

## Article

# Evaluating Teachers' Readiness and Perceptions of Augmented Reality in STEM Education: Considerations for Sustainable Teaching Practices

Besime Uysal \* and Huseyin Bicen 

Department of Computer Education and Instructional Technology, Near East University, 99138 Nicosia, Turkey; huseyin.bicen@neu.edu.tr

\* Correspondence: uysalbesime@gmail.com

## Abstract

Augmented reality (AR) may support science, technology, engineering, and mathematics (STEM) teaching, but continued use depends on teachers' readiness and implementation conditions. This mixed-methods, single-group pre-test/post-test study examined changes in perceived competence and views following an eight-week professional development program involving 23 volunteer secondary-school teachers of science, physics, biology, chemistry, mathematics, and computer education. Data sources were a 35-item questionnaire, semi-structured interviews analyzed thematically, and teacher-developed materials. Mean perceived competence increased from 2.38 (SD = 1.15) to 4.21 (SD = 0.77),  $t(22) = 7.57$ ,  $p < 0.001$ , Cohen's  $d_z = 1.58$ . Participants reported benefits for visualizing abstract concepts, comprehension, lesson efficiency, motivation, and interactive material design. Reported barriers included internet and power interruptions, paid applications, unequal access to resources, and additional time demands. All 23 participants intended to use AR, and 18 believed they could train colleagues. The materials demonstrated practical engagement during the program. The findings indicate short-term implementation readiness and perceived feasibility, not sustained classroom use or causal effectiveness. Longitudinal follow-up, classroom observation, comparison groups, and student-outcome evidence are needed to assess continued implementation.

**Keywords:** augmented reality; STEM education; teacher professional development; perceived competence; implementation readiness; educational technology integration



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## 1. Introduction

In the context of ongoing digital transformation, there is an increasing need for learning environments that help teachers present complex concepts in more concrete, interactive, and accessible ways. This need is particularly pronounced in science, technology, engineering, and mathematics (STEM) education, where concepts are often abstract and difficult to explain solely through text or two-dimensional visuals. As a result, augmented reality (AR), which overlays digital objects, animations, or information onto the physical environment, has emerged as a promising tool to support STEM instruction [1,2].

However, the significance of AR in education should not be limited to its innovative or motivational aspects. Previous studies have shown that AR can enhance visualization, interaction, motivation, and hands-on learning in STEM education [3–5]. At the same time, the literature identifies challenges such as insufficient infrastructure, limited access to

devices, the cost of paid applications, technical maintenance, cognitive load, and teachers' reluctance to adopt new technologies [6–8]. Therefore, the continued use of AR in schools depends not only on the availability of applications but also on teachers' digital-pedagogical competence, alignment with curriculum goals, and institutional support.

UNESCO's Education for Sustainable Development framework concerns the knowledge, skills, values, and attitudes needed to address environmental, social, and economic challenges [9,10]. The present study did not measure these learner outcomes and therefore does not claim to evaluate Education for Sustainable Development in a broad sense. In this study, sustainability is used more narrowly to refer to the conditions needed to maintain AR-supported instructional practices beyond a short-term training experience. These conditions include access to affordable tools, teachers' ability to select and design AR-supported materials, alignment with STEM learning outcomes, and institutional support for infrastructure, maintenance, and continuing professional development. Because the data were collected during and immediately after the program, the study evaluates short-term readiness and perceived feasibility rather than sustained classroom use.

Another conceptual focus of this study is STEM education itself. In this research, STEM education is defined as an integrated instructional approach that brings together science, technology, engineering, and mathematics through problem-solving, inquiry, design thinking, evidence-based reasoning, and real-world applications. From this perspective, STEM is not viewed merely as the replacement of existing curricula or the simple use of technology in classroom instruction. Rather, it emphasizes that technologies such as AR are meaningful only when they contribute to students' deeper understanding of disciplines, the development of critical thinking skills, and the achievement of learning outcomes.

This study addresses two research gaps. First, much of the AR literature focuses on students' achievement and motivation, whereas research examining STEM teachers' perspectives remains limited. Second, although AR is often discussed in relation to innovative and sustainable educational practices, less is known about the factors and barriers that teachers associate with its continued classroom use. The study therefore combines pre-test/post-test survey data, interviews, and teacher-developed materials to examine teachers' perceived competence, evaluations of mobile AR applications, material-design experiences, and views on the conditions that may support or constrain continued implementation. The findings may inform teacher professional development, curriculum planning, and future longitudinal research.

### *1.1. The Importance of AR in STEM Education*

Augmented reality is used today in many educational levels and a wide variety of fields, including mathematics, physics, chemistry, biology, astronomy, museum education, and art [11–13]. Augmented reality (AR) is an important learning tool, especially in STEM education, because abstract concepts are much more complex for students to understand. It makes the content they struggle with more understandable by visualizing it. In addition, it helps students develop their three-dimensional and spatial thinking skills. AR applications make the learning process more effective, engaging, and lasting by allowing students to interact with their learning environment while simultaneously experiencing digital content during the teaching process. The literature generally highlights various benefits of AR in education. AR can provide more interactive learning experiences, increase students' attention and motivation, support inquiry-based and experiential learning, and help make abstract scientific concepts more understandable [14–17]. Studies in science and STEM education also show that AR-supported learning environments can improve students' academic achievement, classroom engagement, and practical skills [18,19].

However, the literature does not present AR as a problem-free or universally superior instructional approach. Many studies emphasize that AR applications may be limited by factors such as cost, device access, software updates, technical issues, insufficient teacher preparation, cognitive load, and curriculum alignment [6,20–22]. Based on these findings, AR should not be considered a standalone solution in STEM education. Instead, it should be integrated with other instructional approaches such as inquiry-based learning, gamification, blended learning, simulations, and textbook-supported digital resources.

The training included AR or AR-enabled applications as well as complementary digital tools. Google View 3D, selected Google Lens functions, Video AR, Humanoid 4D+, and Halo AR were used for visual or augmented content. Photomath and Exam Reader supported mathematics- and assessment-related activities; QR codes and Vocaroo supported access to content; and Padlet and Wordwall supported sharing, interaction, and gamified learning. These tools are therefore not treated as belonging to a single technological category.

On the other hand, location-based AR applications and advanced head-mounted AR systems were outside the scope of this study. The main reason for this exclusion is that the study aimed to focus on tools that teachers can easily access and implement using smartphones in real classroom environments under everyday school conditions.

#### 1.1.1. Sustainability and Transferability of AR-Supported Teaching

In this study, teachers' positive perceptions and stated willingness to use AR are treated as indicators of readiness, not as proof of continuous classroom use. The study combines pre-test and post-test survey data, interviews, and teacher-developed materials to examine short-term perceptions of usability, usefulness, limitations, and classroom integration. Participants also suggested that AR could be used in geography, history, social studies, foreign language, and art courses. These views indicate perceived transferability, but the study did not test learning outcomes in those subjects. AR-based activities should therefore be aligned with each subject's learning objectives rather than applied uniformly across courses.

#### 1.1.2. AR and Conditions for Sustainable Teaching Practices

Within this study, the sustainability lens does not refer to measured Education for Sustainable Development competencies. It concerns whether AR-supported teaching is perceived as accessible, economical, pedagogically meaningful, technologically usable, and institutionally applicable [9,10,23]. The study examines perceived accessibility through the use of mobile and low-cost tools, pedagogical relevance through the visualization of abstract STEM concepts and teacher material design, and institutional relevance through curriculum integration, professional development, and school-level support. These dimensions identify conditions that may be relevant to continued use, but they are not direct measures of long-term sustainability. Accordingly, the phrase 'Considerations for Sustainable Teaching Practices' in the title refers to implications for the conditions under which AR-supported practices may continue; it does not identify sustained implementation as an outcome measured by this study.

Previous research has linked AR with sustainable learning environments. Karagözlü [24] argues that AR can contribute by making abstract concepts concrete and supporting interactive learning; Badilla-Quintana et al. [25] discuss its use with students with and without special educational needs; and Lee and Hsu [26] examine AR-supported sustainable education in vocational certification courses. In the present study, the program emphasized teacher-centered, mobile, and freely accessible applications, thereby reducing the need for specialized equipment. AR-supported teaching is therefore considered in terms of cost, ac-

cessibility, teacher competence, technological usability, and curriculum compatibility. This perspective is consistent with Sustainable Development Goal 4's emphasis on inclusive, equitable, and quality education; however, the study does not treat AR as sustainable in itself. Continued use would require accessible applications, regular teacher development, technical support, monitoring, and curriculum alignment.

### 1.2. The Aim of the Study

This study aimed to examine how an eight-week professional development program involving AR applications was associated with STEM teachers' perceived competence, material-design practices, and views on integrating AR into education. More specifically, the study examined changes in perceived competence after training, teachers' evaluations of the applications and materials used, and the technological, socio-economic, pedagogical, and institutional conditions that participants associated with the possible continuation of AR use in schools.

The main research question was: How did participating STEM teachers' perceived competence, practical engagement, and views on the feasibility and possible continuation of mobile AR use change following the professional development program? The following sub-questions organized the analysis:

1. What advantages, disadvantages, and implementation conditions did participants associate with AR in STEM education?
2. How did participants evaluate the methods, applications, and materials used during the training?
3. In which other subject areas did participants believe AR could be used?
4. Did participants intend to use AR after the training?
5. Did participants perceive themselves as able to provide AR-related training after the program?

## 2. Materials and Methods

This mixed-methods study used a single-group pre-test/post-test design to evaluate an eight-week professional development program for 23 STEM teachers. The questionnaire described changes in self-reported AR competence, while interviews and teacher-developed materials provided contextual evidence about perceived benefits, constraints, and classroom feasibility. Findings were integrated during interpretation [27–29]. The design supports conclusions about observed change and short-term implementation readiness, not causal effects or sustained classroom use.

The training program was organized using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) [30]. Teachers were introduced to the technologies, practiced with the applications, developed lesson materials, and evaluated the process. TPACK Model was used to consider the interaction of technological, pedagogical, and content knowledge, but it was not the primary research design [31].

The study was conducted during the fall semester of the 2023–2024 academic year with 23 volunteer secondary-school teachers from science, physics, chemistry, biology, computer science, and mathematics. All participants contributed to both strands and provided informed consent. Convenience sampling was used because the program required face-to-face laboratory attendance and weekly participation for eight weeks [32]. Participant characteristics are presented in Table 1, and the findings are interpreted within this study group.

**Table 1.** Participant characteristics.

| Characteristic                                                    | Category             | <i>n</i> | %    |
|-------------------------------------------------------------------|----------------------|----------|------|
| Distribution of participants by gender                            | Female               | 18       | 78.3 |
| Distribution of participants by gender                            | Male                 | 5        | 21.7 |
| Distribution of participants by age                               | 30–35                | 4        | 17.3 |
| Distribution of participants by age                               | 36–40                | 4        | 17.3 |
| Distribution of participants by age                               | 41–45                | 2        | 8.7  |
| Distribution of participants by age                               | 46–50                | 6        | 25.9 |
| Distribution of participants by age                               | 51–55                | 4        | 17.4 |
| Distribution of participants by age                               | 56–60                | 3        | 12.9 |
| Distribution of participants according to years in the profession | 0–5                  | 2        | 8.7  |
| Distribution of participants according to years in the profession | 6–10                 | 3        | 13   |
| Distribution of participants according to years in the profession | 11–15                | 3        | 13   |
| Distribution of participants according to years in the profession | 16–20                | 4        | 17.3 |
| Distribution of participants according to years in the profession | 21–25                | 4        | 17.3 |
| Distribution of participants according to years in the profession | 26–30                | 3        | 13   |
| Distribution of participants according to years in the profession | 31–35                | 4        | 17.3 |
| Branch                                                            | Science/Physics      | 5        | 21.7 |
| Branch                                                            | Science/Biology      | 2        | 8.7  |
| Branch                                                            | Science              | 2        | 8.7  |
| Branch                                                            | Mathematics          | 8        | 34.8 |
| Branch                                                            | Computer             | 5        | 21.7 |
| Branch                                                            | Chemistry            | 1        | 4.3  |
| Position in the profession                                        | Teacher              | 20       | 87   |
| Position in the profession                                        | School Administrator | 3        | 13.0 |

Note. *n* = frequency. Percentages may not total 100 because of rounding.

### 2.1. Operational Framework and Short-Term Indicators Relevant to Sustainability

The operational framework organizes the evidence into behavioral, socio-economic, technological, scientific/pedagogical, and institutional dimensions relevant to the possible continuation of AR-supported STEM teaching. Indicators include stated intentions, perceived accessibility, operating-system compatibility, curriculum relevance, and materials developed during training. They represent perceived feasibility and short-term implementation readiness rather than sustained use. Table 2 summarizes the evidence collected and the longitudinal evidence still required.

**Table 2.** Short-term indicators and future considerations in augmented reality (AR)-supported science, technology, engineering, and mathematics (STEM) education.

| Dimension                         | Short-Term Evidence in This Study                                                                       | Data Source                                                      | Current Interpretation                                                   | Evidence Needed for Longitudinal Assessment                                                                |
|-----------------------------------|---------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|--------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
| Behavioral readiness              | Altogether, 23/23 intended to use AR; 18/23 felt able to provide AR-related training.                   | Post-training interviews and descriptive frequency analysis.     | Positive short-term implementation readiness.                            | Teacher usage logs and repeated interviews over at least one academic term.                                |
| Socio-economic conditions         | The program prioritized mobile, free, or readily accessible tools; no specialized headset was required. | Tool-selection criteria, program records, and teacher feedback.  | A lower-cost entry point within the training context.                    | Cost analysis, student device-access data, and school-level equity indicators.                             |
| Technological conditions          | Applications were tested on Android and iOS smartphones before and during training.                     | Application testing, implementation notes, and teacher feedback. | Perceived feasibility in the training environment.                       | Internet reliability, technical support requests, application updates, and device compatibility over time. |
| Scientific/pedagogical conditions | Teachers developed and presented instructional materials using the introduced tools.                    | Teacher products, final presentations, and interview responses.  | Practical engagement and increased perceived competence during training. | Classroom observations, student-learning outcomes, and assessment of lesson quality.                       |
| Institutional conditions          | Teachers discussed possible use in STEM and other disciplines.                                          | Curriculum reflections and interview themes.                     | Perceived compatibility, not documented institutional adoption.          | School-policy data, curriculum-integration records, and administrative-support indicators.                 |
| Boundary of the evidence          | The study measured short-term readiness, not long-term sustained use.                                   | Limitations and future monitoring plan.                          | Evidence supports perceived feasibility and readiness only.              | Longitudinal follow-up over at least one academic term.                                                    |

## 2.2. Professional Development Setting

The program was conducted face-to-face over eight weeks, with two-hour sessions once a week. The professional development training took place in the computer lab of a state secondary school in Northern Cyprus.

## 2.3. Professional Development Program

The eight-week program was designed around curriculum relevance, teacher needs, and accessible mobile tools. Participants used Android- or iOS-based smartphones and progressed from introductory AR concepts and demonstrations to guided practice, material development, peer presentation, and feedback. PowerPoint-supported face-to-face demonstrations and Word-based guides were made available through Google Classroom. Table 3 presents the weekly content. The program did not use head-mounted or location-based AR systems.

**Table 3.** Eight-week professional development program.

| Week | Training Content                                                                                                                                                                                                      |
|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1    | General information about STEM Education and Augmented Reality<br>Introduction of augmented reality with short videos<br>Setup of WhatsApp group<br>Introduction of Google Classroom<br>Differences between AR and VR |
| 2    | Current areas of AR use<br>Examples used to distinguish AR from other digital applications (Pokémon Go, Google Meet, Snapchat)                                                                                        |
| 3    | Google View 3D and Google Lens applications<br>The usage potential of these applications in education<br>Video AR and Humanoid 4D+ applications                                                                       |
| 4    | Photomath and Exam Reader as supporting digital tools<br>Their possible uses and benefits in education                                                                                                                |
| 5    | Use of QR codes in education<br>Vocaroo and QR Code Generator as supporting content-access tools                                                                                                                      |
| 6    | Halo AR app<br>Applications for adding different content to images                                                                                                                                                    |
| 7    | Padlet and Wordwall as supporting digital platforms<br>Creating interactive and gamified learning activities<br>Sharing interactive course content prepared by teachers                                               |
| 8    | General evaluation of the course<br>Obtaining feedback with data collection tools                                                                                                                                     |

Table 3 shows the progression from conceptual information to classroom-oriented material development. The program included AR or AR-enabled applications—Google View 3D, selected Google Lens functions, Video AR, Humanoid 4D+, and Halo AR—and complementary digital tools. Photomath and Exam Reader supported mathematics and assessment activities; QR Code Generator and Vocaroo supported access to digital content; and Padlet and Wordwall supported sharing, interaction, and gamified activities. The intervention, therefore, centered on mobile, QR/marker-supported, and image-based practices rather than head-mounted or location-based AR systems.

## 2.4. Data Collection Tools

Data came from three sources: the 35-item pre-test/post-test perception questionnaire, post-training semi-structured interviews, and teacher-developed instructional materials. The sources were compared during interpretation to examine convergence and complementarity.

#### 2.4.1. Mixed-Methods Data Sources

The semi-structured interview questions were developed by the researcher and reviewed by 10 field experts. They addressed perceived benefits and limitations, views on the applications and materials, possible use in other subjects, intention to use AR after training, and perceived ability to train colleagues. Participants' responses were analyzed thematically, and the resulting themes were reported, supported by frequency values where appropriate.

#### 2.4.2. Quantitative Data Collection and Analysis

Participant-level scale scores were calculated by averaging the 35 items. Means, standard deviations, Cronbach's alpha coefficients, and frequencies were calculated, and a paired-samples t-test compared pre-test and post-test scores. Normality of the paired differences was assessed with the Shapiro–Wilk test. Cohen's *d* was calculated as the mean paired difference divided by the standard deviation of the differences. Given the small voluntary sample and absence of a control group, the results are interpreted as within-group exploratory evidence rather than generalizable or causal findings [33].

#### 2.4.3. Survey of Teachers' Perceived Competence in Using AR in STEM Education

The survey was developed after a review of national and international research on AR in education. Because no existing instrument fully aligned with the intended focus on teachers' perceived competence in AR-supported STEM education, the researcher collected written responses from 26 STEM teachers via Google Forms. These responses informed an initial pool of 46 items. Ten academics with relevant research and scale-development experience reviewed the draft, and 11 items were removed, leaving 35 items. Participants responded on a five-point scale ranging from 'I am not competent' to 'I am fully competent'. The pre-test Cronbach's alpha was 0.988. This coefficient indicates high internal consistency within the present sample. Still, the small sample and large number of items mean that it should not be treated as evidence of complete construct or predictive validity. The complete instrument, including the demographic section, 35 perceived-competence items, a five-point response scale, original Turkish wording, and English translation, is provided in Supplementary Materials File S1. The anonymized preliminary needs-analysis responses from the 26 STEM teachers are provided in Supplementary Materials File S3. These preliminary responses were used only to inform item generation and are distinct from the post-training interviews conducted with the 23 program participants.

#### 2.4.4. Qualitative Interviews

Face-to-face semi-structured interviews were conducted with the teachers at the end of the training to obtain explanations of their experiences and views regarding the AR applications.

#### 2.4.5. Participant Interview Form

The 'Lesson Interview Form Regarding Teachers' Use of Augmented Reality in STEM Education' was prepared by the researcher and reviewed by 10 academics with experience in educational technology, STEM education, or instrument development. The interview form consists of five open-ended questions, and in evaluating content validity, the suitability of the interview questions to the research questions, their appropriateness in terms of content, and their overall consistency were considered. The original Turkish versions of the questions and their English translations are presented in Supplementary Materials File S2.

#### 2.4.6. Analysis of Qualitative Data

Interview responses were analyzed thematically through repeated reading, identification of meaning units, descriptive coding, and grouping into themes: perceived benefits, technical difficulties, material access, pedagogical integration, transferability, and readiness to provide AR training. Frequencies were calculated after theme development and are descriptive within this sample; a response could contribute to more than one theme, so totals may exceed 23. Interview findings were compared with survey results and teacher-developed materials during interpretation [34].

For the reporting of illustrative quotations, the 23 post-training interview records were assigned sequential anonymized codes (P01–P23) according to their order in the dataset. The original Turkish statements were translated into English for presentation, with their meaning preserved as closely as possible.

#### 2.4.7. Trustworthiness and Limitations of the Qualitative Analysis

Trustworthiness was supported through expert review of the interview form, transparent reporting of participants and procedures, illustrative quotations, and comparison with questionnaire and material-based evidence [35]. The analysis did not include independent coding, inter-rater agreement, formal saturation testing, or longitudinal observation; these limitations are considered when interpreting the qualitative findings.

#### 2.4.8. Mixed-Methods Integration

Integration occurred at the design, methods, and interpretation levels. The same 23 participants contributed questionnaire, interview, and material-based evidence; interview questions elaborated the observed survey changes; and the three sources were compared to identify convergence, complementarity, and evidentiary limits [28,29].

### 3. Results

#### 3.1. Results Regarding the First Research Question

The first research question examined the advantages, disadvantages, and implementation conditions that participants associated with AR in STEM education. Tables 4 and 5 present the perceived benefits and barriers.

**Table 4.** Participants' perceived advantages of AR applications in STEM education.

| Perceived Advantage                             | Frequency (f) |
|-------------------------------------------------|---------------|
| Making abstract concepts tangible               | 7             |
| Enhancing the efficiency of the lessons         | 17            |
| Providing quick and easy comprehension          | 13            |
| Saving time                                     | 2             |
| Motivating teachers and students for the lesson | 9             |

Note. Participants could provide more than one response; frequencies are descriptive and may not sum to  $n = 23$ .

**Table 5.** Participants' perceived disadvantages of AR applications in STEM education.

| Perceived Disadvantage                                                           | Frequency (f) |
|----------------------------------------------------------------------------------|---------------|
| Deficiencies in the current technological infrastructure (Internet Interruption) | 6             |
| Frequent power outages                                                           | 2             |
| The need for teachers and students to spend more time on technology              | 7             |
| Inequality of opportunity in accessing resources                                 | 3             |

Note. Participants could provide more than one response; frequencies are descriptive and may not sum to  $n = 23$ .

Among the 23 participants, 17 referred to increased lesson efficiency, 13 to quicker or easier comprehension, 9 to teacher or student motivation, 7 to making abstract concepts

tangible, and 2 to time saving. Table 5 shows the reported constraints: additional time spent with technology ( $f = 7$ ), infrastructure or internet problems ( $f = 6$ ), unequal access to resources ( $f = 3$ ), and power outages ( $f = 2$ ). These frequencies describe participants' perceptions rather than demonstrated effects or causes of implementation success or failure.

These findings identify perceived benefits and potential barriers rather than observed long-term classroom outcomes.

Illustrative interview statements show how participants connected these benefits and barriers. One teacher explained that AR can “concretize abstract concepts, attract students' attention, and help them understand three-dimensional objects better, especially in geometry” (P15). Another participant summarized the tension between pedagogical value and infrastructure: “Technical problems such as electricity and internet interruptions may occur. Its greatest advantage is helping students understand abstract topics” (P01).

### 3.2. Results Regarding the Second Research Question

The second research question examined teachers' views on the methods, applications, and materials used during the AR training program. Table 6 presents teachers' responses about the usability, interest value, usefulness, and accessibility of these materials.

**Table 6.** Participants' views of the methods and materials used in the training.

| View of Methods and Materials                    | Frequency (f) |
|--------------------------------------------------|---------------|
| Engaging and interesting                         | 8             |
| Useful                                           | 4             |
| Material design and access to materials are easy | 15            |
| Paid applications limit access to materials      | 3             |

Note. Participants could provide more than one response; frequencies are descriptive and may not sum to  $n = 23$ .

As shown in Table 6, 15 participants referred to easy material design or access, 8 described the activities as engaging or interesting, 4 described them as useful, and 3 stated that paid applications limited access. These responses indicate generally positive views within the study group while also identifying an economic constraint.

Thematic interpretation grouped the responses into perceived benefits, technical and access constraints, and pedagogical integration. Participants associated AR with comprehension, attention, motivation, and participation; they also mentioned power or internet interruptions, device compatibility, and the need to align activities with the STEM curriculum. Because the category included both AR and complementary digital tools, these findings concern the training resources as a whole.

Comments on the training materials revealed both usability and access concerns. One participant stated that “even preparing the materials contributed to my professional development” (P03), whereas another observed that the applications were “easy to use and install . . . but the fact that most are paid limits their use” (P23). A further participant explained that sharing links or QR codes could create “inequality of opportunity” for students without devices or internet access, although classroom smartboards could partly reduce this disadvantage (P10).

### 3.3. Pre-Test and Post-Test Results on Teachers' Perceived Competence in Using AR in STEM Education

The mean perceived competence score increased from 2.38 ( $SD = 1.15$ ) before the professional development program to 4.21 ( $SD = 0.77$ ) afterward. The mean paired difference was 1.82 points (95% CI [1.32, 2.32]),  $t(22) = 7.57$ ,  $p < 0.001$ . Difference scores did not deviate significantly from normality (Shapiro–Wilk  $W = 0.961$ ,  $p = 0.474$ ), and Cohen's  $d_z = 1.58$  indicated a large within-group standardized change. Item-level findings showed higher post-training self-ratings for using AR applications, preparing lesson materials,

using smartphones and QR codes educationally, and sharing digital content. Because the study lacked a control group and an objective performance measure, the change cannot be attributed solely to the program and should not be interpreted as verified classroom competence. Cronbach's alpha was 0.988 at pre-test and 0.991 at post-test, indicating high internal consistency within this sample but not comprehensive construct validity. Table 7 summarizes the participant-level results.

**Table 7.** Descriptive statistics and paired-samples test for perceived competence scores.

| Test      | N  | M    | SD   | Paired Comparison                                   | Cronbach's $\alpha$ |
|-----------|----|------|------|-----------------------------------------------------|---------------------|
| Pre-test  | 23 | 2.38 | 1.15 | Mean difference = 1.82; 95% CI [1.32, 2.32]         | 0.988               |
| Post-test | 23 | 4.21 | 0.77 | $t(22) = 7.57$ ; $p < 0.001$ ; Cohen's $d_z = 1.58$ | 0.991               |

Note. N = number of participants; M = mean; SD = standard deviation; CI = confidence interval;  $\alpha$  = Cronbach's alpha;  $d_z$  = paired-samples standardized mean change. Scores are participant-level means across the 35 questionnaire items. Difference scores met the normality assumption (Shapiro–Wilk  $W = 0.961$ ,  $p = 0.474$ ). The exact two-tailed  $p$  value was  $1.46 \times 10^{-7}$ .

Selected item-level means are presented in Table 8. Responses shifted from lower pre-training self-ratings toward higher post-training self-ratings for preparing lesson materials, selecting topic-appropriate applications, sharing content online, and designing QR-supported activities.

**Table 8.** Selected item-level pre-test and post-test means.

| Questionnaire Item                                                                                        | Pre-Test Mean (M) | Post-Test Mean (M) |
|-----------------------------------------------------------------------------------------------------------|-------------------|--------------------|
| Q.5. I can increase students' interest in lessons by using AR applications.                               | 2.26              | 4.30               |
| Q.7. I can make lessons more comprehensible with AR applications.                                         | 2.30              | 4.30               |
| Q.10. After starting to use AR applications in lessons, I can use my smartphone for educational purposes. | 2.60              | 4.39               |
| Q.12. The use of AR can contribute to the development of my technological literacy.                       | 2.60              | 4.34               |
| Q.15. I can increase my students' participation in lessons using AR applications.                         | 2.60              | 4.30               |
| Q.19. I can add QR codes to my lecture notes.                                                             | 2.26              | 4.43               |
| Q.21. I can easily share my AR project online.                                                            | 2.30              | 4.34               |
| Q.34. I can use pre-prepared lesson content available in AR applications.                                 | 2.39              | 4.30               |

These results represent teachers' self-perceptions and do not constitute objective evidence of classroom performance.

### 3.4. Results Regarding the Third Research Question

The third research question asked in which other subject areas participants believed AR could be used. The responses concern perceived possibilities beyond STEM rather than tested learning outcomes.

Table 9 summarizes the subjects identified by participants. The frequency values are descriptive counts within the study group.

**Table 9.** Subject areas in which participants believed AR could be used effectively.

| Suggested Subject Area           | Frequency (f) |
|----------------------------------|---------------|
| All Courses                      | 8             |
| Geography–History–Social Studies | 5             |
| Foreign Language                 | 2             |
| Art Courses                      | 2             |

Eight participants stated that AR could be used in all courses; five identified geography, history, or social studies; two identified foreign-language education; and two identified art

courses. These responses suggest that participants perceived AR as potentially transferable to subjects involving visual, spatial, or interactive content.

Participants' suggestions also illustrated the perceived cross-curricular scope. For example, one teacher proposed use in "music, ballet, art, literature, and medicine" (P22), while others specifically mentioned geography, history, foreign languages, and physical education. These quotations reflect perceived transferability rather than tested effectiveness.

The study did not test AR activities or learning outcomes in these subjects; therefore, these views should be interpreted as suggestions for future investigation.

### 3.5. Results Regarding the Fourth Research Question

All 23 participants stated that they were considering using AR applications in their lessons after the training. This result indicates stated intention and short-term implementation readiness, not evidence of subsequent or sustained classroom use. Follow-up research would be required to determine the frequency of use, student access, infrastructure, and school support.

One participant described the change in readiness directly: "I had no knowledge or awareness of AR before; after this training, I am considering teaching in this way" (P15). This statement illustrates immediate willingness while not establishing later classroom use.

### 3.6. Results Regarding the Fifth Research Question

The fifth research question examined participants' views on their ability to provide training on AR use after completing the program. Table 10 summarizes the responses.

**Table 10.** Participants' perceived ability to provide AR-related training.

| Participant Response                                                                                        | Frequency (f) |
|-------------------------------------------------------------------------------------------------------------|---------------|
| Yes, I can provide training                                                                                 | 18            |
| I do not think I have enough knowledge right now. When I have enough knowledge, yes, I can provide training | 5             |

Eighteen participants reported that they felt able to provide AR-related training, whereas five stated that they would need further knowledge or experience first. The result indicates different levels of perceived readiness and willingness to share learning; it does not independently verify training competence.

The more cautious responses are also important. One participant stated, "I do not feel sufficiently competent at present, but after using AR applications more, I could provide training in the future" (P12). This quotation supports interpreting the result as perceived readiness at different levels rather than verified expertise.

### 3.7. Teacher-Developed Materials and Presentations

During the program, participants developed and presented instructional materials using the introduced AR and complementary digital tools. The materials were considered in terms of interaction, appropriate tool use, and presentation clarity. They provide evidence of practical engagement within a supported training environment, not of independent classroom performance or long-term effectiveness.

### 3.8. Integrated Mixed-Methods Findings

The quantitative and qualitative strands were integrated through a joint display. The display compares the direction and magnitude of the self-reported pre-test/post-test change with interview themes and teacher-developed materials, identifies areas of convergence and complementarity, and states the evidentiary boundary for each inference. This integration

supports a balanced interpretation of perceived competence and implementation readiness without treating intention or in-program products as proof of sustained classroom use [28,29]. Table 11 presents the integrated evidence.

**Table 11.** Joint display integrating quantitative, qualitative, and material-based evidence.

| Quantitative or Structured Evidence                                                                                                                                                                                            | Qualitative or Material Evidence                                                                                                                                                                                                                          | Integrated Interpretation                                                                                                                                              | Boundary of the Evidence                                                                                                                   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| Perceived competence increased from $M = 2.38$ ( $SD = 1.15$ ) to $M = 4.21$ ( $SD = 0.77$ ), $t(22) = 7.57$ , $p < 0.001$ , Cohen's $d_z = 1.58$ .                                                                            | Participants associated the program with easier comprehension, more efficient lessons, greater motivation, better visualization of abstract concepts, and more interactive material design. Teacher-developed products showed engagement during training. | The strands converge on a large short-term increase in self-reported competence accompanied by positive perceptions and practical engagement in the supported program. | The single-group design, self-report measure, and supported training context do not establish causality or objective classroom competence. |
| All 23 participants stated that they intended to use AR; 18 stated that they could provide AR-related training to colleagues.                                                                                                  | Participants completed and presented instructional materials during the final session.                                                                                                                                                                    | The evidence indicates immediate implementation readiness and perceived confidence in sharing newly acquired knowledge.                                                | Stated intention and in-program task completion do not demonstrate later frequency, consistency, or quality of classroom use.              |
| Reported barriers included additional time for technology ( $f = 7$ ), internet or infrastructure problems ( $f = 6$ ), unequal access to resources ( $f = 3$ ), power outages ( $f = 2$ ), and paid applications ( $f = 3$ ). | The interview themes emphasized technical difficulties, access and affordability, and the need for curriculum alignment.                                                                                                                                  | Positive readiness coexisted with perceived technological, socio-economic, and pedagogical constraints.                                                                | These are perceived risks; the study did not observe whether they caused discontinuity in authentic classrooms.                            |
| Fifteen participants described material design and access as easy; the training prioritized mobile, free, or readily accessible tools.                                                                                         | Participants viewed accessible mobile tools positively, while also noting differences in device capability and school infrastructure.                                                                                                                     | The evidence supports perceived initial feasibility within the training setting rather than system-wide accessibility.                                                 | No school-level cost analysis, device-access audit, infrastructure audit, or longitudinal implementation record was collected.             |

#### 4. Discussion

The study examined changes in participating STEM teachers' perceived competence, practical engagement during training, and views on AR applications. The observed results indicate higher post-training self-ratings and a strong stated willingness to use AR. They should be interpreted as evidence of short-term readiness and perceived feasibility, not as proof of sustained use or a causal effect of the program.

Previous AR research has often focused on student achievement, motivation, or attitudes. Dikkartin Övez and Sezginsoy Şeker [36], for example, examined interdisciplinary AR-supported teaching in primary education, while another study investigated middle-school students' attitudes toward STEM and AR [37]. By contrast, the present study centers on STEM teachers' perceptions, design experiences, and judgments about the conditions that may enable or constrain classroom implementation.

The positive responses may be associated with program features such as the use of readily available mobile devices, free or low-cost tools, guided practice, and the requirement to develop and present lesson content. AR activities were also combined with familiar support platforms, including QR codes, Google Classroom, Padlet, and Wordwall. These features may have facilitated engagement, although the study did not isolate their individual effects.

The study's original contribution is to show that teachers' post-training perceptions were multidimensional rather than uniformly positive. By integrating changes in perceived competence with interview accounts and teacher-developed materials, the analysis identifies a linked pattern: pedagogical value was associated with visualization and material design, whereas continued implementation was conditioned by preparation time, infrastructure, affordability, equitable access, curriculum alignment, and institutional support. This teacher-centered evidence advances the literature by distinguishing immediate implementation readiness from the organizational conditions required for continued use.

#### *4.1. Potential Bias and Interpretation of Teacher Readiness*

Voluntary participation may have attracted teachers with greater interest in educational technology. Accordingly, increased confidence and willingness are interpreted as short-term self-reported readiness within this sample, not as evidence of regular post-program classroom use.

#### *4.2. Comparison with Alternative Instructional Strategies*

AR can support technology-assisted, student-centered STEM teaching, but its pedagogical value depends on whether an activity addresses a learning difficulty, aligns with curriculum objectives, and complements other methods. Inquiry-based learning, gamification, blended learning, simulations, and digital resources remain relevant alternatives or partners. AR should therefore be selected for contexts in which its visual, spatial, or interactive affordances add instructional value rather than treated as a universal solution.

#### *4.3. Perceived Barriers to Continued AR Use*

Participants identified infrastructure deficiencies, power outages, application costs, unequal access to devices, and additional time spent with technology as possible barriers to continued AR use. These findings reflect teachers' perceptions of future implementation conditions; the study did not examine whether these factors actually led to discontinuation. Continued use would require reliable internet and electricity, accessible tools, curriculum-aligned examples, technical support, professional development, and attention to digital inequality.

#### *4.4. Socio-Economic, Pedagogical, and Policy Implications*

The findings suggest that AR integration is shaped by economic constraints, accessibility, learning objectives, teacher competence, and institutional support. Mobile and free or low-cost tools may reduce the initial cost of participation, but this advantage depends on equitable access to devices and reliable infrastructure. Pedagogically, AR may be most relevant for abstract, spatial, dynamic, microscopic, hazardous, costly, or difficult-to-observe content. Schools could examine continued implementation through teacher usage frequency, the number and quality of developed materials, technical support records, student access data, learning outcomes, and participation in professional development. These are recommendations for future monitoring rather than outcomes measured in the present study.

#### *4.5. Discussion of Qualitative Findings*

Overall, 17 of the 23 participants stated that AR could enhance lesson efficiency, and 13 noted faster, easier comprehension. These views are consistent with studies reporting that mobile AR-supported STEM activities can support scientific literacy, achievement, engagement, and comprehension [38,39]. Participants also referred to motivation and making abstract concepts tangible, findings that align with previous teacher-focused and

bibliometric research [40,41]. The present findings describe teachers' perceptions; the study did not directly measure student achievement or motivation.

The interview quotations help explain the theoretical basis of these perceptions. The emphasis on concretizing abstract concepts and visualizing three-dimensional objects supports the view that AR is most pedagogically relevant when it reduces representational difficulty in abstract, spatial, or otherwise hard-to-observe STEM content. Likewise, the statement that material preparation contributed to professional development suggests that teacher learning involved not only application use but also pedagogical design and reflection.

Participants also identified increased time spent with technology, infrastructure deficiencies, and unequal access to resources as disadvantages. Similar concerns appear in research on marker detection, technical failures, device and software costs, and physical discomfort [20,42]. Fifteen participants reported that material design and access were easy, which is consistent with research describing AR and related information technologies as potentially useful for understanding complex concepts, motivation, collaboration, and access to educational resources [41,43]. Similarly, Mohamad and Husnin [44] reported high teacher evaluations of AR-module design ( $M = 4.25$ ), content ( $M = 4.05$ ), and satisfaction ( $M = 4.13$ ), with an overall mean score of 4.14. Participants additionally suggested uses in geography, history, social studies, foreign languages, and art. These suggestions are consistent with prior reports of cross-curricular potential [40], but their effectiveness was not examined in this study.

At the same time, participants' words show why positive perceptions do not automatically imply sustainable implementation. One teacher noted that "preparing AR applications initially requires serious time" and that classroom use may "cause time loss during lessons" (P07). Another stressed that students without devices or internet access may face "inequality of opportunity" (P10). These comments reinforce the theoretical argument that continued use depends on protected preparation time, reliable infrastructure, affordable applications, and equitable access.

All 23 participants intended to use AR, and 18 felt able to provide AR-related training; however, the more cautious response from P12 shows that readiness was not uniform. These results indicate perceived confidence and willingness rather than verified training competence or sustained use. They support models of technology integration in which continued practice requires repeated experience, continuing professional development, and institutional support rather than a one-time training experience.

#### 4.6. Discussion of Quantitative Findings

The mean perceived competence score increased from 2.38 ( $SD = 1.15$ ) to 4.21 ( $SD = 0.77$ ),  $t(22) = 7.57$ ,  $p < 0.001$ , Cohen's  $d_z = 1.58$ . This large within-group change converged with interview reports of increased confidence and willingness. However, the small voluntary sample, self-report measure, and absence of a control group or objective performance measure preclude causal or population-level claims.

The item-level results in Table 8 are consistent with research reporting benefits of mobile AR, QR-supported content, interactive learning, motivation, and collaboration [38,45–48]. Other studies identify technical problems, high costs, limited teacher experience, and difficulty accessing suitable applications or materials [6,22], and some report mixed outcomes, including no significant increase in student motivation [49]. The present findings therefore concern teachers' perceived competence and implementation conditions; they do not establish effects on student learning or long-term classroom use.

#### 4.7. Scope of the Evidence: What Was Measured and What Remains Unknown

What was measured: Table 11 shows convergence among self-reported competence, interview perceptions, and in-program material development. Together, these data support conclusions about perceived competence, perceived feasibility, and short-term implementation readiness within the training context.

What remains unknown: The study does not establish later classroom use, frequency or consistency of implementation, institutional adoption, sustained practice, or student outcomes. These questions require longitudinal observation, usage records, and school- and student-level evidence.

#### 4.8. Limitations

The study involved 23 volunteers from one region, used a single-group pre-test/post-test design, and relied substantially on self-report. Selection bias, testing effects, expectations, and other uncontrolled influences cannot be excluded, and high internal consistency does not establish comprehensive construct validity or actual classroom performance. The qualitative analysis also lacked independent coding, formal saturation evidence, and long-term observation.

Future research should include follow-up after at least one academic term, classroom observations, student learning measures, teacher use records, institutional support data, cost and access indicators, and policy-related evidence. Such data would help distinguish positive post-training intention from actual continued implementation.

### 5. Conclusions

This eight-week mixed-methods study found a large increase in participating teachers' self-reported AR competence, supported by positive interview accounts and engagement in material development. Teachers associated AR with visualization, comprehension, motivation, lesson efficiency, and interactive design, while identifying time, infrastructure, cost, and unequal access as constraints. The principal contribution is a teacher-centered account showing that immediate readiness and pedagogical interest coexist with conditions that may limit continued implementation. The evidence is restricted to short-term perceptions and in-program activity among 23 volunteers in Northern Cyprus; it does not establish causal effectiveness, sustained classroom use, or student outcomes. Future studies should use comparison groups, longitudinal follow-up, classroom observation, usage records, student measures, and institutional data. AR should be selected purposefully where its visual and interactive affordances align with curriculum objectives and complement other teaching methods.

**Supplementary Materials:** The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/su18157694/s1>. Supplementary File S1: Teacher Perceived Competence Questionnaire for the Use of Augmented Reality in STEM Education (original Turkish instrument and English translation); Supplementary File S2: Semi-Structured Interview Form on Teachers' Use of Augmented Reality in STEM Education (original Turkish form and English translation); Supplementary File S3: Anonymized Preliminary Needs-Analysis Responses from 26 STEM Teachers Used to Inform Questionnaire Item Generation.

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## References

1. Azuma, R.T. A survey of augmented reality. *Presence Teleoperators Virtual Environ.* **1997**, *6*, 355–385. [\[CrossRef\]](#)
2. Ibáñez, M.B.; Delgado-Kloos, C. Augmented reality for STEM learning: A systematic review. *Comput. Educ.* **2018**, *123*, 109–123. [\[CrossRef\]](#)
3. Chang, H.Y.; Binali, T.; Liang, J.C.; Chiou, G.L.; Cheng, K.H.; Lee, S.W.Y.; Tsai, C.C. Ten years of augmented reality in education: A meta-analysis of (quasi-) experimental studies to investigate the impact. *Comput. Educ.* **2022**, *191*, 104641. [\[CrossRef\]](#)
4. Eh Phon, D.; Nincarean, D.; Mohd Razali, N.F.R.B. Mobile augmented reality framework in STEM education: A systematic literature review. *Iraqi J. Comput. Sci. Math.* **2024**, *5*, 6. [\[CrossRef\]](#)
5. Giang, N.T.; Van, D.N.; Hong, N.P.N.; Bao, C.D.; Phuong, T.N.; Phuong, T.T.T. Applying augmented reality technology in STEM education: A bibliometrics analysis in Scopus database. *Eur. J. Educ. Res.* **2025**, *14*, 73–87. [\[CrossRef\]](#)
6. Alqarni, T. Comparison of augmented reality and conventional teaching on special needs students' attitudes towards science and their learning outcomes. *J. Balt. Sci. Educ.* **2021**, *20*, 558–572. [\[CrossRef\]](#)
7. Fearn, W.; Hook, J.D. A service design thinking approach: What are the barriers and opportunities of using augmented reality for primary science education? *J. Technol. Sci. Educ.* **2023**, *13*, 329–351. [\[CrossRef\]](#)
8. Perifanou, M.; Economides, A.A.; Nikou, S.A. Teachers' views on integrating augmented reality in education: Needs, opportunities, challenges and recommendations. *Future Internet* **2023**, *15*, 20. [\[CrossRef\]](#)
9. UNESCO. *Education for Sustainable Development Goals: Learning Objectives*; UNESCO: Paris, France, 2017.
10. UNESCO. *Education for Sustainable Development: A Roadmap*; UNESCO: Paris, France, 2020.
11. Di Serio, Á.; Ibáñez, M.B.; Kloos, C.D. Impact of an augmented reality system on students' motivation for a visual art course. *Comput. Educ.* **2013**, *68*, 586–596. [\[CrossRef\]](#)
12. Hwang, G.-J.; Wu, P.-H.; Chen, C.-C.; Tu, N.-T. Effects of an augmented reality-based educational game on students' learning achievements and attitudes in real-world observations. *Interact. Learn. Environ.* **2016**, *24*, 1895–1906. [\[CrossRef\]](#)
13. Sırakaya, M.; Alsancak Sırakaya, D.A. Augmented reality in STEM education: A systematic review. *Interact. Learn. Environ.* **2022**, *30*, 1556–1569. [\[CrossRef\]](#)
14. Bacca Acosta, J.L.; Baldiris Navarro, S.M.; Fabregat Gesa, R.; Graf, S. Augmented reality trends in education: A systematic review of research and applications. *J. Educ. Technol. Soc.* **2014**, *17*, 133–149.
15. Cheng, K.H.; Tsai, C.C. Affordances of augmented reality in science learning: Suggestions for future research. *J. Sci. Educ. Technol.* **2013**, *22*, 449–462. [\[CrossRef\]](#)
16. Dunleavy, M.; Dede, C.; Mitchell, R. Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *J. Sci. Educ. Technol.* **2009**, *18*, 7–22. [\[CrossRef\]](#)
17. Lin, H.-C.K.; Chen, M.-C.; Chang, C.-K. Assessing the effectiveness of learning solid geometry by using an augmented reality-assisted learning system. *Interact. Learn. Environ.* **2015**, *23*, 799–810. [\[CrossRef\]](#)
18. Kalemkuş, J.; Kalemkuş, F. Effect of the use of augmented reality applications on academic achievement of student in science education: Meta analysis review. *Interact. Learn. Environ.* **2023**, *31*, 6017–6034. [\[CrossRef\]](#)
19. Wong, C.H.S.; Tsang, K.C.K.; Chiu, W.K. Using augmented reality as a powerful and innovative technology to increase enthusiasm and enhance student learning in higher education chemistry courses. *J. Chem. Educ.* **2021**, *98*, 3476–3485. [\[CrossRef\]](#)
20. Ajit, G. A systematic review of augmented reality in STEM education. *Stud. Appl. Econ.* **2021**, *39*, 1–22. [\[CrossRef\]](#)
21. Öztaş, E.Ş. Eğitimde artırılmış gerçeklik teknolojisi kullanımı: 2014–2024 sistematik alanyazın taraması. *Ufuk Üniversitesi Sos. Bilim. Enstitüsü Derg.* **2024**, *13*, 33–54. [\[CrossRef\]](#)
22. Pal, R.A.B.; Ade, D.M. Applications and Challenges of Augmented Reality in Education Sector: A report. *Int. J. Res. Appl. Sci. Eng. Technol.* **2022**, *10*, 1266–1273. [\[CrossRef\]](#)

23. United Nations. *Transforming Our World: The 2030 Agenda for Sustainable Development*; United Nations: New York, NY, USA, 2015.
24. Karagözlü, D. Creating a Sustainable Education Environment with Augmented Reality Technology. *Sustainability* **2021**, *13*, 5851. [\[CrossRef\]](#)
25. Badilla-Quintana, M.G.; Sepulveda-Valenzuela, E.; Salazar Arias, M. Augmented Reality as a Sustainable Technology to Improve Academic Achievement in Students with and without Special Educational Needs. *Sustainability* **2020**, *12*, 8116. [\[CrossRef\]](#)
26. Lee, C.-J.; Hsu, Y. Sustainable education using augmented reality in vocational certification courses. *Sustainability* **2021**, *13*, 6434. [\[CrossRef\]](#)
27. Creswell, J.W. *Reflections on the MMIRA, the Future of Mixed Methods*; Task Force Report; Sage Publications: Thousand Oaks, CA, USA, 2016.
28. Creswell, J.W.; Plano Clark, V.L. *Designing and Conducting Mixed Methods Research*, 3rd ed.; SAGE Publications: Thousand Oaks, CA, USA, 2017.
29. Fetters, M.D.; Curry, L.A.; Creswell, J.W. Achieving integration in mixed methods designs—Principles and practices. *Health Serv. Res.* **2013**, *48*, 2134–2156. [\[CrossRef\]](#) [\[PubMed\]](#)
30. Branch, R.M. *Instructional Design: The ADDIE Approach*; Springer: New York, NY, USA, 2009. [\[CrossRef\]](#)
31. Mishra, P.; Koehler, M.J. Technological pedagogical content knowledge: A framework for teacher knowledge. *Teach. Coll. Rec.* **2006**, *108*, 1017–1054. [\[CrossRef\]](#)
32. Guido, R.M.D. Evaluation of a modular teaching approach in materials science and engineering. *Am. J. Educ. Res.* **2014**, *2*, 1126–1130. [\[CrossRef\]](#)
33. Fisher, M.J.; Marshall, A.P. Understanding descriptive statistics. *Aust. Crit. Care* **2009**, *22*, 93–97. [\[CrossRef\]](#) [\[PubMed\]](#)
34. Braun, V.; Clarke, V. Using thematic analysis in psychology. *Qual. Res. Psychol.* **2006**, *3*, 77–101. [\[CrossRef\]](#)
35. Başkale, H. Determination of validity, reliability and sample size in qualitative studies. *Dokuz Eylül Üniversitesi Hemşire. Fakültesi Elektr. Derg.* **2016**, *9*, 23–28.
36. Dikkartin Övez, F.; Sezginsoy Şeker, B. İlköğretimde artırılmış gerçeklik destekli disiplinler arası bir öğretim uygulaması. *Balıkesir Üniversitesi Fen. Bilim. Enstitüsü Derg.* **2022**, *24*, 313–334. [\[CrossRef\]](#)
37. İnancı, E.; Timur, B. Ortaokul Öğrencilerinin STEM e ve artırılmış gerçeklik uygulamalarına yönelik Tutumlarının İncelenmesi. *Kalem Uluslar. Egit. İnsan Bilim. Derg.* **2022**, *12*, 55–86. [\[CrossRef\]](#)
38. Wahyu, Y.; Suastra, I.W.; Sadia, I.W.; Suarni, N.K. The effectiveness of mobile augmented reality assisted stem-based learning on scientific literacy and students' achievement. *Int. J. Instr.* **2020**, *13*, 343–356. [\[CrossRef\]](#)
39. Suhail, N.; Bahroun, Z.; Ahmed, V. Augmented reality in engineering education: Enhancing learning and application. *Front. Virtual Real.* **2024**, *5*, 1461145. [\[CrossRef\]](#)
40. Yorulmaz, A.; Çokalışkan, H.; Akaydın, B.B.; Uysal, H. İlkokulda artırılmış gerçeklik uygulamalarına ilişkin sınıf öğretmenlerinin görüşleri. *Cumhuriyet. Int. J. Educ.* **2023**, *12*, 538–556. [\[CrossRef\]](#)
41. Nguyen, T.C.; Nguyen, T.C.; Nguyen, H.B. The role of information technology in STEM education. *Asian J. Educ. Train.* **2024**, *10*, 18–26. [\[CrossRef\]](#)
42. Khawaji, T.M. The benefits and challenges of augmented reality in the science classroom: A narrative review. *Educ. Q. Rev.* **2024**, *7*, 60–75. [\[CrossRef\]](#)
43. Tene, T.; Marcatoma Tixi, J.A.; Palacios Robalino, M.D.L.; Mendoza Salazar, M.J.; Vacacela Gomez, C.; Bellucci, S. Integrating immersive technologies with STEM education: A systematic review. *Front. Educ.* **2024**, *9*, 1410163. [\[CrossRef\]](#)
44. Mohamad, S.; Husnin, H. Teachers' perception of the use of augmented reality (AR) modules in teaching and learning. *Int. J. Acad. Res. Bus. Soc. Sci.* **2023**, *13*, 9–34. [\[CrossRef\]](#) [\[PubMed\]](#)
45. Lin, P.-Y.; Wu, W.-C.; Yang, J.-H. A QR code-based approach to differentiating the display of augmented reality content. *Appl. Sci.* **2021**, *11*, 11801. [\[CrossRef\]](#)
46. Kan, T.-W.; Teng, C.-H.; Chou, W.-S. Applying QR code in augmented reality applications. In *Proceedings of the 8th International Conference on Virtual Reality Continuum and Its Applications in Industry (VRCAI '09)*, Yokohama, Japan, 14–15 December 2009; Association for Computing Machinery: New York, NY, USA, 2009; pp. 253–257. [\[CrossRef\]](#)
47. AlNajdi, S.M. The effectiveness of using augmented reality (AR) to enhance student performance: Using quick response (QR) codes in student textbooks in the Saudi education system. *Educ. Technol. Res. Dev.* **2022**, *70*, 1105–1124. [\[CrossRef\]](#) [\[PubMed\]](#)
48. Manisha, M.; Gargish, S. Augmented reality and education: A comprehensive review and analysis of methodological considerations in empirical studies. *J. E-Learn. Knowl. Soc.* **2023**, *19*, 99–109. [\[CrossRef\]](#)
49. Gómez-García, G.; Hinojo-Lucena, F.J.; Alonso-García, S.; Romero-Rodríguez, J.M. Mobile learning in pre-service teacher education: Perceived usefulness of AR technology in primary education. *Educ. Sci.* **2021**, *11*, 275. [\[CrossRef\]](#)

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