized learning that prioritizes traditional academic outcomes. Rather than promoting direct observation and learning from the surrounding natural environment, which is easily accessible and offers valuable learning opportunities, they frequently rely on visual aids in the classroom [24]. PSTs, too, are prone to teacher-directed strategies [112] due to their limited teaching experience, and their IBL practice is influenced by the various interpretations of the IBL approach they are exposed to [85]. Research also shows that teachers often feel uncertain when asked to follow the principles of inquiry-based learning, especially when they are not familiar with this learning approach [81,113–117].

PSTs not only need assistance in implementing inquiry-based learning in their own classroom teaching and to personally experience inquiry-based learning from the learner's perspective but also facts and more explicit instruction [25,81]. Both the PSTs and PTs could understand inquiry-based learning and build the concrete knowledge of astronomy needed to teach primary students after participating in concrete scientific inquiry investigations and seeing curricula and resources [34,110]. These results demonstrate the importance of giving PTs and PSTs tailored support and chances to organize and execute scientific inquiry investigations in basic astronomy lessons [34] in order for them to generate new conceptual understandings and internalize the inquiry process [81].

In Int2, a significant number of the PTs and PSTs emphasized the importance of PCK for teaching astronomy to young children, which was not mentioned in Int1. The number of PTs mentioning PCK increased from zero to ten, and the number of PSTs mentioning it increased from one to nine (in Int2). This highlights the importance of proper teacher preparation when teaching the concepts and phenomena of the macrocosm to young children, as noted by 16 PTs and 18 PSTs in Int2. Overall, both groups showed a change in their perceptions regarding the feasibility of astronomy education for young children.

4.5. Improvements to the ABATAC Training Program

Based on the indications discussed above, the following improvements could be beneficial to the ABATAC program:

- Improvements in the delivery of astronomy CK

New approaches such as “slowmation” [73], “refutation modelling” [72], or “backwards faded scaffolding” [25] could be implemented to improve the ABATAC program's effectiveness in enriching participants' CK. This means that a workshop element focused on CK will be added to the online course.

- Improvements focusing on PCK

It is important to provide further support for the comprehension of fundamental concepts related to time and space, as this will help in developing age-appropriate activities

for understanding astronomy phenomena. It is also crucial to emphasize the significance of astronomy during the early years and its connections to other disciplines, such as mathematics or art, to gain a more comprehensive understanding of its position in the curriculum. Finally, it is vital to add a special focus on refraining from teacher-directed practices and increasing children's autonomy to enable the inquiry-based learning (IBL) process.

- Improvements on the ABATAC's components

It is important that the program's BL format should be retained as it suits the busy schedules of PTs and was praised by them. In addition, components or tools could be added that enable us to understand participants' incoming beliefs, especially those of PSTs, and to identify outdated teaching practices that might hinder methodological approaches. Reflection and monitoring activities could be added to workshops and the classroom implementation process to promote an in-depth improvement in PCK approaches for both PTs and PSTs. Moreover, implementing ABATAC over longer periods could allow participants to gain greater familiarity with the learning approach. Finally, the ABATAC course should be reviewed in terms of navigation, workload, and completion time.

4.6. Limitations of the Study and Implications for Future Research

As mentioned before, this study is an exploratory study that focused on the evaluation of an educational design (the ABATAC program). Educational design research is oriented more towards the examination of a posteriori data with respect to a priori commitments concerning sources of bias and probability-related inferential rules [118]. As such, it aims at hypothesis generation rather than hypothesis testing [118–120]. This study represents the initial phase of a series of research aimed at identifying variables and testing models, hypotheses, and, ultimately, theories [118].

Moreover, since this study analyzes the outcomes of a particular process, qualitative methods, such as in-depth discussions, peer observations, and so forth, might provide more insight into the ABATAC program's potential or effects. An open-ended and heuristic approach to training and professional development in astronomy education could also be explored and offer insights into how ABATAC could build on PTs' and PSTs' existing knowledge and potential. Additionally, as this study emphasizes the need for additional evidence regarding the effects of ABATAC on PTs, a larger sample of PTs is required in order to gain a more profound comprehension of their teaching profiles and how these shape their training requirements.

Another limitation of this study was our lack of research following the evolution of the participants' PCK and practice in relation to the effects of ABATAC. Consequently, a longitudinal investigation may offer promise in this regard.

5. Conclusions

In this study, educational design research was used as a means to facilitate enhancements and make explicit judgements about the modification of the ABATAC training program, which is one of the main foci of educational design research [121]. Thus, a research framework was formulated, and data were gathered to provide responses to the subsequent research inquiries: 1. What were the primary outcomes of the initial assessment of the ABATAC program? 2. What is the impact of the ABATAC program on the CK and the PCK of preservice (PSTs) and professional teachers (PTs)? 3. What specific aspects of the ABATAC program are most challenging for preservice teachers and for professional teachers? 4. What improvements were identified as necessary based on the results of the initial assessment?

Our data showed that ABATAC enhanced the CK and certain aspects of the PCK of the participants. The PSTs emerged as the most significantly impacted group, as evidenced by their statistically significant progress in the majority of development indicators. This demonstrates the course's potential as an introductory teacher training program. The biggest challenge for the PSTs seemed to be challenges in their PCK (finding a way to explore and deliver age-appropriate activities, exploit fieldwork and external specialists, and refrain

from teacher-directed practices). Although the outcomes reported by the PTs were also positive, further examination is required to determine how enhanced research and/or training processes could help PTs demonstrate a statistically significant improvement. Thus, in the ABATAC program's subsequent stages, our focus will be on improving its training methodology and evaluation tools, as well as on developing and testing theories to maximize and scale its impact.

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