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Technology-enhanced "GipSci" approach in developing contexts performs well at *interest* and *curiosity*, yet, needs reinforcing at *inquiry* level

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ABSTRACT

Numerous studies explore inquiry in science centers, but technology-enhanced science centers' (TeSC) curricula remain relatively nascent. This mixed-methods study explores how the GiPSci model, a technology-enhanced science center program developed in-house by curriculum experts, supports learners' inquiry skills aligned with international standards. Data were collected through learners' products ($n = 161$), lesson observations ($n = 20$), train-the-trainer activities ($n = 405$), expert evaluations ($n = 14$), and interviews with trainers ($n = 10$). Findings reveal curiosity and interest scored higher than inquiry, highlighting the challenges of inquiry in tech-enhanced settings. Consensus among trainers, observations, and learners' products points to gaps in fostering inquiry skills in the TeSC program. To enhance GiPSci-like models, collaboration among program designers, trainers, and train-the-trainer providers is essential to better align the technology-enhanced science centers' program with inquiry-based learning.

KEYWORDS
Technology-enhanced science centers; mixed-methods research; inquiry skills; interest; curiosity

1. Introduction

Science centers are specialized institutions aimed at making science accessible and inspiring to diverse age groups by integrating technology into learning and teaching. These centers primarily strive to enhance young learners' interest, curiosity, and inquiry skills. However, existing research reveals that these centers often fall short in effectively developing inquiry skills (Bilišňanská and Kireš 2018; Gutwill and Allen 2012; Sasson 2014). This raises the question: why are science center activities unable to sufficiently foster inquiry skills?

This study investigates the successes and barriers in promoting inquiry through the 'Bilim Türkiye' network. Spanning 24 technology-enhanced science centers across five countries, Bilim Türkiye operates interdisciplinary programs covering Design, Nature Sciences, Technology, Mathematics, Astronomy and Aerospace, and Agricultural Technologies (see Figure 1). The study examines how inquiry, a core component of

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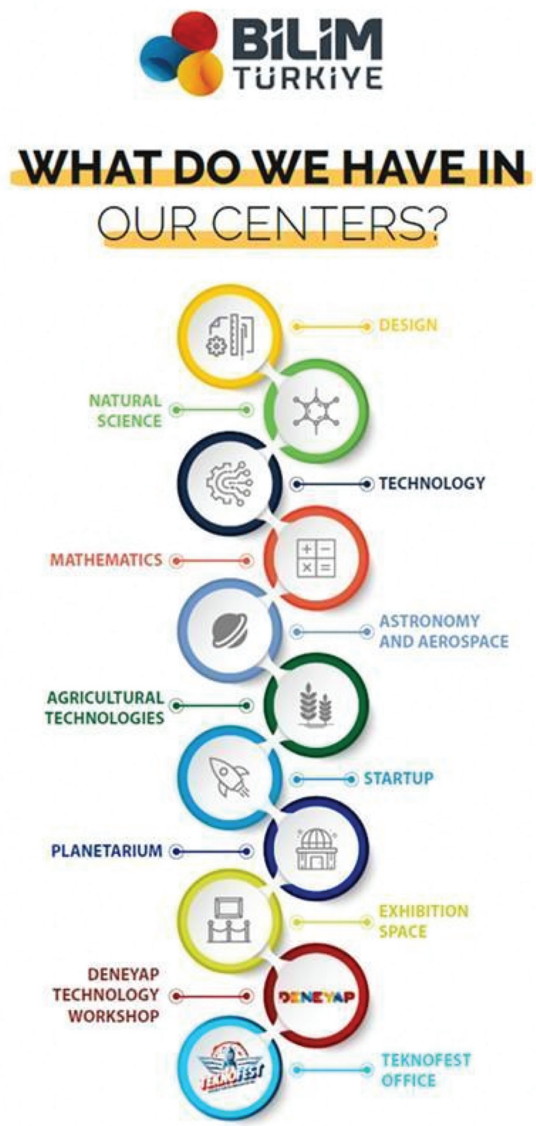

Figure 1. Bilim Türkiye Workshops.

scientific thinking and a vital skill for hypothesis formation and problem-solving (Rönnebeck, Bernholt and Ropohl 2016) can be more effectively cultivated. Enhancing inquiry skills not only deepens scientific understanding but also empowers young learners to innovate, contributing to technological and societal progress.

1.1. Inquiry and the role of technology-enhanced science centers

Technology-enhanced science centers adopt diverse methods, including workshops, exhibits, science shows, and discussions, to promote inquiry-based learning. Workshops, tailored for young learners, are designed to align with developmental stages and encourage active participation. These workshops incorporate contributions from various elements, including trainers, lesson plans, management, and the overall vision of the science center. Trainers play a critical role in the inquiry process, making continuous professional development (PD) essential for integrating recent scientific advancements and inquiry-based pedagogies.

Strategic lesson planning and supportive managerial practices are crucial for maximizing learning outcomes. Despite these efforts, gaps remain. Workshop-focused centers like those in Bilim Türkiye highlight challenges in implementing activities that consistently develop inquiry skills. This study examines how these centers can better support young learners in cultivating inquiry skills within interdisciplinary, exhibition-oriented, and workshop-driven environments (see Figure 2).

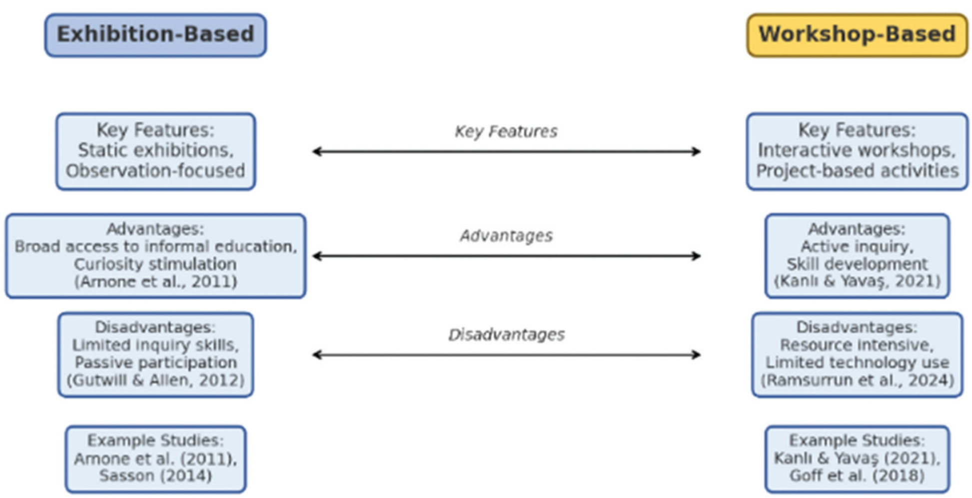

Figure 2. Comparative Flowchart.
Note. Studies adopted from Arnone et al. (2011), Sasson (2014), Gutwill and Allen (2012), Kanlı and Yavaş (2021), Ramsurrun et al. (2024), Goff et al. (2018).

1.2. Public engagement and educational impact

Public interest in science is growing (Dal et al. 2013), with science centers providing unique opportunities to connect theoretical knowledge with practical applications. For young learners, aged 6–14, these centers serve as alternative learning spaces where they can observe the role of science and technology in everyday life. Hands-on activities and interactive exhibits aim to bridge school concepts with real-world applications, allowing learners to experiment and internalize knowledge through exploration.

More than just academic venues, science centers inspire critical thinking and collaboration. With around 2,400 science centers globally attracting nearly 290 million visitors annually, they play a pivotal role in promoting scientific literacy and fostering curiosity. Through community outreach and interactive displays, these centers create dynamic learning environments that transcend traditional classroom settings (Raman et al. 2018).

1.3. The GiPSci model: a theoretical framework

The GiPSci model integrates inquiry-based learning with a workshop-oriented approach to foster scientific curiosity and problem-solving. By emphasizing guided inquiry, GiPSci encourages young learners to explore, hypothesize, and evaluate ideas. Workshops within this model are designed to align with learners' developmental stages, using hands-on tools and real-world applications to stimulate curiosity and foster deeper inquiry.

The GiPSci has been developed for the aim of this study because first, by integrating guided inquiry with product-based learning, technology-supported science centers more effectively foster young learners' curiosity and problem-solving skills (S. K. W. Chu et al. 2021). Second, compared to using pure project-based learning (PBL), GiPSci emphasizes less complex, long-term products and provides more structured guidance than traditional IBL, thereby facilitating technology integration in resource-constrained developing contexts (Marquez et al. 2023; Ramanathan, Carter, and Wenner 2021). This feature makes it particularly ideal for fostering inquiry skills in technology-supported science centers across Eurasian countries (Habig et al. 2020). Third, unlike static models, GiPSci integrates technology-supported tools (e.g. interactive exhibits, simulations) into guided inquiry, which provides a significant advantage in overcoming infrastructure challenges in developing countries (e.g. Crompton and Burke 2024; De Jong 2010) (see Özer and Suna 2023; Kanlı and Yavaş 2021 for hybrid models).

GiPSci–(Guided Inquiry, Product-based, Science Centers) – emphasizing the learning methods before the science centers (see Figure 3)

Figure 3 visually presents the theoretical framework of the GiPSci model, emphasizing its three core components: Guided Inquiry, Product-based Learning, and Science Centers. The central 'GiPSci' label, with converging arrows from each colored box, symbolizes their integrated contribution and responds to the editor's call for meaningful integration of visual elements.

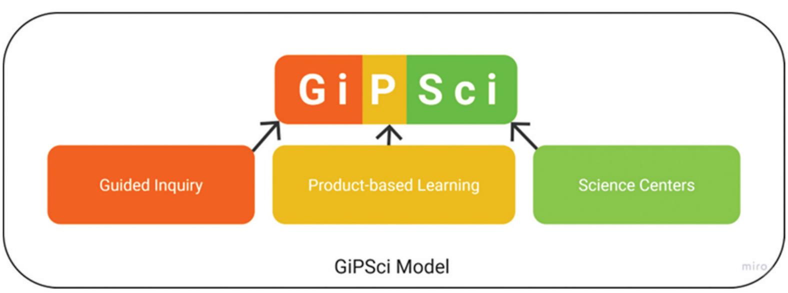

Figure 3. GiPSci Model as Theoretical Framework.

This study explores the effectiveness of the GiPSci model through the following research question:

-How does the *GiPSci Model*, implemented through technology-enhanced science workshops, help young learners acquire inquiry skills?

2. Literature review

This section starts with the definition of inquiry, curiosity, and interest, and discusses the role of technology-enhanced science centers, along with studies that have reviewed youth inquiry skills in both formal and informal learning environments, highlighting how these constructs interact to support meaningful science engagement and learning.

2.1. Operational definitions: inquiry, curiosity, and interest

In technology enhanced science centers, 'inquiry', 'curiosity', and 'interest' are key to fostering youth engagement and learning. These concepts are interconnected yet distinct:

Inquiry involves actively seeking information through questioning and exploration. This includes formulating investigative questions, hypothesis testing, and data collection, promoting critical thinking and analytical skills (Hidi and Renninger 2020).

Curiosity is the intrinsic drive to learn, often sparked by novelty. It encompasses epistemic curiosity (seeking to close knowledge gaps), explanation-seeking curiosity ('why' questions), and transient exploratory states (Ellaway 2014; Liquin and Lombrozo 2020; Silvia and Kashdan 2009).

Interest is a sustained emotional connection to a subject, driving long-term engagement, triggering further questions, and fostering a pursuit of knowledge (Hidi and Renninger 2020; Silvia and Kashdan 2009).

While related, these concepts serve different roles: inquiry channels curiosity, while interest sustains engagement over time. A balanced approach ensures structured inquiry does not stifle natural curiosity.

The constructs differ from each other in that interest is motivation-based, curiosity relies on epistemic gap-driven whereas inquiry is structured around practice-based activities. A review of the literature on our constructs (i.e. interest, curiosity and inquiry) indicates that the majority of studies (~55%) focus on the construct of *inquiry* (e.g. Albion 2015; Capps, Crawford, and Constas 2012; Gutwill and Allen 2012; Lazonder and Harmsen 2016) and some degree of (~25%) *interest* (e.g. Peterson and Hidi 2019; Rubino-Hare et al. 2023). In contrast, only a smaller proportion (~20%) explicitly investigates *curiosity* (e.g. Alan and Mumcu 2024; Arnone et al. 2011; Liquin and Lombrozo 2020; Weible and Zimmerman 2016) in a diverse context of centers. Methodologically, most of these studies rely heavily on usage of self-report instruments, particularly standardized scales, with fewer incorporating quasi-experimental, observational or longitudinal designs (i.e. field studies, case studies). Only a handful used mixed-methods systematically (e.g. Pedaste et al. 2015). In other words, while quantitative approaches dominate, mixed-methods studies that capture the dynamic interaction of these constructs remain sparse. Overall, the literature shows a tendency to measure constructs in isolation, without sufficiently addressing their interconnections, which underscores the relevance of the present study's integrated approach.

2.2. Role of technology-enhanced science centers

These centers play a pivotal role in promoting youth engagement in STEM and related fields (Gelmez Burakgazi, Yıldırım, and Weeth Feinstein 2016). Their benefits include:

2.2.1. Inclusivity

Informal science programs foster belonging among diverse groups, aiding career pathways (Zhao et al. 2023).

2.2.2. Skill development

Hands-on activities enhance scientific thinking and sustain interest in scientific research, often leading to career aspirations in STEM (Habig et al. 2020; Habig, Gupta, and Adams 2021).

2.2.3. Innovative techniques

These programs help underrepresented youth build confidence in inquiry and curiosity, supported by technology (Hsu et al. 2018).

Inquiry-Based Learning (IBL) is a prominent method in science centers, where learners construct knowledge by posing and answering questions (K. W. S. Chu et al. 2021). According to Pedaste et al. (2015), the inquiry-based learning process can be understood through five interconnected phases. *Orientation* involves introducing a problem or phenomenon that sparks curiosity and motivates learners to explore further. During *Conceptualization*, learners frame hypotheses or guiding questions that define the direction of their inquiry. The *Investigation* phase follows, where learners actively experiment, observe, or explore to gather evidence and seek answers to their questions. Afterward, in the *Conclusion* phase, they summarize and interpret their findings to determine whether their hypotheses were supported. Finally, the *Discussion* phase encourages learners to reflect on their results, share insights, and connect their findings to broader concepts or real-world contexts.

This cycle fosters engagement with science through active learning and develops critical thinking skills (Bybee et al. 2006; Vorholzer and von Aufschnaiter 2019). Successful IBL depends on skilled instructors in design and management (Chase et al. 2013). It boosts motivation, scientific literacy, and comprehension of innovations (Schwartz 2017; Tsaliki 2022). Another key method, Product-based Learning (PBL) emphasizes creating tangible outcomes, enhancing practical skills and learning. It is particularly valuable in science fields, fostering creativity, problem-solving, and readiness for real world challenges (Marquez et al. 2023). This approach bridges the digital divide, promoting digital skills and career preparedness (Lorenzo-Yustos et al. 2010). Technology-enhanced science centers thus provide transformative learning experiences, equipping youth with critical skills, fostering curiosity, and sustaining interest in science and technology.

In this study, inquiry skills were operationalized based on the Inquiry-Based Learning (IBL) framework proposed by Pedaste et al. (2015). This framework delineates five stages of inquiry – orientation, conceptualization, investigation, conclusion, and discussion – providing a structured foundation for measurement.

Prior studies have employed various tools, such as observation forms, student products, and interviews, to assess inquiry skills (Bilišňanská and Kireš 2018; Rubino-Hare et al. 2023). The study integrates these tools to achieve a comprehensive mixed evaluation of inquiry skills.

To understand the processes of curiosity, interest, and inquiry and to develop the methodology for the current study, the work of Lazonder and Harmsen (2016) on measures of inquiry in the literature was analyzed, resulting in a categorization of strengths and weaknesses as presented below.

2.3. Notable review on youth inquiry skills measurement

Table 1 provides a chronological overview of key tools and studies used to measure youth inquiry and curiosity, from early observational approaches (e.g. Henderson and Moore 1980) to more refined, mixed-method tools (e.g. Litman and Spielberger 2003).

Table 1. A notable review on youth inquiry skills measurement.

Author(s) & Year	Title	Key Info		
Henderson & Moore (1980)	Exploratory Behavior in Structured Tasks	The tendency to explore novelty. Structured task preference for unknown stimuli in 3.5–5-year-olds. Strength: Several trials for different tasks. Weakness: No coding of exploratory behavior.		
Spielberger et al. (1980)	State-Trait Curiosity Inventory (STCI)	15 items each scale, self-report for adults. Strength: Includes both state and trait curiosity, items based on a reliable anxiety scale.		
Harty & Beall (1984)	Children's Scientific Curiosity	Measures frequency and motivation for science learning. Self-report for 5th graders. Strength: Effective for elementary-aged children. Weakness: Specific behavior focus could confound scientific curiosity with personal interests		
Alberti & Witryol (1994)	Reward Choice (Valued vs Unknown Toy)	Influenced by uncertainty. Preference for unknown objects in 1st and 4th graders. Strength: Controlled for familiarity. Weakness: Did not control for individual toy preferences.		
Loewenstein (1994)	Self-Rating of Curiosity	Motivated by a lack of information. Self-report for adults. Strength: Simple and easy to use. Weakness: Measures curiosity about specific information only.		
Litman & Spielberger (2003)	Curiosity Questionnaire and Behavior	Driven by optimal information level. Self-report and behavior measure for adults. Strength: Captures curiosity responses across different tasks. Weakness: Item-specific curiosity, limits generalizability.		
Byman (2005)	Factor Analysis of Other Measures	A multidimensional trait. Self-report for 5th graders. Strength: Variety of questionnaire types included. Weakness: Modified response scales may affect validity.		
Peterson (2020)	Review	How students' curiosity can be supported in educational contexts		
Children's Scientific Curiosity (Harty & Beall, 1984)	Review	Effective for assessing scientific curiosity in elementary-aged children.	Specific focus on behavior may confound curiosity with individual personal interests.	
Inquiry in Science Centers (Wu et al. 2021; Xu et al. 2023)		Inquiry-based learning is central to science centers, aimed at developing students' inquiry skills by engaging them in scientific practices. It involves cognitive, behavioral, emotional, and social engagement dimensions, influenced by inquiry-related curiosity.	Projects encourage visitors to ask questions and explore curiosities, tailoring content to audience interests.	Measuring and supporting inquiry, curiosity, and interest in science centers poses challenges, especially distinguishing these constructs.

Note. Chronological order.

Recent studies highlight the evolving role of science centers in, transitioning from static exhibitions to more visitor-oriented, interactive spaces that foster shared experiences (Mcguire et al. 2020; Muhtaseb and Burqan 2021; Yun, Shi, and Jun 2022). These centers significantly impact public engagement and out-of-school learning (Yun, Shi, and Jun 2022) while emphasizing frameworks and interactive activities to enhance visitor experiences (Muhtaseb and Burqan 2021).

Research methods include theoretical, qualitative, and quasi mixed-methods approaches, with recent studies focusing on educators' professional development, learner perceptions, and engagement (Love 2022; Yun et al. 2021). Teachers are pivotal in nurturing inquiry, curiosity, and interest – key constructs for effective science education (Wu, Wu, and Huang 2021; Xu et al. 2023). While much research exists on individual aspects, holistic studies, such as the nascent inquiry into 'Bilim Türkiye', are emerging to provide comprehensive insights (see Figures 4 and 5).

2.3.1. *Inquiry in science education*

Inquiry-based learning emphasizes exploration and questioning, allowing teachers to guide rather than direct young learners' experiences. This approach is particularly impactful in preschool, where play becomes a foundation for structured inquiry (Ramanathan, Carter, and Wenner 2021). To implement interdisciplinary science inquiry (ISI) effectively, teachers require professional development and support, which enhances young learners' inquiry skills (Chowdhary et al. 2014).

2.3.2. *Curiosity and interest in learning environments*

Curiosity drives exploration and can be fostered through strategies like information deprivation and tools like the SCILE scale (Weible and Zimmerman 2016; Xu et al. 2023).

Figure 4. Workshop.

Figure 5. An exhibit-oriented science center in the world vs. A workshop-oriented (product-based) science center in Türkiye.

Projects like 'We The Curious' demonstrate its role in enhancing learning outcomes (Alan and Mumcu 2024). Interest, as a deeper, sustained engagement, enriches knowledge over time (Hidi and Renninger 2020). Challenges remain in distinguishing curiosity from interest and leveraging technology to foster these traits (Peterson and Hidi 2019; Arnone et al. 2011). Teacher training is vital to promote inquiry, curiosity, and interest in technology-enhanced science education.

2.4. Addressing the gaps in inquiry-based learning

Despite their potential, many science centers face challenges in effectively integrating inquiry-oriented teaching (Fulmer, Ma, and Liang 2019; Ramsurrun and Elaheebocus, 2024). Inquiry skills often receive less emphasis compared to interest and curiosity. Systematic reviews suggest that while exhibit-based learning settings significantly contribute to informal education, an updated approach incorporating inquiry-driven, workshop-focused activities is needed (Ee, Golf, and Mulvey 2018; Ramsurrun, Elaheebocus, and Chiniah 2024).

Moreover, the body of research about exhibition-based approaches highlights the contribution of static exhibitions in science centers to informal education; however, their capacity to develop inquiry skills is limited (e.g. Gutwill and Allen 2012). The body of research about workshop-oriented approaches proposes more interactive activities that foster inquiry-based learning, yet it may often lack robust technology integration (e.g. Kanlı and Yavaş 2021). This categorization indicates that exhibition-based approaches are predominantly reliant on passive observation, whereas workshop-oriented approaches enhance active participation. Nonetheless, both approaches exhibit deficiencies in adequately fostering inquiry skills (Goff, Mulvey, and Irvin 2018).

Recent research shows that exhibition-based activities can enhance inquiry when focusing on socioscientific issues (e.g. Pedaste et al. 2015), whereas workshop-based ones may limit access in low- and middle-income countries (e.g. Turkish Academy of Sciences 2022). The current gap in the literature reveals the limitations of traditional approaches while pointing to the potential of hybrid models. This synthesis highlights the necessity of technology-integrated models such as GiPSci.

The research gap to be emphasized in the present research indicates that while traditional exhibits in informal and nonformal education are valuable, a more contemporary approach integrating activities that focus on both inquiry-based and workshops-oriented is needed. This study aims to fill this need by investigating how the GiPSci model, which combines guided inquiry, product-based, and technology-enhanced science centers through learning technology, can improve youth's inquiry skills.

3. Methods

This section discusses the context, participants, research team and their roles, data collection tools, data analysis, and study limitations in line with mixed-methods research design (Creswell and Plano-Clark 2023).

3.1. Context

Bilim Türkiye, launched in 2020 by the T3 Foundation, aligns with Türkiye's National Technology initiative to promote science and technology across society (T3 Foundation, 2020). The program fosters science communication, interest in STEM fields, and teamwork-oriented, productive future generations. By 2023, Bilim Türkiye programs span 7 Eurasian countries (e.g. Azerbaijan, Kyrgyzstan, Türkiye), 12 provinces, and 24 centers. From 2018 to 2024, 2,157,611 young participants (some repeatedly) have benefited. Targeting learners aged 6–14, workshops cover seven themes: Technology, Astronomy & Aviation, Mathematics, Natural Sciences, Design, Entrepreneurship, and Agricultural Technologies. Centers also feature interactive exhibits and planetariums to concretize abstract concepts. These diverse educational opportunities engage youth in experiential, hands-on learning while exploring science and technology.

These offerings encompass a diverse range of educational and experiential formats designed to engage participants in different ways. *One-Hour Workshops* provide concise, focused learning experiences that introduce key concepts in a short time. *Package Programs* combine multiple sessions or activities into a cohesive learning journey, allowing for deeper exploration of a topic. *Term-Length Trainings* extend over several weeks or months, supporting sustained skill development and conceptual understanding. *Thematic Workshops* center around specific topics or themes, fostering targeted inquiry and creativity. *Special Events Outside the Workshop* offer unique opportunities for informal learning through guest talks, performances, or hands-on demonstrations. *Interactive Exhibition Tours* enhance engagement by allowing participants to actively explore exhibits and connect theory to real-world applications. Lastly, the *Planetarium Experience* immerses audiences in an interactive, visual exploration of the universe, blending education with awe and discovery.

In the centers, more than 600 unique workshop content series, enriched with learning technologies, are implemented in which young learners are encouraged to be involved in active learning opportunities. In line with the principle of equal opportunity, the workshop concept, educational content and educational equipment of all centers are completely standardized (see Figures 6–9).

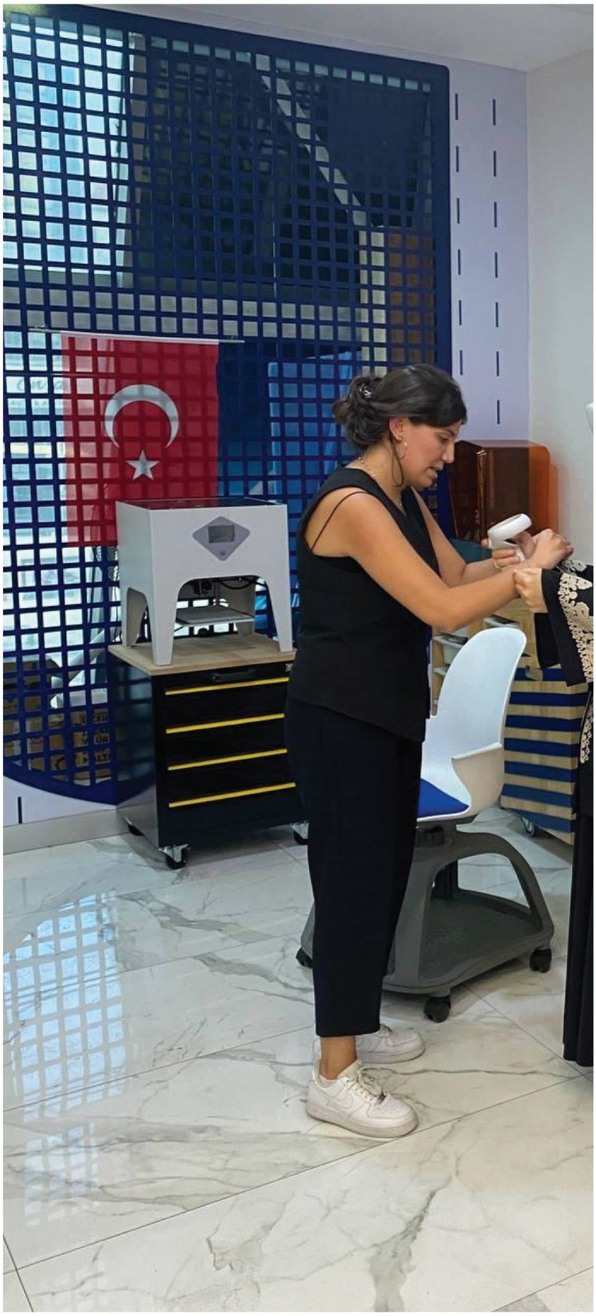

Figure 6. Teacher in a Workshop.

Figure 7. Bilim Türkiye from Istanbul district (23 September 2024).

Figure 8. Bilim Türkiye train-the-trainer camp.

Figure 9. Bilim Türkiye train-the-trainer camp (September 11–13th 2024).

Young learners can attend the courses on the weekdays with their classes in the schools or on the weekends in technology-enhanced science centers hosted by the foundation or Municipality.

3.1.1. Research design

This study follows a *sequential mixed-methods research* flow designed to comprehensively examine *technology-enhanced science centers' inquiry-based learning* processes within the GiPSci program. The research begins with validated data collection instruments grounded in the *5E (Bybee et al. 2006), Inquiry-Based Learning (Pedaste et al. 2015), and ISTE (2023) standards*. The first phase involved *quantitative* and *qualitative* data collection through *lesson observations (n = 20), train-the-trainer sessions (n = 405), expert evaluations (n = 14), and learner product analyses (n = 161)*. Concurrently, *semi-structured interviews (n = 10)* provided in-depth qualitative insights into trainers' and learners' inquiry experiences. Data were analyzed through descriptive *content analysis, coding, and frequency calculations*, integrating findings through *triangulation to ensure validity and reliability*. The final phase synthesized results across five convergent data sources—*observations, interviews, learner products, expert evaluations, and training sessions*—producing a holistic understanding of *how curiosity, interest, and inquiry skills were fostered in technology-enhanced science workshops.*

3.2. Participants

3.2.1. Participant recruitment

Participation in Bilim Türkiye was advertised across K-12 public and private schools in Türkiye's seven regions. Invitations targeted administrators, educators, and engineers. Enrollment was managed by the foundation's Bilim Türkiye directorship.

3.2.2. Young learner participants

Participation was voluntary, with attendees selected by Bilim Türkiye vice coordinators. Around 2.3 million young learners, from 80 schools monthly, participated. Sessions were inquiry-based, held on weekend mornings, and funded by the T3 Foundation. Attendees received end-of-semester certificates.

3.2.3. Trainer participants

Trainers came from diverse fields, including academics ($n = 7$), consultancy ($n = 5$), and foundations ($n = 3$), representing disciplines such as robotics, educational technology, and design. Training topics in Erzurum province included AI in education, informal learning, architectural design, astronomy education, and agricultural technologies. Trainers had an average experience of 0.28 years.

3.2.4. Expert participants

Three experts contributed to the 'train-the-trainer' sessions in the eastern part of the Türkiye. An assistant professor specialized in educational technology, a biology teaching professional, and a science teaching coordinator supported the program. The latter two have extensive experience with Bilim Türkiye programs and their teaching-learning processes.

3.2.5. Workshop Participants

Workshop participants comprised 93 females (73.23%) and 34 males (26.77%) with an average age of 31.2 years and 10 years of teaching experience. They were purposefully selected for the Annual Bilim Türkiye Workshop Day to train trainers in their fields, such as Technology, Mathematics, and Natural Sciences. Most participants were middle or high school teachers or professors, with common certification areas in education (70%) and engineering/science disciplines (30%).

Figure 6 illustrates the workshop themes, including Technology, Astronomy and Aviation, Mathematics, Natural Sciences, Design, Entrepreneurship, and Agricultural Technologies.

Figure 7 documents a Bilim Türkiye workshop held on 23 September 2024, in Istanbul district, Türkiye, within the study's extended data collection phase (2018–2024). This event exemplifies the TeSC model's implementation across diverse regions, contributing to the 2.3 million learner participation reported.

The data in Figures 8 and 9 are supported by observation forms and rubrics obtained from the Train-the-Trainer camp; these materials are available in a Google Drive folder (see Supplementary Materials).

3.2.6. Research team

The research team consisted of five members with expertise in curriculum and instruction, educational technology, science education, and STEM education. Their combined experience spans over a decade, focusing on teacher training, non-formal learning environments, and international education models.

3.3. Data collection tools

Data collection tools were designed using ISTE standards for leaders, educators, and students. Table 2 outlines the integration of these standards into the research methodology. Given the diverse range of data sources used in the existing literature (see Bilišňanská and Kireš 2018 for observation of student inquiry; Gelmez Burakgazi, Yıldırım, and Weeth Feinstein 2016, for documents of school sites; Rubino-Hare et al. 2024 for lesson planning and implementation; Sutiani, Situmorang, and Silalahi 2021 for questionnaires; Williams, Nguyen, and Mangan 2017 for classroom observation and student work), we chose to use various data collection tools to capture both the depth of youth's inquiry skills through qualitative data and the broader patterns and trends through quantitative data, ensuring a comprehensive understanding of technology-enhanced science workshops under GiPSci program.

Table 2. Standards and GiPSci alignment.

ISTE Leader Standard 5: Visionary Planner	Planning of the *train-the-trainer activities* was observed and gathered through the lens of Bilim Türkiye *leadership team* to enhance the goals and the vision of the trainers (youth interest-curiosity-inquiry skills)
ISTE Educator Standards 5–6: Facilitator and Learner	The trainers ***facilitated*** the guided-inquiry skill acquisition of the young learners in the classes. Further, the trainers were also (life long) ***learners*** in the train-the-trainer programs, learning how to conduct inquiry-based instruction.
ISTE Student Standards 3–4–5: Digital Citizen, Knowledge Constructor, Innovative Designer	Young learners in the Bilim Türkiye, as a ***digital citizenship*** (digital natives), acquired skills through technology-enhanced courses, ***constructed knowledge*** through product-based workshops and ultimately achieved ***innovative designership*** through inquiry skills.

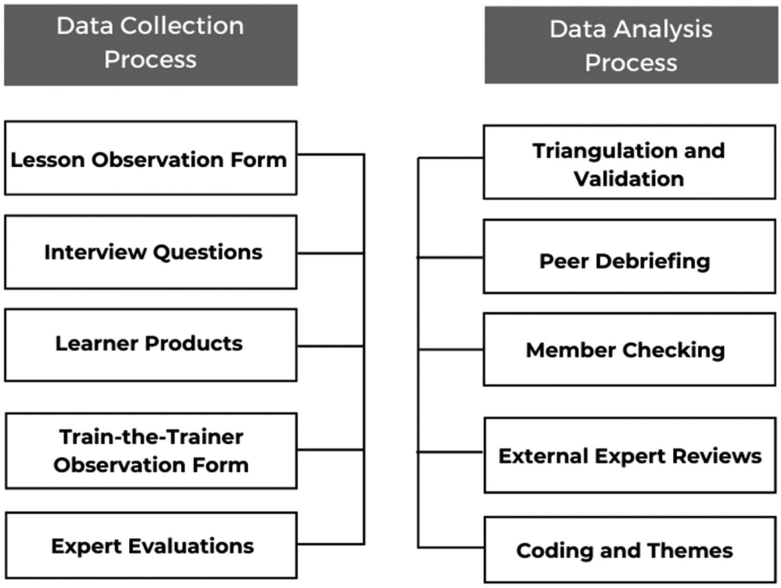

Figure 10. Flowchart of data collection and analysis process.

Table 2 illustrates the alignment between ISTE's leadership, educator, and student standards and the instructional framework of Bilim Türkiye. In particular, the Visionary Planner standard was reflected in the leadership team's proactive efforts to promote curiosity and inquiry among youth. Trainers functioned not only as facilitators but also as learners themselves, developing instructional strategies during the 'train-the-trainer' sessions. For students, the path from digital citizenship to knowledge construction and innovative design represents a progression aligned with 21st-century learning goals (ISTE 2023) (see Figure 10 for development of data collection tools and process through 10 steps below).

Design of Instruments→ Lesson observation forms and interview questions developed based on ISTE (2023), IBL (Pedaste et al. 2015), 5E (Bybee et al. 2006), and Fink's (2003) framework.

(1) **Lesson Observation Form** → 20 lessons observed using the 5E-based form.
(2) **Interview Questions**→ Semi-structured interviews conducted with 10 instructors by the researchers.
(3) **Learner Products**→ 161 physical/digital products assessed according to IBL phases.
(4) **Train-the-Trainer Observation Form**→ 405 sessions observed with Fink's framework and IBL-based form.

Expert Evaluations→ 14 experts evaluated train-the-trainers sessions.

Triangulation and Validation in Data Analysis Process→ Coding, content analysis, and quantitative calculations applied; data triangulated.

Table 3. Descriptive statistics from field notes and learner survey.

Value	*f*	Percentages	Sample Excerpts
Lesson Observation			
Curiosity	56	30.5	'Establishing a connection with mathematics through architectural works'. 'To learn more about dinosaurs'. 'How space shuttles work'. 'How fish live'.
Interest	43	39.72	'Introduction to the topic with examples of projects made around the world'. 'I would like to learn more about space, stars, and galaxies'. 'I would like to learn how fish live'. 'I wanted to research Vincent van Gogh's life'.
Inquiry	42	29.8	'Inquiry activities in the exploration phase provide information about what the student has learned'. 'The defense mechanisms of fish'. 'How the octopus squirts ink'. 'To learn about the challenges astronauts face'

Integration of Findings→ QUALitative and quantitative findings combined and reported.

3.3.1. Lesson observation form

Utilizing the 5E model (Bybee et al. 2006), these forms captured students' behaviors during inquiry processes, such as hypothesis formulation, data collection, and drawing conclusions. The forms assessed the frequency of students' 'why' and 'how' questions and their engagement levels in open-ended tasks. Its five phases – engage, explore, explain, elaborate, and evaluate – encourage young learners to collaboratively observe, analyze, and conclude. Teachers act as facilitators, fostering engagement and critical examination of concepts (Qablan 2024; Qablan et al. 2024). Engagement connects tasks to prior experiences or problems, addressing misconceptions and motivating learners. Exploration promotes hypothesis testing through active engagement, guided by teachers to restore cognitive balance. Explanation helps learners construct answers, transitioning to formal scientific explanations (Ismail 2024). Elaboration reinforces learning through extended activities, while evaluation assesses understanding through feedback. Studies indicate its effectiveness in STEM education surpasses traditional methods. Table 3 shows the frequency of curiosity, interest and inquiry.

As seen in Table 3, *interest* was the most frequently observed category (39.7%), indicating that real-world examples and creative task prompts (e.g. learning about Van Gogh or space missions) had a strong impact on learners. *Curiosity* (30.5%) and *inquiry* (29.8%) were also prevalent, suggesting that students were both engaged and cognitively active during lessons. These results are consistent with the goals of the 5E model, particularly in the Engage and Explore phases (Bybee et al. 2006).

3.3.2. Inquiry framework and tools

The Inquiry-Based Learning (IBL) framework (Pedaste et al. 2015) guided the design of interview and product analysis tools. Its five stages – orientation, conceptualization, investigation, conclusion, and discussion – aligned with the study's focus on inquiry skills in the GiPSci technology-enhanced workshops. Data collection tools were crafted to capture youth inquiry skills comprehensively.

Table 4. Learner statistics on ICI scores by Likert Scale.

Science and Technology Sub-Research	$X_{ICI\ score}$	*SD*
Interest	2.08/3.00	0.94
Curiosity	1.88/3.00	0.68
Inquiry	1.05/3.00	0.86

3.3.3. *Interview questions*

Semi-structured interviews explored each inquiry stage, examining learners' and facilitators' experiences in science center environments. Verbatim transcripts produced a dataset of 51 pages (13,607 words), analyzed qualitatively to identify themes corresponding to inquiry steps. This analysis illuminated how science center practices supported inquiry-based learning. Semi-structured interview questions were designed to explore trainers' and students' experiences in inquiry processes. For example, questions such as 'What types of questions did students ask?' or 'What challenges did you encounter during inquiry activities?' aimed to elucidate how inquiry was implemented in practice.

3.3.4. *Learner products*

A product observation form assessed 161 physical and digital learner artifacts, including lab reports, research posters, and data logs. These outputs were analyzed qualitatively and quantitatively to evaluate engagement with inquiry steps and program effectiveness.

A total of 161 physical and digital products (e.g. lab reports, research posters) were analyzed using a product observation form (see Appendix) to evaluate inquiry skills. This form included indicators measuring students' abilities to question cause-and-effect relationships, pose experimental questions, and interpret data.

3.3.5. *Train-the-trainer observation form*

Adapted from Fink's (2003) Integrated Learning Lesson Plan Form, this tool evaluated professional development sessions for trainers and train-the-trainers. It assessed the incorporation of the 5E model and inquiry-based learning principles into these sessions, ensuring alignment with the science center's instructional framework.

To ensure consistency across these tools, all evaluations were scored using a common rubric aligned with the IBL framework (detailed in Table 4). The rubric categorized inquiry skills as low (1), moderate (2), or high (3), enabling comparative analysis of results across different tools.

These methodologies collectively provided robust insights into the integration of inquiry-based learning in technology-enhanced environments, ensuring alignment with the study's objectives and research questions (see Figure 11 for the mixed-methods design).

Figure 11 illustrates the mixed-methods research design, showing how five data sources – lesson observations, expert evaluations, surveys, focus group interviews, and learner products – converge through triangulation. The pentagonal structure emphasizes the balanced integration of these methods, ensuring a comprehensive evaluation of inquiry skills within the GiPSci model.

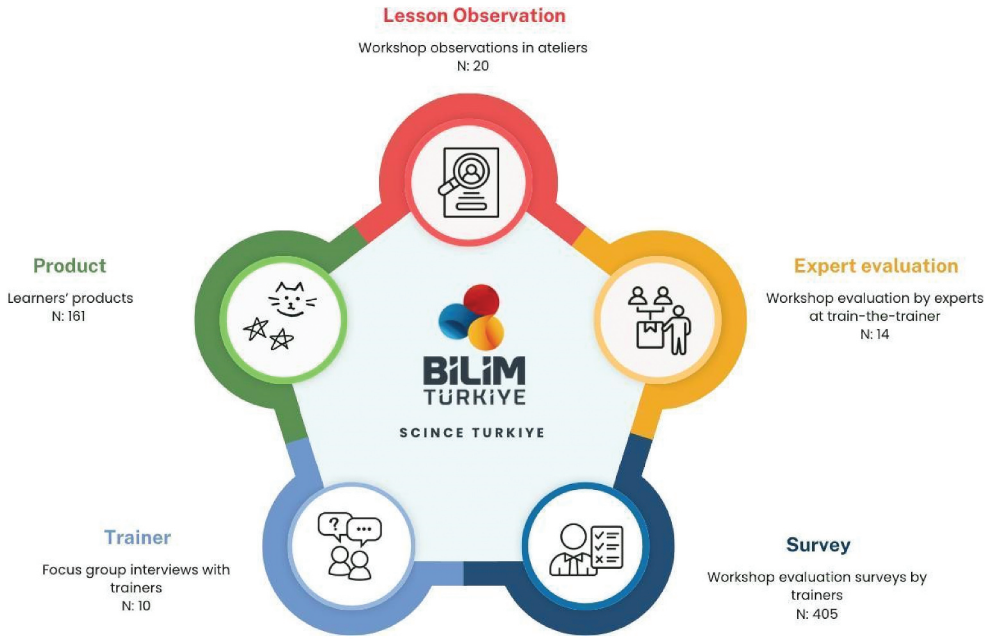

Figure 11. Summary of the mixed-methods design.

3.4. Data analysis

This study employed descriptive content analysis to summarize and interpret data within predetermined themes (Patton 2018; Yıldırım and Şimşek 2016). Content analysis was also used to uncover hidden patterns and relationships in the data, particularly for document analysis (Neuendorf 2017; Patton 2018). Interview transcripts and lesson observations were analyzed to identify themes and codes, revealing similarities and differences. Data were organized into a coherent whole, ensuring participant confidentiality by coding individuals (e.g. P1, P2). Direct quotations were incorporated to support findings, and demographic characteristics were presented in the methods section.

3.4.1. Triangulation and validation

Data were triangulated through interviews, lesson observations, learners' products, document analyses, and train-the-trainer activities. To ensure rigor, methods such as peer debriefing, member checking, and external expert reviews were employed (Lincoln and Guba 1985). Peer debriefing involved reviewing transcripts, field notes, and findings for consistency. Transcripts were reviewed by the coordinator of the research and development unit in the foundation. Field notes were reviewed by a researcher who is expert in mixed-method design in educational research. We compared the field notes alongside the transcripts to verify contextual details about curiosity, interest, and inquiry skills. This process helps us to identify patterns grounded in both deciphered transcribed content and observational data external feedback from two associate professors in science education further validated the study. Researchers collaboratively analyzed and validated the data, refining findings through discussions and brainstorming sessions held twice a week to strengthen credibility of the data.

3.4.2. Coding and themes

Two researchers independently coded responses from surveys and field notes, focusing on themes of inquiry, curiosity, and interest. They conducted agreement-disagreement sessions, resolving mismatches to finalize 275 codes under three themes with a 94% agreement rate (Miles, Huberman, and Saldana 1988). Examples include sentences like 'to provide opportunities for students to discuss and ask questions' under Inquiry, 'Students' excitement and curiosity increased their active participation' under Curiosity, and 'The solar system also attracted attention with a short video presentation' under Interest.

4. Findings

As was anticipated, curiosity and interest were easier to achieve, and so were the findings. On the contrary, as opposed to the ease of curiosity and interest, the inquiry skill was a challenge in literature, as was revealed in the present findings. Further details in harmony will be shared through qualitative and quantitative findings.

Documents ($n = 20$) included teachers' lesson plans ($M_{hours} = 1$ hour, $Range_{age} = 6–14$ years) in science, technology, and mathematics covering topics such as exploration of nature, fractions, development of mobile applications. Inquiry and curiosity were most emphasized traits (nearly half) whereas interest was the least emphasized one (nearly one-fifth each). This prioritization indicates that teachers largely structured their lessons to encourage young learners to engage in investigative and exploratory learning processes, positioning inquiry and curiosity across subjects.

Lesson observations ($n = 10$) included the observation of purposefully selected sample lessons observed by the researchers on-site ($M_{hours} = 3.4$ hours, $Range_{age} = 6–14$ years) covering topics such as management education, Artificial Intelligence, discovery campus, out-of-school learning, new approaches in science and technology, mathematics and algorithm. Interest was the most emphasized trait (nearly half), whereas curiosity and inquiry were second emphasized ones (nearly one-third each). This prioritization indicates that enactment of the lesson plans on-site was able to reflect young learners' interest but minimally available to trigger their curiosity and inquiry skills.

Similar to lesson observations, young learners' products and written open-ended responses into the surveys showed their high interest in the courses (more than half) whereas curiosity and inquiry were minimally emphasized ones (almost one-fifth each). After trainers' workshop observation, adult participants/trainers' written excerpts from the filled survey sparked both positive and negative aspects of workshops and 32 train-the-trainers contents. The following part is the themes and sample excerpts. (See Figure 12)

The image presents a thematic analysis with scores, divided into three categories: Interest, Curiosity, and Inquiry. Each category includes specific themes with the associated scores and standard deviations (SD), indicating the level of engagement and variability in educational contexts.

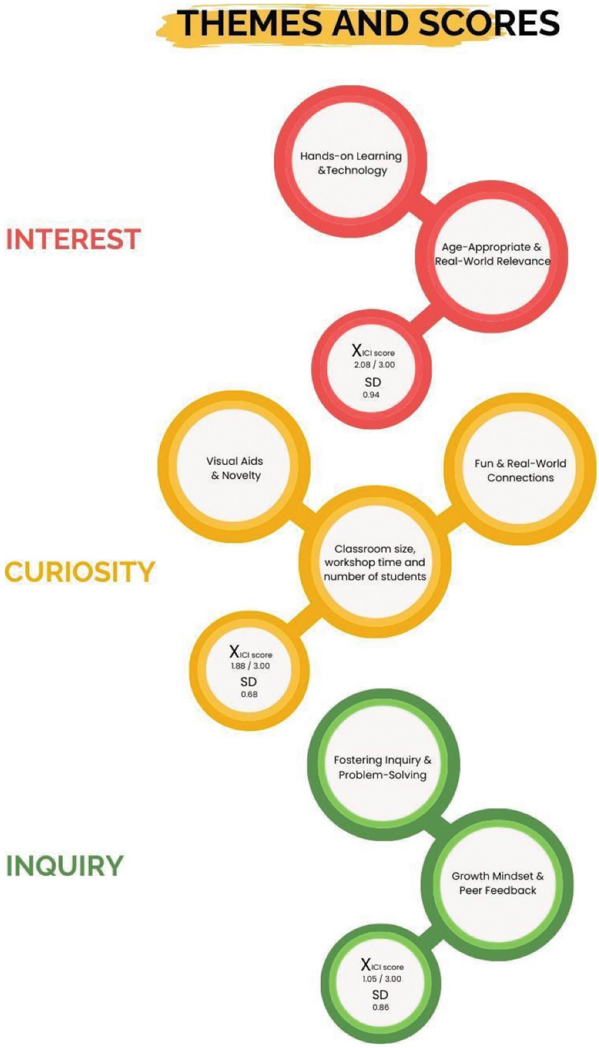

Figure 12. Themes and scores.

4.1. Interest and curiosity in TeSC program

Hands-on Learning & Technology Evidence: Interactive tools (e.g. micro-scopes, 3D pens) and technology (e.g. automated systems) increase student engagement. Example: SPK_1 and SPK_4 saw heightened interest with hands-on tools like microscopes and technology such as automated irrigation.

Age-Appropriate & Real-World Relevance Evidence: Tailoring content to age and linking it to real-world contexts makes learning more relatable and sparks interest. Example: SPK_2 found younger students enjoyed astronomy, while older students were more engaged in topics like smart agriculture.

'By asking more questions and encouraging students to connect with the material through stories, I saw a significant increase in their curiosity'.

'Some of the scientific concepts were too complex for the age group, which made it hard for the students to stay curious and engaged'.

4.2. Curiosity

4.2.1. Visual aids & novelty evidence

Using visual aids (e.g. videos, simulations) and introducing new tools keeps learning dynamic and fuels curiosity. Example: SPK_1 used videos to explain complex concepts and SPK_3 introduced 3D pens to spark deeper exploration.

4.2.2. Fun & real-world connections evidence

Incorporating playful activities and real-world applications helps maintain curiosity. Example: SPK_1 used fun activities like 'magic' telescopes, and SPK_4 applied smart agriculture tools to keep students curious and engaged.

In lesson observations, inquiry skills were assessed based on students' levels of asking open-ended questions and engaging in experimental processes. For instance, in SPK_3's workshop, 30% of students posed 'why' or 'how' type questions, while only 15% attempted to formulate independent hypotheses. In learner products, 20% of laboratory reports contained statements questioning cause-and-effect relationships, whereas 10% of research posters focused on experimental questions. Interviews revealed that trainers faced challenges in structuring inquiry activities and that students required guidance in open-ended tasks.

Reasons for the Low Performance in Inquiry Skills: The findings indicate that inquiry skills scored lower than interest and curiosity (*XICI score* = 1.05, *SD* = 1.86). Several factors may contribute to this outcome: First, while infrastructure was generally sufficient, some trainers reported limited experience and confidence in implementing inquiry-focused teaching strategies, which hindered the enactment of IBL activities. For instance, SPK_3 noted that students struggled with open-ended tasks due to insufficient guidance. Second, while lesson plans clearly emphasize inquiry, on-site implementation often prioritized fostering interest and curiosity. Additionally, the structured and time-bound nature of the workshops, often emphasizing group-based tasks, limited opportunities for individualized inquiry, thereby narrowing the scope for students to initiate independent investigative processes. Finally, the scarcity of use of inquiry skills in math-based workshops ($n = 6$, compared to $n = 152$ in non-math disciplines) suggests that disciplinary differences may pose due to its abstract nature and science of patterns and relationships.

4.3. Classroom size, workshop time and number of students

Evidence: Classroom size, workshop time, and the number of students can limit the ability to foster curiosity in science workshops. Large classes, short time frames, and high student-to-teacher ratios make it difficult to provide the individualized attention and open-ended exploration that encourage inquiry and critical thinking.

Table 5. Mixed-method analysis of interest-curiosity-inquiry (ICI).

Skills Indicators of Inquiry Skills Wording of Inquiry Skills Mouthed by Young Learners
Why?
How?
When?
Which?
Where?
How much?
Who?
In which cases?
Under what conditions?
How can we test this?
What would happen if . . . ?
Can we prove this?
What could happen in the future?
How can we verify its accuracy?
What could be the reason for this?
Can we examine this in more detail?
How does this work?
Could there be a different perspective?
What else can we learn about this?
Is this result accurate?

Example: 'While curiosity was encouraged, there wasn't enough time to explore every question students had, leaving some feeling their curiosity was stifled'.

Example: 'In larger classes, it was difficult to foster interest in each student, as those who were shyer or reserved often didn't get the chance to ask questions'.

The quotes and evidence highlight how various factors impact student curiosity and engagement in the TeSC program. Interactive tools and real-world relevance, such as the use of microscopes and smart agriculture, were shown to enhance interest and foster deeper curiosity. However, the challenges of large class sizes, limited workshop time, and high student-to-teacher ratios hindered the ability to fully support individualized learning and open-ended inquiry. Teachers noted that while they encouraged curiosity, time constraints and classroom dynamics sometimes prevented students from pursuing their questions, stifling their sense of exploration and engagement. These insights emphasize the need for more personalized, flexible learning environments.

4.4. Inquiry in TeSC program

4.4.1. Interviews

Fostering Inquiry & Problem-Solving Evidence. Encouraging independent exploration, problem-solving, and critical thinking nurtures a culture of inquiry.

Example: SPK_3 let students explore answers on their own, and SPK_7 balanced independent research with guidance to deepen inquiry.

'I learned that we, as educators, should not always provide the answers, but rather help students investigate their questions, which enhances their problem-solving skills'.

‘Many students struggled with the open-ended nature of inquiry-based learning. Without clear instructions, they felt lost and unsure of how to approach the problems’.

Growth Mindset & Peer Feedback Evidence. Shifting students’ mindsets to embrace challenges and using peer feedback promotes deeper inquiry. Example: SPK_2 saw students grow in confidence and inquiry skills through peer feedback in entrepreneurship workshops.

‘The lack of foundational knowledge in some students made it hard for them to engage in inquiry-based tasks, as they didn’t have the necessary background to ask deeper questions’.

Next, focus group interviews conducted with the trainers were followed by learner products to make triangulation among data sources.

4.4.2. Learner products

Regarding the thematic analysis of the Inquiry Skills, the below list emerged with the expert-level contributions of three education scientists with Ph.D. and edited in terms of grammar and context.

The Table 5 displays the potential words and phrases that could be used by the young learners to signal inquiry skills. The most commonly encountered types of questions in the activity are ‘Why’, ‘How’, and ‘What could be the reason for this?’ types of questions. Students generally ask questions aimed at establishing cause-and-effect relationships and understanding specific events or mechanisms. Additionally, questions related to experimental inquiry, such as ‘How can we test this?’ and process-based questions like ‘How does this work?’ are also observed.

As for the quantitative scoring aspect of the study, to better understand and measure the Interest, Curiosity and Inquiry skills of the young learners in the present research, a rubric was developed with the expert-level contributions of three education scientists with Ph.D. and editage by Chat-GPT. Using this rubric with 1 (low) −2 (middle/moderate) −3 (high) scoring, each entity (Interest, Curiosity and Inquiry) was enquired between the scores 1 and 3. The rubric and the thematic analysis could be examined in the drive folder whose web link was presented in the supplementary file.

The Table 4 illustrates the Interest, Curiosity, and Inquiry results as mean and standard deviation estimations. Interest is followed by Curiosity and they are both followed by Inquiry as having the lowest score ($X_{ICI\ score} = 1.05$, $SD = 1.86$). This shows the intriguing and challenging nature of teaching Inquiry skills to young learners, particularly in this present study. Findings further reveal the similarities between the quantitative scoring of mean and standard deviation with the trainer views and lesson observations that put forward the shortcomings encountered to handle Inquiry skills in the current technology-enhanced science centers.

In assessing the performance of the technology-enhanced science center program in this study, two complementary indicators stand out as central success criteria. First, during the period between January and May each year, approximately 625,704 students visit the centers (from 22 centers in ten cities domestic and six centers from four countries abroad), demonstrating its significant outreach capacity and role in providing broad access to workshop-oriented education. Second, beyond this large-scale accessibility, an average of 25–30 learners per center remain continuously engaged in workshops throughout

Figure 13. Sample observation form.

the year without attrition. This sustained participation highlights the centers' ability to foster long-term commitment, deeper interest and curiosity, and consistent skill development. Together, these metrics show that the centers are not only effective in attracting a wide audience but also in retaining a core group of learners who benefit from extended, high-quality engagement.

Learner products were cross-checked to see learners' inquiry skills. Next, researchers observed lessons to make triangulation among data sources and to see inquiry-teaching skills in TeSC program enactment.

4.4.3. Lesson observation forms

Workshop observation forms and field notes written by the three experts [all except first author] revealed that nearly two-fifths of the identified categories were related to stimulating interest (39.72%), while approximately one-third were associated with catalyzing inquiry (29.8%) and curiosity (30.5%). Then, as well, analysis of learners' written excerpts (i.e. open-ended reactions and responses just after the workshops) in the survey revealed that nearly more than half were related to stimulating interest (60%), while approximately one-fifth were associated with catalyzing inquiry (23%) and curiosity (17%) depicted in Table 3. (See sample observation forms in Figure 13.)

The TeSC program fosters inquiry through independent exploration, problem-solving, and critical thinking. While teachers encouraged student-driven investigations, some students struggled with the open-ended nature of inquiry-based learning, highlighting the need for more concrete guidance. Peer feedback helped build confidence and inquiry skills, but gaps in foundational knowledge hindered deeper engagement. Quantitative results revealed that, while interest was high, curiosity and inquiry skills were lower (X_{ICI} *score* = 1.05, *SD* = 1.86), indicating challenges in teaching these skills.

Lesson observations showed that interest was most stimulated, with inquiry and curiosity being less emphasized, underscoring the need for targeted inquiry-focused strategies.

4.4.4. Inquiry relevant to the train-the-trainer programs and interdisciplinarity

General Versus Inquiry-oriented Professional Development (PD) Despite the fact that overall professional development evaluation by the trainers yielded positive results, when it comes to the inquiry-teaching skills acquisition, the trainers expressed quite negative opinions. This showed the critical difference between general training and to-the-point, well-planned training sessions, particularly inquiry-teaching skills oriented ones in the current research.

General PD Evaluation. The exit survey applied to trainers after the train-the-trainers PD program held in Erzurum province in Türkiye. The survey had 8 Likert items (measuring understanding the aims of Bilim Türkiye, instructional and assessment aspects) and 2 open-ended ones. The grand mean was found to be 4.3 out of 5. The score of 4.3 demonstrates that respondents rated the item very favorably, with room for slight improvement towards the maximum score of 5. The standard deviation of 0.27 indicates that responses are tightly clustered around the mean, suggesting consistent opinions among participants and trainers.

Inquiry-oriented PD Evaluation. The analysis of trainers' interviews revealed the description, phrases or keywords of inquiry, curiosity and interest. As in line with quantitative findings, interest has been asserted as the most (53.18%), curiosity did moderately (31.82%) and inquiry did the least (15%). For instance, a number of participant expressions with regard to the deficiency in inquiry were provided below:

Example: 'It may be difficult to implement due to infrastructure and inquiry-teaching skills'.

'Difficulties may arise in integrating theoretical knowledge into field applications [inquiry]'.

Despite positive evaluations of general professional development (PD), trainers expressed negative views about acquiring inquiry-teaching skills, highlighting a critical gap between generic training and specialized, inquiry-oriented PD. The exit survey, with a mean score of 4.3 out of 5 and a low standard deviation of 0.27, indicated favorable but slightly improvable ratings on the general PD. However, inquiry-oriented PD was rated less favorably. Trainers noted difficulties in implementing inquiry due to infrastructure limitations and the challenge of applying theoretical knowledge to real-world inquiry teaching. Interest was most emphasized (53.18%), followed by curiosity (31.82%), with inquiry being the least addressed (15%).

4.5. Interdisciplinary challenges in inquiry-based learning

The analysis from trainers' interview excerpts revealed the relatively higher number of inquiry instances in non-math workshop sessions compared to the math workshop sessions. On the contrary, science, social sciences, communication, and digital learning areas revealed a higher number of inquiry instances ($n = 152$).

Non-math Instances (n = 152)

1. 'I was very interested in learning how fish live and what we were going to learn today'.
2. 'Learning that whales are not fish was very exciting'.
3. . . .

60. 'I would like to learn about the sounds of planets and the formation of stars'.

Math-Related Instances (n = 6)

1. 'The hourglass excited me; I would like to learn more about the Middle Ages'. 'Clocks: 1. Hourglass, 2. Water clock, 3. Sundial. It was very fun'.

The results highlighted that young learners' expressions grounded in non-math concepts three times more than math concepts. Trainers' interviews revealed that inquiry instances were more frequent in non-math workshop sessions compared to math sessions. In non-math areas (science, social sciences, communication, and digital learning), there were 152 instances of inquiry. In contrast, math-related inquiry was much lower, with only six instances, highlighting the challenge of engaging students in inquiry-based math learning.

4.6. Integration of quantitative and QUALitative findings

Analysis of the lesson plans revealed that most of the trainers incorporated inquiry-based learning activities at least once a week, highlighting a strong quantitative commitment to fostering curiosity and interest in young learners. Nevertheless, qualitative data from trainer interviews shed light on the variations in enactment of the lesson plans in lesson observations. While many trainers prioritize inquiry in blueprint lesson plans, their approaches for cultivating learners' curiosity and interest can vary significantly based on personal teaching philosophies and contextual constraints after the train-the-trainer sessions. In addition, young learners' surveys, products showed they gained high interest in Bilim Türkiye courses. For instance, the lack of inquiry-teaching skills in train-the-trainer activities were revealed in trainer interviews.

In other words, the triangulated analysis across train-the-trainer interviews, learner products, and lesson observations indicated a consistent pattern regarding the limited presence and enactment of inquiry skills. In interviews, trainers reported difficulty in implementing inquiry-teaching skills, often citing infrastructure challenges and the abstract nature of the concept. Quantitatively, only one tenth of the codes referenced inquiry-skills, far below interest and curiosity. This was mirrored in learner product analysis, where the inquiry dimension received the lowest average score, reinforcing its underdevelopment. Observational data in the lessons similarly showed that while learners were engaged and interested, there was minimal evidence of deep questioning or investigative thinking during the lesson enactments. For example, students were observed to struggle with the open-endedness of tasks, often expressing confusion about how to proceed. Taken together, these data strands converge to support the interpretation that fostering inquiry remains a complex pedagogical challenge, particularly in early learning contexts. (See Inquiry in TeSC Program: Interviews for more evidences.)

All in all, qualitative and quantitative data sources and their analysis were complementary revealing missing instances of inquiry-skills in various teaching and learning moments.

5. Discussion

The underperformance of inquiry skills within the GiPSci model can be attributed to both pedagogical and structural factors. The literature emphasizes that effective implementation of inquiry-based learning requires educators to receive adequate professional development (PD) (Fitzgerald, Danaia, and McKinnon 2019; Gutierrez 2015). However, our study found that trainers were insufficiently prepared in inquiry-focused PD programs, as evidenced by their reports of infrastructure limitations and challenges in translating theoretical knowledge into practical application. Additionally, students' lack of foundational knowledge, particularly in abstract disciplines such as mathematics, hindered their ability to engage in deep inquiry. These findings indicate that the GiPSci model requires more targeted strategies and interdisciplinary adaptations to effectively foster inquiry skills.

Teachers often face barriers such as inadequate professional development, limited resources, and a focus on content assessment over inquiry-based skills (Gutierrez 2015). Furthermore, teachers with low self-efficacy are less likely to adopt IBL strategies, especially in higher grades (Roehrig and Luft 2004; Teig, Scherer, and Nilsen 2019). These issues are exacerbated by gaps in teachers' understanding of scientific inquiry, pedagogical knowledge, and classroom management (Karklelyte 2023). Despite these obstacles, research consistently shows that well-implemented IBL can significantly foster critical thinking and scientific literacy in young learners (Sasson 2014). Addressing these barriers through professional development programs, particularly those incorporating IBL and PBL, can enhance teachers' ability to balance structure with exploration in inquiry-based environments (Nicol 2021).

Guided inquiry, which provides a structured framework for exploration while allowing students to make discoveries, has been found to improve both student engagement and understanding in science education. This method encourages students to ask questions, hypothesize, and experiment, fostering deeper learning. Similarly, PBL supports students in applying inquiry skills to real-world problems, promoting collaboration, problem-solving, and the integration of knowledge across subjects. Both of these pedagogical approaches are particularly effective when integrated with technology, allowing students to investigate complex issues interactively and with real-time feedback.

5.1. Professional development and teacher competency

Professional development (PD) is a critical factor in equipping educators with the necessary skills for successful inquiry-based teaching. Effective PD programs should focus on deepening teachers' understanding of scientific inquiry and equip them with hands-on experience in implementing IBL and PBL techniques. PD also needs to address how teachers can use technology to enhance inquiry learning (Seneviratne et al. 2019a, 2019b). Teachers' beliefs about science, education, and their students significantly influence how they implement IBL (Lotter, Harwood, and Bonner 2007). Although PD can improve teacher competencies, the impact on teachers' beliefs, teaching practices, and student outcomes remains inconsistent. Future research should focus on aligning PD programs with comprehensive outcomes, ensuring that they lead to substantial changes in teacher practices and measurable improvements in student achievement.

5.2. Impact of inquiry-based learning on students

IBL enhances problem-solving, critical thinking, and scientific literacy in students, as it encourages them to engage deeply with content through both project-based and inquiry-based learning approaches (Albion 2015). These methods require students to actively participate in their learning, solving real-world problems while developing essential skills in research and analysis. However, the successful implementation of IBL requires skilled educators and well-designed assessments that focus on competencies rather than rote memorization (Reinmann 2019). Tools like the PISA Problem Solving Framework support the evaluation of problem-solving competence within IBL contexts (Zervas et al. 2015). Additionally, inquiry-based approaches in subjects like mathematics show similar success, demonstrating that IBL is not limited to science alone (Kinsey, Moore, and Prassidis 2015; Thacker et al. 1994).

5.3. Role of technology in inquiry-based learning

Technology significantly enhances IBL by providing interactive tools such as simulations, virtual labs, and collaborative platforms that foster critical thinking and engagement (De Jong 2010). These tools foster critical thinking by enabling students to explore complex concepts, while educators scaffold learning innovatively The ISTE Standards, which align with IBL, emphasize the integration of technology to develop inquiry skills and digital literacy (Ayad and Ajrami 2017; Crompton and Burke 2024). Despite this potential, the underimplementation of the ISTE Standards underscores the need for targeted teacher training and awareness of how technology can be used effectively in inquiry learning. Educators should align IBSE principles with technology, ensuring PD addresses traditional classroom challenges (Chaerunisa, Ramli, and Widoretno 2023).

5.4. Professional development and teacher competency

Professional development (PD) plays a pivotal role in equipping teachers with the skills needed for inquiry-based teaching. Effective PD integrates deep scientific inquiry understanding, hands-on experience, and skills for guiding students (Seneviratne et al. 2019b, Seneviratne et al. 2019a). Teachers' beliefs about science, education, and young learners significantly influence IBL implementation (Lotter, Harwood, and Bonner 2007). While PD can improve teacher competencies, its impact on beliefs, practices, and student outcomes remains inconsistent (Capps, Crawford, and Constas 2012). Future research should examine how PD can better impact teacher practice and student achievement.

5.5. *Impact of inquiry-based learning on students*

IBL encourages active engagement through project-based and problem-based approaches (Albion 2015). However, implementing IBL effectively requires skilled educators and well-designed assessments tailored to competency-oriented teaching (Reinmann 2019). Incorporating tools like the PISA Problem Solving Framework into inquiry teaching supports domain-specific evaluations of problem-solving competence (Zervas et al. 2015). Moreover, inquiry-based approaches in mathematics demonstrate comparable success, challenging the notion that math is less suitable for inquiry learning (Kinsey, Moore, and Prassidis 2015; Thacker et al. 1994).

5.6. *Role of technology in inquiry-based learning*

Technology enhances IBL by providing interactive tools, such as simulations and remote labs, that foster engagement and critical thinking (De Jong 2010). The ISTE Standards align with IBL, emphasizing technology integration to develop inquiry skills and digital literacy (Ayad and Ajrami 2017; Crompton and Burke 2024). However, despite the potential, the low implementation of ISTE Standards highlights the need for targeted training and awareness (Ayad and Ajrami 2017). To maximize impact, educators should design activities that integrate IBL and technology, requiring ongoing professional development to address challenges in traditional educational settings (Chaerunisa, Ramli, and Widoretno 2023).

5.7. *Inquiry-based learning in Türkiye among other developing contexts*

Türkiye has achieved significant success in international assessments like TIMSS, with notable improvements in science and mathematics performance (MoNE, 2024; Turkish Academy of Sciences 2022). These gains likely stem from initiatives such as IBL and technology integration under the National Technology Initiative (Özer and Suna 2023). Research further highlights the effectiveness of workshop-based interventions and inquiry-driven programs in science centers, which enhance students' conceptual understanding and engagement (Kanlı and Yavaş 2021). Sustaining these policies and expanding evidence-based strategies would be critical for maintaining progress. IBL in technology-enhanced science centers offers transformative educational opportunities. However, challenges persist such as time constraints, teacher preparedness, and resource limitations persist, strategic professional development and effective technology use. Inquiry approaches, supported by the ISTE Standards and well-designed assessments, foster critical thinking and engagement across STEM disciplines. Emerging evidence from Türkiye demonstrates the potential of inquiry-based programs to improve student outcomes, emphasizing the need for sustained policy support and innovation in educational practices.

5.8. The comparison of GiPSci model with inquiry-based learning (IBL) and project-based learning (PBL)

The GiPSci model integrates IBL with a developmentally appropriate, hands-on workshop design to foster scientific curiosity and problem-solving among young learners. In this regard, it shares core principles with both IBL and PBL frameworks – namely, learner-centered exploration, real-world relevance, and being involved in an active learning process. However, GiPSci differentiates itself through its structured guidance during the inquiry process, tailored to young learner's developmental needs. Unlike traditional IBL (Ramanathan, Carter, and Wenner 2021), GiPSci employs guided inquiry, balancing autonomy with scaffolded support. Our findings suggest that this model helps maintain learner interest and curiosity, though inquiry remains the most challenging component to develop, as evident in both trainer interviews and learner products. Compared to PBL (Marquez et al. 2023), GiPSci places less emphasis on creating complex, long-term products, and instead focuses on cultivating inquiry habits during the learning-by-doing process. This shift positions *GiPSci as a hybrid model*, offering a pragmatic pathway for enabling young learners to take responsibility for their own learning while practicing inquiry through hands-on, cognitively challenging experiences.

6. Conclusion

Inquiry-based learning (IBL) in technology-enhanced science centers has significant potential to develop scientific thinking, problem-solving, and critical thinking skills in young learners. However, challenges like time constraints, limited resources, and insufficient professional development impede its full implementation. Teachers' self-efficacy and understanding of IBL are crucial for adopting these methods. Despite these barriers, well-supported IBL programs that balance guidance with exploration can lead to improved science education outcomes. To maximize IBL's impact in both formal and informal settings, addressing these challenges through ongoing professional development and institutional support is vital.

Recommendations for Practitioners: Practitioners should engage in sustained professional development to deepen their understanding of IBL. Creating scaffolded inquiry activities and incorporating assessments that focus on scientific competencies, rather than rote memorization, will align instruction with IBL's goals. Administrators should provide adequate resources, time, and opportunities for collaboration across disciplines.

Recommendations for Researchers: Future studies should explore the long-term effects of professional development on teachers' inquiry facilitation skills and examine how teachers' beliefs about science impact their practices. Research on adaptable assessment models and the application of IBL across diverse contexts will help refine its effectiveness.

Recommendations for Leaders: Leaders should build supportive infrastructures that include targeted professional development, hands-on tools, and equitable access to resources. Evaluating the effectiveness of these programs and fostering interdisciplinary curricula will promote innovation and align with ISTE standards.

Recommendations for Educators: Educators should design dynamic lessons that balance inquiry and curiosity, using real-world challenges and digital tools like simulations. Reflecting on professional development feedback will help refine instructional strategies and support diverse learners.

Recommendations for Students: Students should be encouraged to take ownership of their learning through inquiry-driven activities and self-guided exploration. Collaborative projects that connect science and technology to real-world issues can enhance critical thinking and curiosity.

By aligning these strategies with ISTE standards, technology-enhanced science centers can effectively foster inquiry, curiosity, and interest, equipping young learners with essential skills for the digital age.

7. Limitations and future suggestions

The study's short duration of 3-month observation and data collection limited the ability to collect longitudinal data such as performance score or learner analytics scores. The future practitioners in technology-enhanced workshop-oriented science centers can include measurement and evaluation processes in their yearly program. Trainers should be exposed to more training about diverse knowledge and skills in the field of measurement and evaluation related to informal learning environments. Results may not be broadly generalizable but reflect the multicultural contexts of regions such as Eurasian regions, Balkans, Azerbaijan, Cyprus, and Kyrgyzstan. While the sample cannot be proudly diverse, it represented average demographics of K-12 participants, educators, and informal learning settings in the studied regions (Barrowclough and Kozul-Wright 2008). This study serves as a foundational investigation, providing a basis for future research on the topic.

Future studies should focus on professional development programs that enhance trainers' inquiry-focused pedagogical skills to address the GiPSci model's shortcomings in fostering inquiry skills. Additionally, extending workshop durations and reducing class sizes could support individualized inquiry activities. The limited presence of inquiry in disciplines such as mathematics indicates a need for developing inquiry-based tasks tailored to these fields.

Future research could also address these limitations by exploring additional data sources, expanding the sample size, or incorporating longitudinal approaches. To illustrate, first, student observations were limited to Istanbul province, and trainers participated from Türkiye. Future studies could expand data collection to include practices from other developing countries. Second, when trainer participants were asked to update their teacher training contents with an inquiry-based teaching focus, they could not make the necessary revisions. Future researchers could explore the reasons behind this resistance to change. Third, mathematics educators were the group least able to incorporate inquiry-based teaching and encourage questioning among their students. Future mixed-methods studies can collect in-depth data from mathematics teachers to explore this further. For instance, mathematical topics such as the journey of prime numbers, the reasoning behind theorems, and proofs could serve as starting points for more inquiry-driven exploration. Fourth, test forms and school-type scales commonly preferred in many studies (e.g. Alan and Mumcu 2024; Bilišňanská and Kireš 2018; Sutiani, Situmorang, and Silalahi 2021) are inconsistent with the nature of informal learning environments, which is why they were not selected for our study. To better align with the environment's spirit, future research could use digital assessment tools, artificial intelligence tools, digital games, and measure inquiry skills in authentic settings to collect more relevant quantitative data. Last but not least, longitudinal data could be collected in future studies to replicate this research and reassess the results over time.

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References

Alan, S., and I. Mumcu. 2024. "Nurturing Childhood Curiosity to Enhance Learning: Evidence from a Randomized Pedagogical Intervention." *The American Economic Review* 114 (4): 1173–1210. https://doi.org/10.1257/aer.20230084.

Alberti, E. T., and S. L. Witryol. 1994. ""the Relationship Between Curiosity and Cognitive Ability in Third- and Fifth-Grade Children." the." *The Journal of Genetic Psychology: Research and Theory on Human Development* 155 (2): 129–145. 10.1080/00221325.1994.9914767.

Albion, P. 2015. "Project-, Problem-, and Inquiry-Based Learning." *Teaching and Digital Technologies: Big Issues and Critical Questions*, 240–240. https://research.usq.edu.au/download/3ae2c8b7f0cadd7afef51b9514d534e592b6374e598e0c25f757def1f76496e0/135385/Albion_Ch19_AV.pdf.

Arnone, M. P., R. V. Small, S. A. Chauncey, and H. P. McKenna. 2011. "Curiosity, Interest and Engagement in Technology-Pervasive Learning Environments: A New Research Agenda." *Educational Technology Research & Development* 59 (2): 181–198. https://doi.org/10.1007/s11423-011-9190-9.

Ayad, F. I., and S. J. Ajrami. 2017. "The Degree of Implementing ISTE Standards in Technical Education Colleges of Palestine." *The Turkish Online Journal of Educational Technology* 16 (2): 107–118. https://files.eric.ed.gov/fulltext/EJ1137808.pdf.

Barrowclough, D., and Z. Kozul-Wright. 2008. *Creative Industries and Developing Countries: Voice, Choice and Economic Growth*. Abingdon: Routledge.

Bilišňanská, M., and M. Kireš. 2018. "The Analysis of Conceptual Understanding and Selected Inquiry Skills of Students within Non-Formal Education Activities in the Science Centre." *Journal of Physics: Conference Series* 1076 (1): 12020–12020. https://doi.org/10.1088/1742-6596/1076/1/012020.

Bybee, R. W., J. A. Taylor, A. Gardner, P. Van Scotter, J. C. Powell, A. Westbrook, and N. Landes. 2006. "The BSCS 5E Instructional Model: Origins and Effectiveness." In *Colorado Springs*, CO: BSCS.

Byman, R. 2005. "Curiosity and sensation seeking: a conceptual and empirical examination." *Personality & Individual Differences* 38 (6): 1365–1379. 10.1016/j.paid.2004.09.004.

Capps, D. K., B. A. Crawford, and M. A. Constas. 2012. "A Review of Empirical Literature on Inquiry Professional Development: Alignment with Best Practices and a Critique of the Findings." *Journal of Science Teacher Education* 23 (3): 291–318. https://doi.org/10.1007/s10972-012-9275-2.

Chaerunisa, Z. F., M. Ramli, and S. Widoretno. 2023. "Students' Inquiry Skills Progression Based on STEM Approach and Inquiry Lab." *Jurnal Pendidikan Biologi Indonesia* 9 (2): 206–216. https://doi.org/10.22219/jpbi.v9i.

Chase, J. A., R. Topp, C. E. Smith, M. Z. Cohen, N. Fahrenwald, J. J. Zerwic, L. E. Benefield, C. M. Anderson, and V. S. Conn. 2013. "Time Management Strategies for Research Productivity." *Western Journal of Nursing Research* 35 (2): 155–176. https://doi.org/10.1177/0193945912451163.

Chowdhary, B., Liu, X., Yerrick, R., Smith, E., & Grant, B. 2014. "Examining Science Teachers' Development of Interdisciplinary Science Inquiry Pedagogical Knowledge and Practices." *Journal of Science Teacher Education* 25 (8): 865–884. https://doi.org/10.1007/s10972-014-9405-0.

Chu, K. W. S., S. K. Tse, E. K. Y. Loh, K. Chow, H. Fung, and H. W. R. Ng. 2021. "Primary Four Students' Development of Reading Ability Through Inquiry-Based Learning Projects." IASL Annual Conference Proceedings (Berkeley, USA). https://doi.org/10.29173/iasl7964.

Chu, S. K. W., R. B. Reynolds, N. J. Tavares, M. Notari, and C. W. Y. Lee. 2021. "21st Century Skills Development Through Inquiry-Based Learning From Theory to Practice." *Springer*. https://doi.org/10.1007/978-981-10-2481-8.

Creswell, J. W., and V. L. Plano Clark. 2023. "Revisiting Mixed Methods Research Designs Twenty Years Later." In *The Sage Handbook of Mixed Methods Research Design*, edited by A. Tashakkori and C. Teddlie, 21–36. SAGE Publications.

Crompton, H., and D. Burke. 2024. "The Nexus of ISTE Standards and Academic Progress: A Mapping Analysis of Empirical Studies." *TechTrends* 68 (4): 711–722. https://doi.org/10.1007/s11528-024-00973-y.

Dal, B., Y. Özdem, N. Öztürk, and U. Alper. 2013. "Building Capacity for Public Understanding of Science: A Report on the Role of Science Centers." *Bilge Strategy* 5 (8): 57–67. https://dergipark.org.tr/tr/download/article-file/43469.

De Jong, T. 2010. "Technology Supports for Acquiring Inquiry Skills." In P. Peterson, E. Baker, & B. McGaw (Eds.), *International Encyclopedia of Education*, 167–171. Elsevier. https://doi.org/10.1016/b978-0-08-044894-7.00734-x.

Ee, Goff, K. L. Mulvey. 2018. "Irvin 2018. Applications of Augmented Reality in Informal Science Learning Sites: A Review." *Journal of Science Education Technology* 27 (5): 433–447. https://doi.org/10.1007/s10956-018-9734-4.

Ellaway, A. 2014. "The Impact of the Local Social and Physical Local Environment on Wellbeing." In *Wellbeing and the Environment* , edited by R. Cooper, E. Burton, and CL. Cooper. Wiley-Blackwell, 57-68. https://doi.org/10.1002/9781118539415.wbwell057.

Fink, D. L. 2003. *A Self-Directed Guide to Designing Courses for Significant Learning*. SanFrancisco: Jossey-Bass. https://inside.southernct.edu/sites/default/files/a/inside-southern/facultydevelopment/Self-Directed_Guide_to_Course_Design_-_Sept_10.pdf.

Fitzgerald, M., L. Danaia, and D. H. McKinnon. 2019. "Barriers Inhibiting Inquiry-Based Science Teaching and Potential Solutions: Perceptions of Positively Inclined Early Adopters." *Research in Science Education* 49 (2): 543–566. https://doi.org/10.1007/s11165-017-9623-5.

Fulmer, G. W., H. Ma, and L. L. Liang. 2019. "Middle School Student Attitudes Toward Science, and Their Relationships with Instructional Practices: A Survey of Chinese Students' Preferred versus Actual Instruction." *Asia-Pacific Science Education* 5 (1): 1–21. https://doi.org/10.1186/s41029-019-0037-8.

Gelmez, Burakgazi S., A. Yıldırım, and N. Feinstein. 2016. "Communicating Science to Impact Learning? A Phenomenological Inquiry into 4th and 5th Graders' Perceptions of Science Information Sources." *Journal of Science Education Technology* 25:244–262. https://doi.org/10.1007/s10956-015-9590-4.

Gutierrez, S. B. 2015. "Collaborative Professional Learning Through Lesson Study: Identifying the Challenges of Inquiry-Based Teaching." *Issues in Educational Research* 25 (2): 118–134. http://www.iier.org.au/iier25/gutierez.html.

Gutwill, J. P., and S. Allen. 2012. "Deepening Students' Scientific Inquiry Skills During a Science Museum Field Trip." *Journal of the Learning Sciences* 21 (1): 130–181. https://doi.org/10.1080/10508406.2011.555938.

Habig, B., P. Gupta, and J. D. Adams. 2021. "Disrupting Deficit Narratives in Informal Science Education: Applying Community Cultural Wealth Theory to Youth Learning and Engagement." *Cultural Studies of Science Education* 16 (2): 509–548. https://doi.org/10.1007/s11422-020-10014-8.

Habig, B., P. Gupta, B. Levine, & Adams, J.2020. "An Informal Science Education Program's Impact on STEM Major and STEM Career Outcomes." *Research in Science Education* 50:1051–1074. https://doi.org/10.1007/s11165-018-9722-y.

Harty, H., and D. Beall. 1984. "Attitudes Toward Science of Gifted and Nongifted Fifth Graders." *Journal of Research in Science Teaching* 21 (5): 483–488. 10.1002/tea.3660210505.

Henderson, B., and S. G. Moore. 1980. "Children's Responses to Objects Differing in Novelty in Relation to Level of Curiosity and Adult Behavior."." *Child Development* 51 (2): 457–465. 10.2307/1129279.

Hidi, S., K. A. Renninger. 2020. "On Educating, Curiosity, and Interest Development." *Current Opinion in Behavioral Sciences* 35:99–103. https://doi.org/10.1016/j.cobeha.2020.08.002.

Hsu, H.-Y., F.-H. Liu, H.-T. Tsou, and Chen L.-J. 2018. "Openness of Technology Adoption, Top Management Support and Service Innovation: A Social Innovation Perspective"." *Journal of Business & Industrial Marketing*. https://doi.org/10.1108/JBIM-03-2017-0068.

Ismail, O. A. 2024. "Digital Transformation in Education: Navigating the Challenges and Opportunities of Remote Learning." *Building Resilient Education Models Post Crisis*: 133–149 doi:10.4018/979-8-3693-8125-0.ch007.

Kanlı, U., and S. Yavaş. 2021. "Bilim merkezlerinde sergilerin pedagojik olarak modellendiği atölye çalışmalarının öğrencilerin kavramsal başarılarının gelişimine etkisinin incelenmesi." *Uluslararası Bilim Eğitimi Dergisi* 43 (1): 79–104. https://doi.org/10.1080/09500693.2020.1858203.

Karklelyte, I. 2023. "Primary School Teachers' Experiences of Inquiry-Based Education in Science Lessons." *Natural Science Education in a Comprehensive School* 29 (1): 4–19. https://doi.org/10.48127/gu/23.29.04.

Kinsey, L. C., T. E. Moore, and E. Prassidis. 2015. *Geometry and Symmetry*. 1st ed. Wiley. https://www.wiley.com/en-us/Geometry+and+Symmetry%2C+1st+Edition-p-9780470499498.

Lazonder, A. W., and R. Harmsen. 2016. "Meta-Analysis of Inquiry-Based Learning: Effects of Guidance." *Review of Educational Research* 86 (3): 681–718. https://doi.org/10.3102/0034654315627366.

Lincoln, Y. S., and E. G. Guba. 1985. "Naturalistic Inquiry." In *Beverly*, Hills, CA: Sage Publications, Inc.. https://doi.org/10.1016/0147-1767(85)90062-8.

Liquin, E., and T. Lombrozo. 2020. "A Functional Approach to Explanation-Seeking Curiosity." *Cognitive Psychology* 119:119 101276. https://doi.org/10.1016/j.cogpsych.2020.101276.

Litman, J. A., and C. D. Spielberger. 2003. "Measuring Epistemic Curiosity and Its Diversive and Specific Components."." *Journal of Personality Assessment* 80 (1): 75–86. 10.1207/S15327752JPA8001_16.

Loewenstein, G. 1994. "The Psychology of Curiosity: A Review and Reinterpretation." *Psychological Bulletin* 116 (1): 75–98. 10.1037/0033-2909.116.1.75.

Lorenzo-Yustos, H., P. Lafont, A. Diaz Lantada, A. F. F. Navidad, J. L. Munoz Sanz, and J. M. Munoz-Guijosa, … J. Echavarri Otero. 2010. "Towards Complete Product Development Teaching Employing Combined CAD–CAM–CAE Technologies." *Computer Applications in Engineering Education* 18 (4): 661–668.

Lotter, Christine, William S. Harwood, and Janet J. Bonner. 2007. ""The Influence of Core Teaching Conceptions on Teachers' Use of Inquiry Teaching Practices." *Journal of Research in Science Teaching* 44 (9): 1318–1347. https://doi.org/10.1002/tea.20191.

Love, T. S. 2022. "Examining the Influence That Professional Development Has on Educators' Perceptions of Integrated STEM Safety in Makerspaces." *Journal of Science Education and Technology* 31 (3): 289–302. https://doi.org/10.1007/s10956-022-09955-2.

Marquez, R., N. Barrios, R. E. Vera, M. E. Mendez, L. Tolosa, F. Zambrano, and Y. Li. 2023. "A Perspective on the Synergistic Potential of Artificial Intelligence and Product-Based Learning Strategies in Biobased Materials Education." *Education for Chemical Engineers* 44:164–180. https://doi.org/10.1016/j.ece.2023.05.005.

Mcguire, L., K. L. Mulvey, E. Goff. 2020. "STEM Gender Stereotypes from Early Childhood Through Adolescence at Informal Science Centers." *Journal of Applied Developmental Psychology* 67 doi:10.1016/j.appdev.2020.101109.

Miles, M. B., A. B. Huberman, and J. Saldana. 1988. *Qualitative Data Analysis: A Methods Sourcebook*. London: Sage.

Ministry of National Education (MoNE). TIMSS 2023 National Report. https://odsgm.meb.gov.tr/meb_iys_dosyalar/2024_12/16131900_timss2023.pdf.

Muhtaseb, R., and H. Burqan. 2021. "Exploring the Potential of Design Thinking as an Approach for Exhibit Development: The Case Study of the "Motion and Stillness" Science Exhibition." *Journal of Formative Design in Learning* 5 (2): 89–96. https://doi.org/10.1007/s41686-021-00060-y.

Neuendorf, K. 2017. *The Content Analysis Guidebook*. Thousand Oaks, CA: SAGE Publications, Inc. https://doi.org/10.4135/9781071802878.

Nicol, C. 2021. "Building Inquiry Teaching Skills through Year-Round Professional Development Programs." *Journal of Science Teacher Education* 32 (4): 389–405.

Özer, M., and H. E. Suna. 2023. "The Importance of Intellectual Property and Industrial Rights in the National Technology Initiative: Recent Educational Improvements in Turkey." *ResearchGate*. https://doi.org/10.53478/TUBA.978-625-8352-16-0.ch04.

Patton, Michael Quinn. 2018. "Nitel Araştırma ve Değerlendirme Yöntemleri." *Ankara: Pegem Akademi Yayıncılık*.

Pedaste, M., M. Mäeots, L. A. Siiman, T. de Jong, S. A. N. van Riesen, E. T. Kamp, C. C. Manoli, Z. C. Zacharia, and E. Tsourlidaki. 2015. "Phases of Inquiry-Based Learning: Definitions and the Inquiry Cycle." *Educational Research Review* 14:47–61. https://doi.org/10.1016/j.edurev.2015.02.003.

Peterson, E. G. 2020. "Supporting Curiosity in Schools and Classrooms." *Current Opinion in Behavioral Sciences* 35: 7–13. 10.1016/j.cobeha.2020.05.006.

Peterson, E. G., and S. Hidi. 2019. "Curiosity and Interest: Current Perspectives." *Educational Psychology Review* 31 (4): 781–788. https://doi.org/10.1007/s10648-019-09513-0.

Qablan, A. 2024. "Active Learning." *Advances in Educational Technologies and Instructional Design Book Series*: 31–41. https://doi.org/10.4018/979-8-3693-0880-6.ch003.

Qablan, A., A. M. Alkaabi, M. H. Aljanahi, and S. A. Almaamari. 2024. "Inquiry-Based Learning." *Advances in Educational Technologies and Instructional Design Book Series*: 1–12. https://doi.org/10.4018/979-8-3693-0880-6.ch001.

Raman, S., P. Hobson-West, M. E. Lam, and K. Millar. 2018. "Science Matters' and the Public Interest: The Role of Minority Engagement." In *Science and the Politics of Openness*, 230–250. Manchester University Press.

Ramanathan, G., D. R. Carter, and J. A. Wenner. 2021. "Framework for Scientific Inquiry in Preschool." *Early Childhood Education Journal* 50 (7): 1263–1277. https://doi.org/10.1007/s10643-021-01259-1.

Ramsurrun, H., R. Elaheebocus. 2024. "Digital Tools in Informal Science Education Sites: A Systematic Literature Review." *Journal of Science Education and Technology* 33:569–589. https://doi.org/10.1007/s10956-024-10105-z.

Reinmann, G. 2019. "Assessment and Inquiry-Based Learning." *Springer eBooks*: 91–105. https://doi.org/10.1007/978-3-030-14223-0_9.

Roehrig, G. H., and J. A. Luft. 2004. "Constraints Experienced by Beginning Secondary Science Teachers in Implementing Scientific Inquiry Lessons." *International Journal of Science Education* 26 (1): 3–24. https://doi.org/10.1080/0950069022000070261.

Rönnebeck, S., S. Bernholt. 2016. "Ropohl Searching for a Common Ground-A Literature Review of Empirical Research on Scientific Inquiry Activities." *Studies in Science Education* 52 (2): 161–197. https://doi.org/10.1080/03057267.2016.1206351.

Rubino-Hare, L., B. A. Whitworth, F. Boateng, and N. Bloom. 2023. "The Impact of Geospatial Inquiry Lessons on Student Interest in Science and Technology Careers." *Journal of Research in Science Teaching* 61 (2): 419–456. https://doi.org/10.1002/tea.21904.

Rubino-Hare, L., B. A. Whitworth, F. Boateng, and N. Bloom. 2023. "The Impact of Geospatial Inquiry Lessons on Student Interest in Science and Technology Careers." *Journal of Research in Science Teaching* 61 (2): 419–456. 10.1002/tea.21904.

Sasson, I. 2014. "The Role of Informal Science Centers in Science Education: Attitudes, Skills, and Self-Efficacy." *JOTSE: Journal of Technology and Science Education* 4 (3): 167–179. https://doi.org/10.3926/jotse.123.
Schwartz, S. H. 2017. "The Refined Theory of Basic Values." In *Values and Behavior: Taking a Cross Cultural Perspective*, edited by S. Roccas and L. Sagiv, 51–72. Cham, Switzerland: Springer International Publishing. https://doi.org/10.1007/978-3-319-56352-7_3.
Seneviratne, K., J. A. Hamid, A. Khatibi, F. Azam, and S. Sudasinghe. 2019a. "Multi-Faceted Professional Development Designs for Science Teachers' Self-Efficacy for Inquiry-Based Teaching: A Critical Review." *Universal Journal of Educational Research* 7 (7): 1595–1611. https://doi.org/10.13189/ujer.2019.070714.
Seneviratne, K., J. A. Hamid, A. Khatibi, F. Azam, and S. Sudasinghe. 2019b. "Teachers' Sense of Efficacy: A Challenge for Professional Development Toward Teaching Science as Inquiry." *Science Education International* 30 (4): 274–283. https://doi.org/10.33828/sei.v30.i4.4.
Silvia, P. J. 2009. "Tb.Kashdan. 2009. Interesting Things and Curious People: Exploration and Engagement as Transient States and Enduring Strengths." *Social and Personality Psychology Compass* 3 (5): 785–797. https://doi.org/10.1111/j.1751-9004.2009.00210.x.
Spielberger, C. D., L. Barker, S. Russell, R. Silva De Crane, L. Westberry, J. Knight, and E. Marks. 1980. "Preliminary manual for the State-Trait Personality Inventory (STPI)." Unpublished manuscript, University of South Florida.
Sutiani, A., M. Situmorang, and A. Silalahi. 2021. "Implementation of an Inquiry Learning Model with Science Literacy to Improve Student Critical Thinking Skills." *International Journal of Instruction* 14 (2): 117–138. https://eric.ed.gov/?id=EJ1290975.
T3 Foundation. 2020. "Turkish Technology Team Website." https://t3vakfi.org/en/
Teig, N., R. Scherer, and T. Nilsen. 2019. "I Know I Can, but Do I Have the Time? The Role of Teachers' Self-Efficacy and Perceived Time Constraints in Implementing Cognitive-Activation Strategies in Science." *Frontiers in Psychology* 10:1697–1697. https://doi.org/10.3389/fpsyg.2019.01697.
Thacker, B., E. Kim, K. Trefz, and S. M. Lea. 1994. "Comparing Problem Solving Performance of Physics Students in Inquiry-Based and Traditional Introductory Physics Courses." *American Journal of Physics* 62 (7): 627–633. https://doi.org/10.1119/1.17480.
Tsaliki, L. 2022. "Constructing Young Selves in a Digital Media Ecology: Youth Cultures, Practices and Identity." *Information Communication & Society* 25 (4): 477–484. https://doi.org/10.1080/1369118X.2022.2039747.
Turkish Academy of Sciences. 2022. "National Technology Movement: Societal Reflection and Future of Türkiye." *Turkish Academy of Sciences Publication, Science and Thought Series* (: 42). https://doi.org/10.53478/TUBA.978-625-8352-17-7.
Vorholzer, A., and C. von Aufschnaiter. 2019. "Guidance in Inquiry-Based Instruction – an Attempt to Disentangle a Manifold Construct." *International Journal of Science Education* 41 (11): 1562–1577. https://doi.org/10.1080/09500693.2019.1616124.
Weible, J., and H. T. Zimmerman. 2016. "Science Curiosity in Learning Environments: Developing an At-Titudinal Scale for Research in Schools, Homes, Museums, and the Community." *International Journal of Science Education* 38 (8): 1235–1255. https://doi.org/10.1080/09500693.2016.1186853 .
Williams, P. J., N. Nguyen, and J. Mangan. 2017. "Using Technology to Support Science Inquiry Learning." *Journal of Technology and Science Education* 7 (1): 26–57. https://doi.org/10.3926/jotse.234.
Wu, C., F. Wu, and Y. Huang. 2021. "One Teacher Is Enough? Pre-Trained Language Model Distillation from Multiple Teachers." In *ArXiv*, Cornell University. https://doi.org/10.48550/arxiv.2106.01023.
Xu, X., X. Wang, Y. Zhang, H. Zhang, and Y. Wu. 2023. "Applying ChatGPT to Tackle the Side Effects of Personal Learning Environments in Higher Education: A Teacher and Teaching Perspective." *Frontiers in Artificial Intelligence and Applications*. https://doi.org/10.3233/faia230769.
Yıldırım, A., and H. Şimşek. 2016. *Sosyal Bilimlerde Nitel Araştırma Yöntemleri. 10. Baskı*. Ankara: Seçkin Yayıncılık.
Yun, A. C. Shi, and B. G. Jun. 2022. "Dealing with Socio-Scientific Issues in Science Exhibition: A Literature Review." *Research in Science Education* 52 (1): 99–110. 10.1007/s11165-020-09930-0.

Yun, A., C. Shi, and B. G. Jun. 2022. “Dealing with Socio-Scientific Issues in Science Exhibition: A Literature Review.” *Research in Science Education* 52 (1): 99–110. https://doi.org/10.1007/s11165-020-09930-0.

Yun, J. J., E. Jeong, S. Kim, H. Ahn, K. Kim, S. D. Hahm, and K. Park. 2021. “Collective Intelligence: The Creative Way from Knowledge to Open Innovation.” *Science, Technology and Society* 26 (2): 201–222. https://doi.org/10.1177/09717218211005604.

Zervas, P., S. Sotiriou, R. Tiemann, and D. G. Sampson. 2015. “Assessing Problem Solving Competence Through Inquiry-Based Teaching in School Science Education.” *International Association for Development of the Information Society*. In Proceedings of the 12th International Conference on Cognition and Exploratory Learning in Digital Age (CELDA 2015).

Zhao, M., C. J. Mathews, K. L. Mulvey. 2023. “Promoting Diverse Youth’s Career Development Through Informal Science Learning: The Role of Inclusivity and Belonging.” *Journal of Youth & Adolescence* 52 (2): 331–343. https://doi.org/10.1007/s10964-022-01694-2.