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RESEARCH ARTICLE

Digital Educational Technologies in Gifted STEAM Education: A Qualitative Case Study of Teachers' Perceptions and Practices in a Mixed-Ability Learning Context

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ABSTRACT

This qualitative case study examines how teachers perceive and implement digital educational technologies in Gifted STEAM Education within a mixed-ability learning context involving gifted and non-gifted students. The study was situated in an annual professional development program on Gifted STEAM Education and involved six purposively selected teachers with experience in STEM/STEAM Education and/or Gifted Education. Data were collected through semi-structured interviews, mini focus groups, overt observation, field notes, and textual documents, and were analyzed using thematic analysis. The findings show that teachers viewed digital technologies not as neutral technical resources, but as pedagogical mediators that could shape inquiry, differentiation, participation, and creative production. Meaningful technology integration required explicit digital-skill goals, structured guidance, and formative monitoring. Digital tools supported Gifted STEAM learning when they were connected to interdisciplinary inquiry, design activities, multimedia production, creative expression, and differentiated forms of participation. Equity was understood as a multidimensional concern involving device access, meaningful participation, differentiated support, role distribution, ethical use, data protection, and equivalent non-digital pathways. Implementation, however, was limited by inadequate infrastructure, outdated equipment, software incompatibility, unstable internet access, time pressure, unequal access, and institutional ambiguity. The study contributes to the literature by clarifying how digital technologies can support inclusive differentiation, interdisciplinary integration, and ethical digital practice in Gifted STEAM Education. The findings should be interpreted in light of the small sample, the specific professional development context, the non-formal educational setting, and the limited transferability of a single qualitative case study.

KEYWORDS

Gifted STEAM education; digital educational technologies; mixed-ability learning context; differentiated learning; qualitative case study

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1. INTRODUCTION

The concept of childhood giftedness is shaped by the historical, social, and ideological characteristics of each era, and, accordingly, perceptions and attitudes towards giftedness vary depending on the cultural or research context in which they are examined [1], [2], [3]. Contemporary theoretical models of childhood giftedness draw on evidence from diverse manifestations of gifted children's behavior and action, while commonly identified characteristics include intellectual alertness, sensitivity, idealism, curiosity, organization, problem-solving ability, strong memory, and a rapid pace of learning [4], [5]. At the same time, gifted children often demonstrate asynchronous development, since their intellectual, emotional, and physical growth does not necessarily progress at the same pace. This makes differentiated educational provision particularly important [6].

The transition from STEM to STEAM can also be understood through pedagogical, inclusive, and socio-cultural perspectives that frame gifted education as a field concerned with creativity, socio-emotional imagination, meaning-making, and the educational conditions that support high cognitive potential. Rather than treating giftedness solely as advanced cognitive performance, arts-integrated STEAM approaches foreground the roles of imagination, empathy, reflective thinking, and creative production in developing learners' potential [7]. From this perspective, the Arts do not function as an external addition to STEM, but as a means of enriching inquiry, strengthening divergent and convergent thinking, and supporting students in transforming intellectual ability into innovative and socially meaningful outcomes [8]. Such an orientation is particularly relevant for gifted learners, whose educational needs often require cognitively demanding, creative, and affectively engaging learning environments.

Within this context, interdisciplinary approaches such as STEAM create new possibilities for educational inclusion and for the development of cognitive and socio-emotional skills in mixed-ability groups of gifted and non-gifted learners. From a holistic perspective in Gifted STEAM Education, such approaches can support both advanced learning and meaningful participation for all students [9]. In the present study, Gifted STEAM Education is understood as a pedagogical framework that combines principles of gifted education with the interdisciplinary logic of STEAM Education. It includes high cognitive challenge, creativity, inquiry, enrichment, differentiated support, socio-emotional awareness, and opportunities for advanced learning within shared educational activities. It therefore does not refer only to programs designed exclusively for formally identified gifted students, but also to learning environments in which gifted and non-gifted students participate through multiple entry points and differentiated pathways.

The term mixed-ability learning context is used in this study to refer to a heterogeneous educational group that may include formally identified gifted students, high-ability students without formal identification, typically developing students, and students who require additional learning support. This clarification is important because the empirical setting of the study did not concern a large-scale survey of ordinary classrooms across multiple schools, but a bounded qualitative case within a professional development and implementation context. In this setting, teachers designed and implemented a Gifted STEAM learning scenario for a heterogeneous group of primary school students in a non-formal educational environment. The concept of mixed ability is therefore used analytically to capture the coexistence of different levels of readiness, learning needs, interests, and forms of participation within a shared high-challenge learning activity.

Educational technologies play a significant role in this process by enabling interdisciplinary inquiry, multimodal representation, collaborative production, and authentic learning experiences [10]. Artificial Intelligence has also emerged as a promising tool, particularly for differentiated learning across the STEAM fields [11]. However, the present study distinguishes between the broad field of educational technologies and the more specific empirical focus on digital educational technologies. In the empirical analysis, digital educational technologies refer to digital tools, platforms, devices, applications, and digitally mediated practices used for teaching and learning, including tablets, projectors, Google Drive, multimedia materials, video and image resources, software applications, internet access, digital file sharing, cameras, microphones, and data protection procedures. This distinction is necessary to avoid treating educational technology as an undifferentiated concept and to clarify the specific tools and practices examined in the study.

Several additional concepts require clarification. Technological proficiency refers to teachers' and students' practical ability to operate, select, manage, and troubleshoot digital tools to support the learning task. Digital skills refer to specific operational abilities, such as searching for information, using a tablet, editing a file, managing digital content, or creating multimedia material. Digital competences refer to a broader set of pedagogical, critical, ethical, collaborative, and reflective abilities associated with the meaningful use of digital technologies in learning. Equity is used in a multidimensional sense. It includes access to devices and digital resources, meaningful participation, differentiated support, safe use, role distribution, recognition of different levels of readiness, and the provision of alternative routes to the same learning goals. Equivalent non-digital pathways are offline or analogue alternatives that allow students to achieve the same learning objective when digital access, digital readiness, or technical conditions are limited. Implementation resilience refers to teachers' capacity to sustain the pedagogical purpose of a learning activity despite technical failures, infrastructural limitations, or organizational constraints.

Although educational technologies, STEAM Education, and gifted education have each been widely discussed in contemporary educational research, their intersection remains insufficiently examined, particularly in mixed-ability settings where gifted and non-gifted students participate in shared learning activities. Existing studies on educational technologies often focus on digital competence, access, tool use, or technology-enhanced learning in general classroom contexts. Research on STEAM Education frequently emphasizes interdisciplinarity, creativity, design-based learning, and authentic problem-solving. Studies on gifted education, in turn, tend to focus on differentiation, enrichment, acceleration, talent development, or specialized programs for identified gifted learners. Less attention has been given to how teachers integrate digital educational technologies into Gifted STEAM learning activities for heterogeneous groups of gifted, high-ability, typically developing, and non-gifted students.

This gap is particularly important because technology integration in Gifted STEAM Education cannot be reduced to the use of devices or software. It concerns how digital tools mediate interdisciplinary learning, support differentiated participation, enable or constrain equity, and how teachers manage ethical, organizational, and infrastructural challenges. The issue is especially relevant in educational contexts where gifted education remains institutionally underdeveloped and where teachers are often required to design innovative practices without a stable policy framework, specialized support structures, or sufficient technological infrastructure. In such contexts, digital educational technologies may create opportunities for enriched and differentiated learning while also making visible new forms of inequality, resource dependency, and implementation uncertainty.

The novelty of the present study lies in its focus on the intersection of three areas that are often examined separately: digital educational technology integration, STEAM Education, and Gifted Education. Previous research has examined the pedagogical value of digital technologies, the interdisciplinary nature of STEAM learning, and the need for differentiated provision for gifted learners. However, fewer studies have examined how teachers integrate digital educational technologies into Gifted STEAM activities designed for mixed-ability learning contexts in which gifted and non-gifted students participate in a common learning task. The present study addresses this gap by examining teachers' perceptions and practices within a bounded professional development and implementation context. In doing so, it advances existing research by showing how technology integration in Gifted STEAM Education involves pedagogical alignment, interdisciplinary coherence, differentiated participation, ethical safeguards, and implementation resilience.

The present study, therefore, investigates how teachers perceive and enact the integration of digital educational technologies in Gifted STEAM Education within a mixed-ability learning context. More specifically, it addresses the following research questions:

1. What are teachers' attitudes, perceptions, and practices regarding the integration of digital educational technologies into Gifted STEAM Education?
2. Which pedagogical, technological, ethical, and organizational parameters should be considered when integrating digital educational technologies into Gifted STEAM Education?
3. What enabling factors support teachers in integrating digital educational technologies into Gifted STEAM Education?
4. What challenges do teachers face when integrating digital educational technologies into Gifted STEAM Education?

By addressing these questions, the study seeks to clarify how digital educational technologies can strengthen interdisciplinary creativity, problem-solving, critical thinking, differentiated participation, and ethical digital practice in mixed-ability Gifted STEAM settings. Its original contribution lies in examining technology integration not as a neutral technical addition, but as a pedagogical and organizational process through which teachers attempt to connect STEAM interdisciplinarity, gifted education, inclusive differentiation, and implementation feasibility. The study, therefore, contributes to the literature by providing an empirically grounded account of how teachers understand and negotiate the integration of digital educational technology in a small-scale, information-rich qualitative case study of Gifted STEAM Education.

2. Theoretical Background

The theoretical background of the present study is organised around three interconnected fields: gifted education, Gifted STEAM Education, and digital educational technology integration. These fields are not treated as independent domains, but as overlapping dimensions of a common pedagogical problem. The study examines how teachers understand and enact technology integration in learning environments where gifted and non-gifted students participate in shared interdisciplinary activities. For this reason, the theoretical framework must account for high cognitive challenge, differentiated participation, STEAM interdisciplinarity, digital competence, ethical use of technologies, and implementation conditions.

A central assumption of the present study is that educational technology cannot be understood only as a collection of tools. Its educational value depends on the pedagogical aims it serves, the learning processes it supports, and the conditions under which it is implemented. Similarly, STEAM Education cannot be reduced to the simple addition of the Arts to STEM fields, nor can Gifted Education be reduced to accelerated content for high-achieving students. The intersection of these three fields requires a more precise framework in which technology functions as a mediator of inquiry, representation, design, creativity, differentiation, and ethical participation.

2.1. Education of Gifted Children

According to the Three Ring Model of Giftedness, gifted behaviour emerges through the interaction of above-average ability, creativity, and commitment to task performance [12]. From this perspective, giftedness is not understood as a fixed trait expressed solely through high test scores, but as a dynamic potential that becomes visible through creative productivity, motivation, and engagement with meaningful tasks. This model remains relevant to the present study because Gifted STEAM Education requires learning environments that allow students to demonstrate advanced reasoning, creative production, persistence, and problem-solving through authentic, interdisciplinary activities.

The education of gifted children, therefore, requires differentiated approaches and the application of alternative and innovative teaching and learning methods [13]. It also presupposes a holistic and interdisciplinary orientation to knowledge that responds to learners' particular abilities and developmental characteristics [14]. In parallel, a supportive educational framework is needed to strengthen psychosocial adjustment and to prevent or reduce negative emotional experiences often associated with giftedness [15]. The ultimate aim is the development of cognitive and emotional capacities to the highest possible level [16].

However, the education of gifted learners also involves a persistent tension between excellence and equity. On the one hand, gifted students need advanced, enriched, and challenging learning opportunities. On the other hand, gifted education has often been criticised when it appears to operate as a selective or elitist form of provision. Contemporary approaches attempt to move beyond this opposition by treating giftedness as one dimension of learner diversity that requires recognition, support, and appropriate educational response. In this sense, equitable gifted education does not mean reducing challenge, but ensuring that opportunities for advanced learning are accessible, pedagogically justified, and responsive to different learners' profiles.

This view is consistent with the NAGC Pre-K–Grade 12 Gifted Programming Standards, which emphasise student outcomes, learning and development, assessment, curriculum planning, learning environments, programming, and professional learning as interconnected dimensions of quality gifted education [17]. These standards are particularly relevant to the present study because they frame gifted education as a matter of program quality and systematic educational provision, rather than as isolated enrichment activities. They also highlight the importance of professional development, assessment, and learning environments, all of which are central to implementing Gifted STEAM Education.

Within gifted education, STEAM approaches can foster creative thinking by providing interdisciplinary learning environments that activate both analytical and imaginative forms of engagement. Research on STEAM-based activities, including music-related coding and design-oriented engineering projects, suggests that such experiences may strengthen divergent exploratory thinking, understood as the generation of multiple original ideas, as well as convergent integrative thinking, understood as the synthesis of complex information into functional solutions [18]. From a pedagogical and holistic perspective, arts-integrated learning can support social-emotional imagination, reflective meaning-making, careful observation, spatial reasoning, and analogical thinking, thereby enriching the educational conditions through which gifted learners engage creatively and meaningfully with knowledge [19].

At the same time, gifted learners do not form a homogeneous group. They differ in cognitive strengths, socio-emotional needs, cultural backgrounds, linguistic profiles, motivation, interests, and levels of digital readiness. Some may show advanced performance in specific domains, while others may remain underidentified because learning difficulties, language barriers, socio-economic disadvantage, or limited opportunities mask their abilities. This is particularly important in mixed-ability settings, where teachers must design learning experiences that remain sufficiently challenging for gifted learners while also enabling meaningful participation for non-gifted students. Gifted Education, therefore, constitutes an approach that closely connects cognitive and emotional support. It contributes to the overall socio-emotional development of gifted learners and may also be implemented in mixed-ability settings through collaboration between gifted and non-gifted children [20].

Common pedagogical approaches in this field include inquiry-based learning, authentic problem-solving, and the interactive construction of knowledge [21]. These approaches are especially compatible with STEAM Education because they allow learners to investigate complex problems, create artefacts, test ideas, negotiate meaning, and communicate outcomes. However, the implementation of inclusive forms of Gifted Education is strongly influenced by educational policy and by each country's wider social and cultural assumptions about giftedness [22]. This is significant in contexts where gifted education remains institutionally underdeveloped, because teachers may be expected to design advanced and differentiated learning experiences without clear policy guidance, specialised resources, or systematic professional support.

2.2. Gifted STEAM Education

STEM Education refers to an integrated educational philosophy that combines Science, Technology, Engineering, and Mathematics in a coherent interdisciplinary framework [23]. STEAM Education extends this framework by incorporating the Arts, thereby offering a broader and more holistic approach to learning [24], [25]. This inclusion encompasses not only visual arts, language arts, and liberal arts, but also music, theatre, and dance [26], [27]. The correction of this distinction is important. STEM should be grounded in literature that addresses the integration of Science, Technology, Engineering, and Mathematics. In contrast, STEAM should be grounded in literature that explains the pedagogical addition of the Arts and the movement towards more creative, aesthetic, communicative, and human-centred learning.

The shift from STEM to STEAM is theoretically meaningful because it changes the nature of the learning process. The Arts do not simply make STEM activities more attractive. They introduce forms of representation, interpretation, imagination, embodiment, communication, aesthetic judgement, narrative construction, and creative production. In this sense, STEAM can support both cognitive and socio-emotional dimensions of learning. It allows students to approach scientific and technological problems through design, creativity, ethical reflection, and social meaning-making. This is especially relevant for gifted learners, whose educational needs often include complexity, autonomy, originality, depth, and opportunities for creative transformation of knowledge.

Common approaches in STEAM Education include the use of educational software, programming, and Artificial Intelligence for inquiry-based learning through collaborative projects [28], the collaboration of teachers from different specializations [29], and the exploration of global issues through local and intercultural educational examples [30], [31], [32]. In addition, particular importance is attached to the development of clear and reliable assessment methods that address both the learning process and the educational environment [33]. These features show that STEAM Education is not only a curriculum structure, but also a design logic for learning activities that combine inquiry, collaboration, production, reflection, and evaluation. This interpretation is also supported by approaches that conceptualize STEAM as an innovative educational technology organized around project-based learning, creative spaces, and the active integration of disciplinary knowledge through collaborative production [34]. In teacher education, STEAM has also been discussed as a benchmark for innovative professional preparation, particularly when creative projects are used to connect technological, artistic, and disciplinary forms of problem-solving [35].

In recent years, increasing interest has been observed in the application of STEAM approaches to the education of gifted children [36]. Research suggests that such integration can enhance gifted learners' problem-solving, inquiry, and innovation skills [37] while also fostering critical thinking, creativity, and collaboration [38]. STEAM Education supports the deepening and application of knowledge across its constituent fields through creative problem-solving [39], and it provides a flexible learning framework that enables the balanced development of cognitive and creative capacities while drawing on the distinctive strengths of gifted learners [40]. At the same time, Gifted STEAM Education emphasizes the development of communication and collaboration among all learners, so that individual growth is supported through shared effort and collective work [41].

Nevertheless, the relationship between STEAM Education and Gifted Education should not be taken for granted. A central challenge is that STEAM can sometimes be implemented as a thematic combination of subjects without genuine interdisciplinary integration. In such cases, Science, Technology, Engineering, the Arts, and Mathematics may appear in the same activity, but they do not necessarily contribute equally or coherently to the learning process. For Gifted STEAM Education to be pedagogically meaningful, the STEAM fields must interact around a shared problem, question, artefact, or design challenge. This requires teachers to make explicit how each field contributes to inquiry, representation, problem-solving, creative production, and reflection.

Integrating STEAM education into gifted programs also provides a meaningful framework for socio-emotional development, as it supports a broader understanding of gifted learners beyond purely cognitive indicators. Arts-integrated STEAM experiences can cultivate social-emotional imagination by encouraging students to consider alternative perspectives, connect knowledge to human and social purposes, and develop more reflective forms of engagement with learning [42]. This interdisciplinary orientation may also foster collective creativity, teamwork, empathy, and communication, particularly when students participate in collaborative inquiry-based projects and design challenges [43]. In this respect, Gifted STEAM Education can support intrinsic motivation and affective engagement by allowing gifted learners to connect advanced cognitive work with personal meaning, ethical reflection, and collaborative problem-solving [44].

The present study understands Gifted STEAM Education as an inclusive and differentiated pedagogical framework. It does not refer only to separate enrichment programs for formally identified gifted students. Rather, it refers to the design of high-challenge interdisciplinary learning activities in which gifted, high-ability, typically developing, and non-gifted students can participate through multiple entry points and differentiated pathways. This interpretation is important because it connects gifted education with broader principles of inclusive education and Universal Design for Learning.

The Universal Design for Learning Guidelines 3.0 provide a useful framework for understanding this relationship, because they emphasise learner variability, access, meaningful participation, and multiple means of engagement, representation, and action or expression [45]. In the context of Gifted STEAM Education, UDL principles are valuable because they support flexible access to learning. However, they need to be combined with the specific requirements of gifted education, especially enrichment, depth, complexity, creativity, and advanced inquiry. Access alone is not sufficient for gifted learners. They also require challenge. Therefore, a Gifted STEAM framework must meet two pedagogical demands: it must provide advanced and meaningful learning opportunities for gifted learners while also ensuring that non-gifted students can participate actively in the same learning environment.

This synthesis is central to Gifted STEAM Education for mixed-ability learners. In such contexts, differentiation does not mean assigning disconnected tasks to different students. It means designing a common learning core that remains cognitively rich while allowing students to engage through different forms of support, representation, collaboration, pace, role allocation, and product development. Digital educational technologies may contribute to this process, but only when they are embedded in a clear pedagogical design.

2.3. Digital Educational Technologies in STEAM Education

Educational technologies constitute a broad field of applications that use digital systems, tools, and processes to support, enrich, and transform teaching and learning [46]. Their effectiveness depends on aligning their functions with clear pedagogical aims and on selecting them rationally to support gradual cognitive challenge, differentiated participation, and formative assessment [47]. Within STEAM Education, such technologies include interactive whiteboards and projectors, virtual and augmented reality tools, educational robotics software, digital platforms, multimedia production tools, programming environments, data visualisation applications, and specialised educational simulators [48]. These tools enable modelling, simulation, data visualisation, and design-based learning in ways well suited to inquiry-based learning and creative problem-solving [49].

For conceptual clarity, the present study distinguishes between educational technologies as a broad field and digital educational technologies as the article's empirical focus. Educational technologies may include tools, systems, processes, methodological frameworks, and learning design approaches. Digital educational technologies, as examined in the empirical part of this study, refer more specifically to devices, platforms, applications, software, digital media, online resources, file-sharing practices, multimedia production tools, and digitally mediated safety procedures used in teaching and learning. This distinction responds to the need to avoid conceptual ambiguity. The article does not claim to examine the entire field of educational technology. It examines teachers' perceptions and practices regarding the pedagogical use of digital tools in a specific Gifted STEAM learning context.

The pedagogical value of digital educational technologies in STEAM Education lies in their ability to connect inquiry, representation, experimentation, production, and communication. STEAM educational technologies support scientific creativity by allowing students to experiment with representations, compare hypotheses, and explore multiple solution pathways [50]. Moreover, the purposeful design of activities around the investigation, evaluation, and interpretation of information can strengthen critical thinking and evidence-based decision-making [51]. In technology-rich STEAM environments, students may collect data, visualise patterns, simulate processes, construct models, design digital artefacts, produce videos, develop multimedia narratives, and present solutions to authentic problems.

In the context of Gifted STEAM Education, these affordances take on added significance. Gifted learners often benefit from open-ended inquiry, complex tasks, autonomy, rapid access to advanced information, and opportunities for creative production. Digital tools can support these needs by expanding access to resources, enabling advanced representation, allowing iterative design, and providing opportunities for self-directed exploration. At the same time, non-gifted learners may benefit from the same technologies when they offer scaffolding, visual support, collaborative structures, multiple forms of expression, and differentiated entry points. Therefore, digital tools can support mixed-ability Gifted STEAM learning only when they are designed to serve both enrichment and inclusion.

This point requires careful theoretical emphasis. Digital technologies do not automatically produce differentiation, equity, creativity, or STEAM integration. Their value depends on how teachers connect them with learning objectives, how students are guided in their use, how roles are distributed, how digital competences are developed, and how ethical and technical risks are managed. A tablet, projector, simulation, digital platform, AI tool, or video editor can support meaningful learning, but it can also become a superficial addition if it is disconnected from the interdisciplinary task. This is why the present study treats digital educational technologies as pedagogical mediators rather than neutral tools.

In the context of STEAM educational technologies, digital tools can further support critical thinking when they are embedded in inquiry-driven, design-based, and reflective learning activities. Technology-enhanced STEAM environments can help gifted learners move beyond rote knowledge by engaging them in analyzing complex problems, comparing alternative solutions, critiquing different strategies, and synthesizing information across disciplines [52]. Digital simulations, multimedia design tools, programming environments, data visualisation applications, and music technology projects can provide opportunities for argumentation, experimentation, aesthetic judgement, and creative problem-solving. In this way, digital educational technologies do not merely facilitate access to information, but can support adaptive expertise by helping students establish meaningful connections across STEAM fields and transform their intellectual curiosity into collaborative and innovative inquiry.

The rapid development of Artificial Intelligence adds further complexity to this discussion. AI tools can support personalised learning, formative feedback, multimodal production, idea generation, coding, visual creation, and differentiated access to information. However, they also raise significant concerns related to transparency, accountability, bias, authorship, data protection, student autonomy, and the reliability of generated content. UNESCO's guidance for generative AI in education and research emphasises the need for a human-centred approach, age-appropriate use, data protection, human agency, inclusion, equity, and institutional regulation of generative AI applications in education [53]. This guidance is directly relevant to Gifted STEAM Education because advanced learners may be particularly capable of using generative AI creatively, while younger or less digitally prepared learners may require stronger guidance, safeguards, and alternative pathways.

Ethical use is therefore not an external addition to digital technology integration. It is part of the pedagogical design itself. Teachers must consider informed consent, access controls, safe browsing, file management, privacy, camera and microphone use, copyright, awareness of Creative Commons, and verification of AI-generated material. These issues become especially important in STEAM activities that involve multimedia production, online searching, video recording, image generation, digital collaboration, and public communication of students' products. In mixed-ability contexts, ethical design also includes preventing exclusion. Students should not be disadvantaged because of lower digital readiness, limited device access, or different learning needs.

The implementation of digital educational technologies also depends on institutional and infrastructural conditions. A coherent digital education ecosystem requires reliable infrastructure, access to appropriate devices and software, technical support, teacher professional development, data protection frameworks, and policies that clarify responsibilities and expectations [54]. Without such conditions, technology integration depends excessively on individual teacher initiative and may reproduce inequalities between schools, teachers, and learners. This is particularly relevant in contexts where Gifted Education is not systematically supported, because teachers may need to combine innovation, differentiation, and digital pedagogy without adequate institutional resources. This organizational dimension is important because school digitalization is not limited to introducing devices or platforms. It also depends on how digital change is conceptualized, planned, and enacted within the school organization, as well as on whether teachers and institutions develop shared understandings of the purposes of digital transformation [55].

2.3. Analytical Synthesis of the Framework

The study's theoretical framework brings together gifted education, STEAM Education, UDL-informed differentiation, digital competence, TPACK-oriented technology integration, and ethical digital practice. The study, therefore, examines digital educational technology integration in Gifted STEAM Education through four interconnected analytical dimensions.

The first dimension is pedagogical alignment. Digital tools must be connected to clear learning objectives, STEAM tasks, and assessment criteria. Their use should support inquiry, design, production, representation, collaboration, and reflection. Technology use that remains disconnected from the learning task does not constitute meaningful Gifted STEAM integration.

The second dimension is interdisciplinary coherence. In Gifted STEAM Education, digital tools should help students move across Science, Technology, Engineering, the Arts, and Mathematics in ways that create a shared problem-solving and meaning-making process. The issue is not whether all STEAM fields are mentioned, but whether they interact productively within the learning activity.

The third dimension is inclusive differentiation. Gifted and non-gifted students require different kinds and levels of support. However, they can participate in a shared high-challenge learning task when the activity includes multiple entry points, flexible roles, scaffolding, multimodal representation, formative guidance, and equivalent non-digital pathways. Equity is therefore understood as meaningful participation in a common learning process, rather than as simple equality of device distribution.

The fourth dimension is implementation resilience. Digital educational technology integration requires teachers to anticipate technical, ethical, organizational, and infrastructural challenges. This includes backup plans, offline alternatives, safe data practices, clear rules of use, and institutional support. In this sense, resilience is not merely a teacher's improvisational skill, but a design principle that allows learning to continue despite unstable conditions.

This framework directly informs the empirical analysis of the present study. The research does not ask only whether teachers consider digital technologies useful. It examines how they understand their pedagogical role, how they connect them to STEAM integration, how they use them to support differentiation and equity, and how they respond to ethical and implementation challenges. In doing so, the study addresses a specific gap in the literature: the limited empirical understanding of how teachers integrate digital educational technologies into Gifted STEAM Education in mixed-ability learning contexts involving both gifted and non-gifted students.

3. Methods

3.1. Research Design and Context

The present study adopted a qualitative methodological approach within the framework of a pragmatic case study. This design was selected because the study aimed to examine a specific educational phenomenon in depth, namely, teachers' perceptions and practices regarding the integration of digital educational technologies into Gifted STEAM Education within a mixed-ability learning context. The pragmatic orientation of the study allowed the research design to focus on practical questions of educational design, implementation, equity, feasibility, and teacher decision-making, using methods appropriate to the nature of the research questions [56].

The case examined in the present article was part of an annual professional development program entitled Gifted STEAM Education, implemented under the scientific supervision of European University Cyprus. The program included synchronous and asynchronous professional development activities, collaborative planning, implementation of a Gifted STEAM learning scenario, and collective reflection on the pedagogical use of digital educational technologies. The empirical focus of the present article is the qualitative case-study phase, which explored how a small central group of teachers conceptualised, designed, and enacted technology integration in mixed-ability Gifted STEAM learning activities.

The professional development program was organised in five successive phases. The first phase consisted of four public online seminars on gifted education, STEAM Education, technology integration in Gifted STEAM Education, and the design of Gifted STEAM learning scenarios. The second phase involved forming a central group of six teachers who participated in a more systematic professional development program. The third phase focused on the collaborative design of a Gifted STEAM learning scenario. The fourth phase involved implementing the learning scenario in a non-formal primary education setting. The fifth phase focused on developing educational materials based on the implemented scenario. The present article primarily draws on data produced by the central group during the professional development, planning, implementation, and reflection phases.

The learning scenario implemented by the teachers was entitled "Cinema, Nature and Society: Creating an Awareness-Raising Documentary". It was designed for sixth-grade primary school students and aimed to combine environmental inquiry, cinematic and artistic production, digital media creation, design thinking, and social communication. The scenario was implemented in a non-formal primary education centre in Athens, Greece, and consisted of seven sequential learning activities conducted over four educational days. The total duration of the implementation was 24 teaching hours, every 45 minutes.

3.2. Participants and Sampling

Participants were selected through purposive sampling. The central group consisted of six teachers with prior experience in STEM/STEAM Education and/or Gifted Education who were willing to participate in all stages of the professional development program, including training, collaborative planning, implementation, reflection, interviews, focus groups, and observation. The sampling criteria included previous involvement or interest in Gifted Education, STEAM Education, educational innovation, and the pedagogical use of digital technologies, as well as willingness to invest time and remain engaged throughout the case-study process.

The small sample was considered appropriate for the qualitative case-study design because the participants were information-rich cases directly involved in all phases of the intervention. The purpose of the study was not statistical representativeness, but an in-depth understanding of teachers' experiences, decisions, and practices within a clearly bounded educational case. The sufficiency of the sample was evaluated in relation to the specificity of the research aim, the professional relevance of the participants, and the intensity of the data generated. All six teachers participated in repeated interviews, mini focus groups, collaborative planning, professional development meetings, observed implementation, and textual interaction. Recurrent patterns became stable across the different data sources, and no substantially new thematic categories emerged in relation to the main research questions during the later stages of analysis.

The six participants were aged 25-49 and represented different subject specializations, educational settings, and prior experience relevant to Gifted Education, STEAM Education, digital technologies, and educational innovation. Gender is not reported to strengthen participant anonymity in the small sample. Their main professional characteristics are summarized in Table 1.

Table 1. Participant profile

Participant	Subject specialization	Educational setting and experience	Previous relevant experience
T1	Primary education	Primary and non-formal music education; postgraduate studies in Education Sciences and Music	Contact with diagnosed gifted children; interdisciplinary and innovative teaching
T2	Philology	Non-formal special education and public secondary education; postgraduate studies in Special Education	Gifted Education and STEM professional development; educational innovation activities
T3	ICT	Public and private, primary and secondary, general and special education; postgraduate studies in educational technologies and Special Education	STEM/STEAM programs; trainer/presenter in educational innovation activities
T4	Physics	Private secondary education; postgraduate studies in Science Education and STEM Education	Contact with diagnosed gifted children; STEM and intercultural education training
T5	Economics	Public secondary education; postgraduate studies in Education Sciences and Special Education	Contact with diagnosed gifted children; educational innovation and STEM career guidance
T6	Primary education	Public and private, formal and non-formal, general and special primary education; postgraduate studies in Education Sciences	ICT, interdisciplinary education, robotics, and STEM programs

The learning scenario was implemented with 12 sixth-grade students, aged approximately 11 to 12 years. Three students had identified characteristics of giftedness and/or were members of the Greek Mensa. The wider student group included students with typical abilities, high-ability students without formal identification, and students with learning difficulties or special educational needs. This composition was central to the study because it allowed the analysis to focus on how teachers used digital educational technologies to support differentiated participation, collaboration, and access to a common high-challenge Gifted STEAM task.

3.3. Data Collection

Data were collected through semi-structured interviews, mini focus groups, overt observation, field notes, and textual document collection. The use of multiple sources was intended to capture both what teachers stated about technology integration and what they enacted during planning and implementation.

At the beginning of the case-study phase, six individual semi-structured interviews were conducted, one with each teacher. A second round of six individual semi-structured interviews was conducted after the learning scenario was completed. In total, twelve individual interviews were conducted. The first interview protocol focused on teachers' expectations from the programme, their usual pedagogical approaches, their use of innovative technologies, their confidence in using digital tools, their prior familiarity with Gifted STEAM Education, their understanding of STEAM integration, and their views on the resources and challenges associated with Gifted STEAM teaching. Indicative questions included: "Do you use innovative technologies in your classroom? If yes, how?", "What do you consider Gifted STEAM Education to be?", and "How are Science, Technology, Engineering, Arts, and Mathematics integrated in Gifted STEAM Education?". The second interview protocol focused on teachers' reflections after implementation, including their overall impressions, possible changes in their views on STEAM and gifted education, their collaboration with colleagues, their implementation decisions, and the positive or challenging aspects of their first experience with Gifted STEAM Education.

Mini focus groups were conducted during and after the implementation of the learning activities. Each mini focus group included three to four teachers, depending on the subgroup that had designed and implemented the relevant activities. The focus group protocol examined teachers' collective reflections on the implemented activities, the integration of the STEAM fields, differentiated learning, creativity and critical thinking, socio-emotional support, the combination of physical and digital resources, group organisation, assessment practices, implementation difficulties, enabling factors, and possible revisions for future applications. Indicative questions included: "Which elements of Gifted STEAM Education did you apply in the lesson?", "How did you ensure the interdisciplinary connection of the STEAM fields?", and "What difficulties emerged during the activity and what adaptations did you make?"

The individual semi-structured interviews lasted approximately 45–60 minutes each. Six mini focus groups were conducted during and after the implementation of the learning activities, and each lasted approximately 45–60 minutes. All audio-recorded interviews and focus group discussions were transcribed verbatim in Greek by the researcher. This procedure ensured the analysis remained grounded in the participants' original language before the selected excerpts were translated into English for publication.

Observation was conducted in two forms. First, overt participant observation was conducted during the professional development and collaborative planning process, particularly during the central group's synchronous online meetings. The central group participated in ten weekly synchronous meetings, each lasting 120 minutes. These meetings focused on themes such as giftedness, STEAM interdisciplinarity, assessment, TPACK, digital competences, educational technologies, learning scenario design, and pedagogical extensions. Second, overt non-participant observation was conducted during the implementation of the learning scenario in the non-formal primary education setting. The observation covered seven sequential learning activities implemented over four educational days, totaling 24 teaching hours of 45 minutes each.

During the observation process, field notes were kept systematically. These included descriptive notes on the setting, participants, activities, interactions, tools, and classroom organization, as well as reflective notes on emerging interpretations, potential tensions, and the researcher's preliminary analytical observations. The STEAM Classroom Assessment for Student Learning Experiences rubric was used as a structured observation guide. It was not used as a formal evaluative instrument for judging teachers, and individual scores were not communicated to participants.

Textual documents were also collected from the digital environments used during the professional development and planning process. These included materials from the asynchronous Open eClass platform, publicly shared communication within the central group's Rakuten Viber group, and documents produced during the collaborative design of the learning scenario. Private messages between participants were not collected. Data were collected in Greek, which was the language of the participants and the educational setting. The excerpts reported in the manuscript were translated into English by the authors for publication purposes.

3.4. Data Analysis

The qualitative data were analysed through thematic analysis [57]. The dataset included interview transcripts, focus group transcripts, observation notes, field notes, textual documents, and educational materials produced during the design and implementation of the learning scenario. Thematic analysis was selected because it allows the systematic identification and interpretation of patterns of meaning across qualitative data while remaining sufficiently flexible for educational case-study research.

The analysis followed six iterative phases: familiarisation with the data, generation of initial codes, search for themes, review of themes, definition and naming of themes, and selection of illustrative extracts for the development of an analytical narrative. These phases were treated as recursive rather than strictly linear. The researcher repeatedly moved between the coded material, the research questions, the theoretical framework, and the emerging themes to refine the interpretation.

The coding process combined deductive and inductive logic. Deductive coding was informed by the conceptual framework of the study, including Gifted STEAM Education, differentiated learning, educational technology integration, TPACK, digital competences, and the STEAM Classroom Assessment of Learning Experiences model. Inductive coding allowed additional categories to emerge from teachers' accounts, focus group discussions, observed practices, field notes, and textual documents. Examples of inductive codes included "device rotation", "technical assistant role", "digital congestion", "non-digital alternative", "software licence problem", "fear of equipment damage", "gifted student as peer supporter", "role allocation", "hidden differentiation", and "implementation backup plan".

The movement from codes to themes was based on repeated comparison of coded material across participants and data sources. Codes related to basic tool operation, explicit instructions, user guides, peer technical support, and formative monitoring were grouped under the theme "Technological Proficiency and Digital Skills Goal-Setting". Codes concerning tablets, projectors, Google Drive, video materials, multimedia production, documentary creation, and the connection between tool use and STEAM tasks were grouped under the theme "Interdisciplinary Integration and Learning Differentiation". Codes related to device access, role distribution, group balance, peer assistance, participation thresholds, and formative assessment informed the theme "Equity, Guidance, and the Assessment of Digital Competences". Codes related to camera and microphone restrictions, safe browsing, consent, file management, data protection, software licences, and AI-related caution informed the theme "Ethics and Data Protection as Principles of Use". Codes concerning infrastructure, outdated equipment, software incompatibility, internet access, time pressure, professional development, collaborative planning, and institutional support informed the theme "Challenges and Enabling Factors".

The analysis proceeded in two complementary directions. First, a within-case analysis was conducted for each teacher to preserve the specificity of individual professional trajectories, subject specializations, and perspectives. Second, a cross-case thematic analysis was conducted to identify convergences, divergences, and recurring patterns across participants. This two-level procedure enabled examination of both individual differences and shared patterns in teachers' perceptions and practices.

The researcher conducted coding. Since the coding was not conducted independently by multiple coders, intercoder agreement was not calculated. No qualitative data analysis software was used. The coding process was conducted manually through repeated reading of the transcripts and field material, the development of manual coding tables, and the iterative refinement of a coding index. The coding index included code definitions and illustrative examples from the data, while analytic memos documented emerging interpretations, coding decisions, potential relationships among codes, and the gradual evolution from initial codes to broader themes.

Manual coding was considered appropriate for the scope of the study because the dataset was bounded, the number of participants was small, and the analysis required close interpretive engagement with participants' accounts, observed practices, and contextual field material. Analytical consistency was strengthened through repeated comparisons across data sources, systematic documentation of coding decisions, within-case and cross-case analysis, and continuous refinement of the coding index during theme development.

3.5. Data Sufficiency and Information Power

The use of six participants was justified by the qualitative case study design, the article's narrow empirical focus, and the information-rich character of the cases. The participants were not peripheral informants but core actors in the professional development and implementation process. They participated in training, collaborative planning, teaching implementation, reflection, interviews, focus groups, and textual interaction. The intensity and multiplicity of the data sources increased the information value of the sample.

Data sufficiency was assessed through the recurrence and stability of patterns across interviews, focus groups, observation, field notes, and textual documents. During the later stages of analysis, the same central patterns repeatedly emerged regarding technological proficiency, STEAM integration, differentiation, equity, ethics, infrastructure, and professional support. In the observation process, repeated observation of related educational situations did not generate substantially new categories for the study. The study, therefore, claims analytical sufficiency within the boundaries of the case, rather than broad empirical saturation across a wider teacher population.

3.6. Trustworthiness and Researcher Reflexivity

Several strategies were used to strengthen the study's trustworthiness. Credibility was supported through triangulation across semi-structured interviews, mini focus groups, overt observation, field notes, textual documents, and educational materials. The use of both individual and collective data collection enabled comparisons of what teachers stated individually, what they negotiated collectively, and what they enacted during the implementation of the learning scenario.

A limited form of member checking was also used through participant feedback on initial interpretations. This process allowed the researcher to examine whether the emerging interpretations corresponded meaningfully to participants' experiences. The procedure was limited and did not constitute full participant validation of all stages of analysis, but it provided an additional check on the plausibility of the interpretations.

Dependability was supported through structured interviews and focus group protocols, systematic field notes, an observation guide, a coding index, and analytic memos. These materials formed an audit trail documenting the movement from data collection to coding, theme development, interpretation, and reporting. Transferability was supported through a thick description of the professional development context, the participants, the learning scenario, the mixed-ability student group, the implementation conditions, and the digital tools used.

Researcher reflexivity was considered throughout the study. The researcher occupied a dual role as designer and facilitator of the professional development program and as collector and analyst of the data. This position may have influenced participants' responses or practices through social desirability, reactivity, or awareness of being observed. To reduce this risk, the study did not treat teachers' statements as self-sufficient evidence. Instead, interview data were compared with focus group discussions, observation notes, textual documents, educational materials, and field notes. Reflexive memoing was also used to monitor the researcher's assumptions, emerging interpretations, and potential influence on the analytic process.

The researcher's proximity to the field of giftedness was also acknowledged as part of the reflexive process. This proximity could have shaped theoretical sensitivity and interpretive focus. For this reason, the analysis remained grounded in empirical material and relied on repeated comparison between interpretations and primary data. The absence of independent observers and independent coders is recognised as a methodological limitation, but the use of triangulation, coding documentation, participant feedback, and reflexive monitoring was intended to strengthen the credibility of the interpretation.

3.7. Ethical Considerations

Ethical standards were carefully observed throughout the study. Participants were informed about the purpose, procedures, requirements, and voluntary nature of the research. Written informed consent was obtained from all teacher participants. The consent procedure included agreement to participate in interviews and focus groups, permission to record audio, consent to be observed during the professional development and implementation phases, and consent to document educational materials.

Because the learning scenario involved minors, written consent was obtained from the students' legal guardians. Guardians were informed about the nature of the educational activities, the observation process, the possible documentation of educational materials, the use of information relevant to the students' educational profiles, and the protection of personal data. Participation was voluntary, and participants retained the right to withdraw from the research.

Anonymity, confidentiality, pseudonymisation, and secure handling of personal data were ensured in accordance with the principles of the General Data Protection Regulation. The minimum necessary data were collected for the study. Data were securely stored in the institutional digital environment available to the researcher through European University Cyprus. The study received ethical approval from the Research Ethics Committee of European University Cyprus under approval number 2023.65.

4. Results

The thematic analysis identified five interrelated themes regarding teachers' perceptions and practices in integrating digital educational technologies into Gifted STEAM Education. These themes were: technological proficiency and digital skills goal-setting; interdisciplinary STEAM integration and learning differentiation; equity, guidance, and the assessment of digital competence; ethics, data protection, and implementation resilience; and challenges and enabling factors. The themes are presented below as analytic categories rather than as isolated descriptive topics. Each theme is linked to one or more research questions and illustrates how teachers interpreted the pedagogical role of digital technologies in a mixed-ability Gifted STEAM learning context.

Table 2 summarizes the main themes, indicative sub-themes, related research questions, and representative quotations.

Table 2. Themes, sub-themes, related research questions, and representative quotations

Main theme	Indicative sub-themes	Main RQs addressed	Representative quotation
Technological proficiency and digital skills goal-setting	Basic tool operation; explicit digital skills objectives; user guides; technical assistant roles; formative monitoring	RQ1, RQ2	"I consider knowledge of technology essential for STEAM, at least the basics. Otherwise, it could not succeed".
Interdisciplinary STEAM integration and learning differentiation	STEAM coherence; collaborative digital planning; multimodal representation; differentiated access; documentary production; digital and non-digital routes	RQ1, RQ2	"We work with Drive. Everyone uploads what they want, and then someone else edits it afterwards. It is a great help".
Equity, guidance, and the assessment of digital competence	Device access; role rotation; group balance; peer support; participation thresholds; assessment of digital readiness	RQ2, RQ3	"If they are older, I give one tablet to each group. If the children are very young, I would want more, because it is not easy for them to collaborate and talk over only one screen".
Ethics, data protection, and implementation resilience	Consent; safe use; camera and microphone restrictions; software licences; compatibility; offline alternatives; AI-related caution	RQ2, RQ4	"I delete the history, I disable the camera so they cannot take photographs. I checked everything on the computer before and after, to avoid unpleasant incidents".
Challenges and enabling factors	Infrastructure limitations; outdated equipment; unstable internet access; software incompatibility; time pressure; professional development; online learning communities; institutional support	RQ3, RQ4	"Most of the equipment in a public school is either old or even non-existent, so we bring our own laptops, or someone even carries a projector".

The findings show that teachers' accounts did not support a simplistic view of technology as automatically beneficial. Instead, teachers repeatedly treated digital technologies as conditional pedagogical resources. Their value depended on the clarity of learning aims, the degree of STEAM coherence, the availability of guidance, the organization of access, the management of group roles, and the ability to sustain the activity despite infrastructural or technical difficulties. The results also reveal several tensions. Teachers valued digital technologies, but resisted tool-centred instruction. They recognized the advanced digital abilities of some gifted students, but disagreed about whether these students should be assigned special technological roles. They supported equity but understood it differently across contexts, including access to devices, meaningful participation, differentiated support, ethical safety, and alternative learning pathways. These tensions are analytically important because they show that digital technology integration in Gifted STEAM Education is not only a technical issue, but also a pedagogical, relational, ethical, and organizational process.

4.1. Technological Proficiency and Digital Skills Goal-Setting

Teachers described technological proficiency as a prerequisite for the meaningful integration of digital educational technologies into Gifted STEAM Education. Technological proficiency was understood as the practical ability to operate, manage, select, and troubleshoot digital tools in relation to the learning task. It was therefore distinguished from a broader notion of digital competence, which also included critical, ethical, collaborative, and pedagogical uses of digital technologies. This distinction was visible in teachers' emphasis on explicit digital skills goals. Most participants did not view technological knowledge as a supplementary aid, but rather as a central dimension of instructional design that required clear expectations for tool operation, information search and evaluation, data analysis, representation of ideas, documentation of solutions, and the production of digital or multimodal artefacts.

This became especially evident in teachers' insistence that technology align with clearly articulated learning aims. As one participant stated, "I consider knowledge of technology essential for STEAM. At least the basics. Otherwise, it could not succeed". Another teacher observed that "we were emphasising the other subject areas in STEAM, but we were not setting equally clear goals for Technology. When children see a projector, but do not know how to use it, that is not a skill. We have to teach them specific things". These comments indicate that teachers did not regard the presence of a digital device as evidence of technology learning. Rather, they argued that Technology, as a component of STEAM, should include teachable and observable skills. In this sense, the findings directly address RQ1 by showing that teachers' attitudes towards digital technologies were positive but conditional: they valued technology when it was part of an explicit learning design.

Teachers also linked digital skills goal-setting with formative practices that made progress visible and supported differentiation. They reported devoting considerable time to explaining how tools should be used, distributing printed "User Guides" and "Materials Guides", and assigning more digitally experienced students the role of "technical assistant" when appropriate. These practices transformed digital skills from implicit expectations into visible participation thresholds. Students were not simply expected to use tablets, projectors, files, images, videos, or platforms independently. They were guided through staged procedures that helped them understand how a tool contributed to inquiry, design, documentation, or production.

The data also reveal a difference between teachers' general attitudes and their actual practices. In principle, teachers endorsed technology as essential for STEAM. In practice, they did not assume that students, including gifted students, could automatically use digital tools in a pedagogically meaningful way. This discrepancy is important because it prevents the interpretation of teachers' views as uncritical enthusiasm for technology. Teachers' practices show that they treated digital skills as teachable and assessable, yet unevenly distributed among students. This was particularly important in a mixed-ability context, where differences in readiness, age, reading ability, prior digital exposure, and confidence could affect participation.

Teachers' subject specialization also shaped how technological proficiency was interpreted. Participants with stronger ICT or STEM backgrounds tended to place greater emphasis on tool operation, technical preparation, troubleshooting, and the visibility of students' digital performance. Teachers with primary education or humanities backgrounds placed stronger emphasis on accessibility, instruction, communication, and the need to prevent digital tools from increasing cognitive load. These differences did not produce a simple opposition between technologically confident and technologically hesitant teachers. Instead, they showed that teachers evaluated technology through the priorities of their disciplinary and pedagogical background.

Overall, this theme shows that integrating digital technology into Gifted STEAM Education begins by clarifying what students are expected to learn through technology. Teachers' accounts suggest that technological proficiency should not be treated as a prerequisite possessed by some students and absent from others, but as a learning objective that can be scaffolded, monitored, and differentiated. This finding is directly relevant to RQ2 because it identifies explicit goal-setting for digital skills as a key parameter for meaningful integration.

4.2. Interdisciplinary Integration and Learning Differentiation

Teachers understood interdisciplinary integration as a process achieved when digital educational technologies functioned as cognitive and representational mediators connecting the STEAM fields through common objects, shared problems, multimodal artefacts, and forms of documentation. Technology was not treated merely as equipment used during the activity. It became relevant when it helped students move between observation, inquiry, design, artistic production, communication, and reflection.

The broader dataset illustrates this through teachers' descriptions of technology as a collaborative infrastructure across specializations and subject areas. One participant stressed that teachers from different disciplinary backgrounds needed to work together and ensure that their plans were "realistic and feasible". Another teacher described collaborative digital practice more concretely, stating, "We work with Drive. Everyone uploads what they want, and then someone else edits it afterwards. It is a great help". A third participant summarized the pedagogical value of such collaboration by noting that "when one learns a little from the other, that also helps the flow, especially when you co-teach". These comments indicate that digital technologies supported STEAM integration before classroom implementation, by enabling teachers to exchange material, revise resources, organise responsibilities, and coordinate disciplinary contributions.

The STEAM component became more visible when teachers discussed the learning scenario as a sequence of interdisciplinary tasks rather than as a general digitally supported activity. In the documentary-oriented scenario, Science was connected with environmental inquiry, observation, discussion of ecological problems, and the organization of evidence. Technology appeared both as a field of learning and as a practical medium through tablets, projectors, digital files, internet resources, image and video materials, and multimedia production. Engineering was less visible as a formal curriculum area, but emerged through design-based problem-solving, sequencing, technical configuration, material adaptation, and the need to make products and tools function under real constraints. The Arts were central through cinema, documentary thinking, image composition, music, visual communication, poster design, and aesthetic decision-making. Mathematics appeared more implicitly through sequencing, timing, proportionality, organization of information, and spatial or temporal structuring of the final product.

This uneven distribution across STEAM fields is a significant finding. The data do not show that all STEAM fields were always integrated with equal strength. Rather, they show that Technology and the Arts were the most visible dimensions of the learning scenario; Science was present through environmental inquiry; Engineering appeared mainly through design and problem-solving processes; and Mathematics was embedded more indirectly in organization, sequencing, and representation. This finding strengthens the analysis by showing that the STEAM component was not used as a decorative label. Instead, the data reveal both the possibilities and the limits of interdisciplinary integration in a real implementation context.

Teachers also pointed out that this interdisciplinary architecture favoured learning differentiation. Digital environments could provide multiple pathways of access to the same problem and allow adjustments in depth, pace, and mode of expression. The possibility of gradually increasing complexity, documenting ideas through multimedia, using image-based resources, and combining digital and non-digital products allowed students to progress at different rates without undermining the coherence of the shared task. One participant observed that "the use of screens helps children with learning difficulties a lot", while another described image-based platforms such as Pinterest as particularly helpful "for younger ages that cannot read texts, and for multilingual children". Technology was thus viewed not only as a bridge across disciplines but also as a means of making a shared project accessible through differentiated representational pathways.

At the same time, teachers did not suggest that differentiation could be achieved solely throughlely through d means. They repeatedly connected digital tools with printed materials, oral explanation, peer support, group roles, and teacher guidance. This combination is important because it shows that digital tools were part of a broader differentiated learning design. For gifted students, digital technologies offered opportunities for more complex inquiry, faster access to information, creative production, advanced documentation, and autonomous exploration. For non-gifted students or students who needed additional support, the same tools could offer visual scaffolding, multimodal expression, and more accessible routes into the task. The pedagogical challenge was to maintain a common high-level learning core while allowing students to contribute in different ways.

The findings also show that digital technology became more closely aligned with STEAM when it was tied to Teachers referred to operation checks, explicit quality criteria, printed guides, rotating technical support roles, and equivalent non-digital pathways as necessary conditions for maintaining both participation and coherence. The data therefore suggest that technology becomes an organic element of interdisciplinary learning when digital skills goals are clearly formulated and aligned with the logic of inquiry, design, and production. Conversely, when tool use is separated from these goals, digital activity risks becoming an isolated or decorative component of the lesson.

4.3. Equity, Guidance, and the Assessment of Digital Competences

Teachers described equity as a fundamental principle of instructional design in Gifted STEAM Education, but they did not use the term in a narrow or single-dimensional way. In their accounts, equity was understood to encompass at least four interconnected dimensions: access to devices and resources, meaningful participation in group work, differentiated support based on readiness, and safe or ethically appropriate use of digital tools. This broader use of the term helps explain why teachers sometimes discuss equity through the language of infrastructure, group roles, differentiation, and data protection or digital safety.

In practice, equity was expressed through the deliberate organization of access to devices, the allocation of roles within groups, and the avoidance of digital congestion. One teacher explained that "if they are older, I give one tablet to each group. If the children are very young, I would want more, because it is not easy for them to collaborate and talk over only one screen". Another argued in favour of one device per group because "it helps supervision and it helps everyone remain focused in one place". Additional teachers emphasised rotation and prior role assignment, suggesting that the tablet should "change hands" and that it should be decided from the beginning "who will do what and who will use the device". These comments show that equity was not reduced to the equal numerical distribution of technology. It was interpreted as a pedagogically managed balance between access, supervision, collaboration, role distribution, and meaningful participation.

Structured guidance was also understood as a bridge between the digital tool and the cognitive objective. Teachers stated that usage instructions should be incorporated into the educational material itself and that these instructions should make visible the relationship between each tool's functions and the demands of the activity. The broader findings reinforce this point by showing that teachers invested substantial time in explaining the use of tools, distributing printed support materials, and designating more experienced students as technical assistants to scaffold others' participation. The pedagogical value of these practices lies in their capacity to reduce cognitive friction and enable students to focus more productively on inquiry, collaboration, and creative production. Guidance was therefore described as a staged progression from demonstration to assisted practice and then to more autonomous performance.

In relation to monitoring progress, teachers placed particular emphasis on formative practices for assessing digital competence, making development visible, and guiding targeted interventions. The assessment of digital competence was not described as a separate test of technical ability. Rather, it was embedded in students' ability to participate in the STEAM task, use resources appropriately, contribute to group production, follow safety rules, and document or communicate ideas. This finding is important because it connects assessment with participation. Digital competence was evaluated through students' capacity to use tools meaningfully within an interdisciplinary and collaborative activity.

The data also reveal an important tension regarding the technological role of gifted students. One participant stated that "gifted children know better how to use the software", and another added, "I let the gifted child help the other one". Yet another teacher resisted assigning a special technological role to the gifted learner, explaining, "I would not do anything special regarding that role. It disrupts the balance of the group. We want equal access." These contrasting views indicate that teachers did not agree on whether the advanced digital skills of gifted students should be formalised as a support mechanism for the group.

This tension is one of the most analytically significant findings of the study. On the one hand, some teachers saw gifted students' digital proficiency as a resource that could support peer learning and accelerate group progress. On the other hand, other teachers worried that such role assignment could reinforce hierarchy, label students too visibly, or reduce equal participation. The issue was therefore not only technical. It concerned group balance, social positioning, peer relations, and the risk that differentiation might become a form of unequal responsibility. Teachers' concern with digital competence was therefore deeply pedagogical and relational.

The findings also indicate that equity in mixed-ability Gifted STEAM Education cannot be achieved by giving all students the same task in the same way. Nor can it be achieved by separating gifted students from the rest of the group. Teachers attempted to construct a common activity in which students could contribute through varying levels of readiness, support, pace, and expression. Digital tools were useful when they expanded these possibilities. They became problematic when they intensified differences in access, confidence, speed, or control over the final product.

4.4. Ethics and Data Protection as Principles of Use

Teachers emphasised that the integration of digital educational technologies into Gifted STEAM Education must be grounded in clear ethical principles and data protection standards, so that digital practice serves learning objectives without undermining rights, safety, or trust. Their accounts included references to clear rules of use, informed consent, data minimisation, access control, awareness of Creative Commons, file management, and restrictions on camera and microphone use. One participant explained, "I delete the history, I disable the camera so they cannot take photographs. I checked everything on the computer before and after, to avoid unpleasant incidents". Another stressed the importance of limits: "For technology to be integrated, they should not use the camera and microphone without permission, they should not enter inappropriate websites, they should not record others, and so on". These comments show that ethical use was experienced not as an abstract legal principle, but as a set of preventive routine practices embedded in the everyday management of digital learning.

Ethical practice was also linked to the specific character of the learning scenario. Because the activities involved digital files, images, video materials, possible recordings, shared resources, and public-facing artefacts, teachers had to consider how students would access, produce, store, and share these materials. This made ethics part of the learning design rather than a separate administrative requirement. Teachers' accounts suggest that ethical digital practice in Gifted STEAM Education includes explicit instruction on responsible use, teacher control over sensitive functions, careful device checks, and critical discussion of the reliability or appropriateness of generated and collected content.

According to teachers, ethical principles were directly linked to risk prevention, licensing, access control, and implementation resilience. This became especially evident in discussions of software licences, compatibility, and offline contingency planning. One teacher noted that "without software licences, you have operational problems, for example with Word. We were lucky to have them. If I had no other option, I would use whatever I had, some free tools. However, you have to search to find something of quality". The same participant added that "you have to check compatibility, find applications for the machine you actually have, and make sure everything works properly." At the same time, another participant recommended offline alternatives: "There are applications that do not need internet access, such as PowerPoint. If the internet went down, we had already prepared images and videos for the children. We had downloaded them beforehand". These statements show that responsible use also includes lawful access to software, appropriate infrastructure choices, compatibility checks, and protection from pedagogical disruption.

Implementation resilience emerged as a distinct practical concern. Teachers did not describe resilience only as improvisation in response to technological failure. They described it as preparation in advance: downloading files, preparing offline materials, using secure local storage, having alternative activities available, and creating equivalent non-digital pathways. Equivalent non-digital pathways were therefore not understood as inferior substitutes. They were part of an inclusive and resilient design that allowed students to continue working towards the same learning goals when digital access, digital readiness, or technical conditions were limited.

The ethical dimension also intersects with AI-related concerns. Teachers emphasized the need for clear restrictions on AI applications and personal data, as well as for a critical review of generated content rather than accepting it unreflectively. Although AI was not the study's central empirical focus, these references indicate that teachers were aware of emerging ethical issues related to digital authorship, reliability, data use, and student safety. The findings, therefore, suggest that Gifted STEAM Education requires ethical digital literacy alongside technical skill development.

A further analytical point concerns the relationship between ethics and equity. Teachers' accounts show that unsafe or poorly regulated digital use can create new forms of exclusion or vulnerability. Students with lower digital readiness may depend more heavily on peers, students with stronger digital skills may control the activity, and students' data or images may be exposed if rules are unclear. For this reason, ethical safeguards were also equity safeguards. They protected participation, clarified boundaries, and reduced the likelihood of avoidable risks from digital tools.

4.5. Challenges and Enabling Factors

Teachers acknowledged that the challenges involved in integrating digital educational technologies into Gifted STEAM Education concerned interrelated material, institutional, and pedagogical parameters. Their accounts vividly illustrated the pressure created by inadequate infrastructure. One participant observed that "if the school does not provide the means, it is not easy to achieve digital equity. We cannot expect the work to be done from home". At the same time, another highlighted differences by educational level, noting that in secondary education, students "have their own phones. I can very easily send them the material there or even conduct an electronic assessment through mobile phones". A more acute picture emerged in accounts from public schooling, where teachers reported that "most of the equipment in a public school is either old or even non-existent, so we bring our own laptops, or someone even carries a projector", and that they were constantly worried that "with all this moving around, the machines might break". Another teacher added that they "could not let anyone touch my laptop, neither children nor colleagues", while another described a lesson disruption caused by an outdated software version that would not play a video file. These excerpts show that resource inequalities are not abstract systemic problems, but material conditions that directly shape teachers' instructional decisions and students' access to technology-rich learning.

Teachers also pointed to operational fragility and time pressure as major constraints. One participant described the everyday reality of technological failure through a sequence of recurring problems: "Ah, the internet was not working. Ah, we did not have a good camera. Ah, we did not have a projector at that moment. Ah, we did not have the right cable". Another concluded that "in one school I had nothing, and I was forced to teach only on the board", while a third reported that "the whole school had only one projector", which had to be reserved in a notebook and could easily become a source of conflict. These examples suggest that technology integration was experienced as a continuous process of adaptation rather than as a stable condition already secured by the institution.

The relationship between infrastructure and teacher attitudes was complex. Teachers did not reject digital technologies because of these difficulties. Instead, they developed a more conditional and pragmatic orientation. They were willing to use digital tools when the tools were reliable, pedagogically meaningful, and manageable within available time and resources. However, repeated technical failures, equipment shortages, or the need to use personal devices created caution, anxiety, and reluctance to allow students or colleagues to handle the equipment. This finding helps explain why positive attitudes towards technology did not always lead to more extensive digital integration.

Differences between educational levels were also evident. Teachers with experience in secondary education referred to students' personal mobile phones as potential resources for communication, material distribution, or electronic assessment. Teachers working with younger students were more cautious because younger learners required more guidance, more supervision, and, in some cases, more devices to prevent passive observation around a single screen. These differences indicate that implementation cannot be separated from students' age, autonomy, reading ability, collaboration skills, and prior digital readiness.

Teachers also identified several enabling factors that strengthened sustainability and effectiveness. They considered targeted professional development, especially when focused on learning integration and formative assessment, to be essential for aligning goals, activities, and digital tools. They also identified participation in online learning communities, the exchange of experiences, access to model teaching materials, collaborative planning, technical preparation, and institutional support as important enabling conditions. The program's synchronous and asynchronous online environments supported communication, resource sharing, collaboration, and flexibility of timing. More broadly, teachers described a system in which training, planning, technical support, and institutional organization needed to work together. Institutional support, organised resource platforms, clear policy frameworks, stable funding, and school-level technical support were all presented as preconditions for reducing uncertainty and scaling implementation equitably.

The findings, therefore, show that enabling factors and challenges should not be treated as separate lists. They are mutually connected. Professional development can help teachers plan more effectively, but it cannot fully compensate for absent infrastructure. Digital tools can support differentiation, but only when access is organised and students receive guidance. Institutional support can reduce uncertainty, but teachers still need pedagogical judgement to align tools with learning goals. This interdependence is central to implementing digital technologies in Gifted STEAM Education.

4.6. Cross-Theme Synthesis by Research Question

The thematic findings can be synthesised in relation to the study's four research questions.

In relation to RQ1, teachers' attitudes, perceptions, and practices regarding the integration of digital educational technologies into Gifted STEAM Education were positive but conditional. Teachers perceived digital technologies as valuable when they supported inquiry, collaboration, documentary production, multimodal representation, differentiated access, and the development of digital competence. They did not treat digital technologies as inherently transformative. Their practices included the use of tablets, projectors, Google Drive, multimedia materials, video and image resources, digital file sharing, printed guides, technical assistant roles, peer support, and equivalent non-digital alternatives. The main discrepancy concerned the gap between valuing technology in principle and limiting its use in practice due to infrastructure constraints, time pressure, safety concerns, or group dynamics.

In relation to RQ2, the main parameters for integrating digital educational technologies into Gifted STEAM Education were pedagogical alignment, explicit goal-setting for digital skills, STEAM coherence, differentiated guidance, formative assessment, access management, ethical safeguards, and implementation resilience. Teachers' accounts show that integrating digital technologies is not simply a matter of tool selection. It requires decisions about what students should learn through technology, how the STEAM fields are connected, how students with different readiness levels participate, how digital competence is assessed, and how the activity continues when technical conditions fail.

In relation to RQ3, the main enabling factors were targeted professional development, collaborative planning, interdisciplinary co-teaching, online learning communities, access to shared resources, model teaching materials, technical preparation, reflective discussion, and institutional support. Teachers especially valued the program's collective dimension because it enabled them to exchange ideas, share responsibilities, and learn from colleagues with diverse subject specializations. This was particularly important in Gifted STEAM Education, where no single teacher necessarily possesses all the disciplinary, technological, pedagogical, and differentiation-related knowledge required by the learning scenario.

In relation to RQ4, the main challenges were inadequate infrastructure, outdated equipment, unstable internet access, lack of software licences, software incompatibility, limited devices, time pressure, use of personal equipment, fear of equipment damage, unequal access, and institutional ambiguity. These challenges did not simply create practical inconvenience. They shaped teachers' instructional decisions, limited the scale of digital integration, affected equity, and increased the need for backup plans. The findings, therefore, show that implementation challenges are simultaneously technical, pedagogical, institutional, and ethical.

Overall, the Results section shows that the study's empirical contribution lies in specifying how teachers negotiate the integration of digital educational technologies in a mixed-ability Gifted STEAM context. The findings do not merely repeat the general claim that technology can support learning. They show that, in this context, technology integration depends on the interplay among STEAM coherence, gifted education principles, differentiated participation, ethical safeguards, teacher collaboration, and the material realities of implementation.

5. Discussion

The findings of the present study indicate that teachers conceptualised digital educational technologies in Gifted STEAM Education primarily as pedagogical mediators whose value depended on instructional relevance, interdisciplinary coherence, differentiated participation, ethical safeguards, and implementation feasibility. This interpretation is important because it moves the discussion beyond a general claim that digital technologies are useful in education. The participants did not value technology for its novelty or technical sophistication, but for its capacity to support specific pedagogical functions within a mixed-ability Gifted STEAM learning context. These functions included inquiry, design, collaborative production, multimodal representation, formative monitoring, differentiated access, and the development of digital competences.

In relation to the first research question, teachers' attitudes towards digital educational technologies were generally positive but clearly conditional. They viewed digital tools as valuable when they supported the logic of the learning task, strengthened students' active participation, enabled documentation or production, and contributed to the integration of different STEAM fields. At the same time, they resisted a tool-centred understanding of educational technology. Their comments repeatedly indicated that the presence of devices, platforms, or software did not automatically produce meaningful learning. This finding is consistent with the literature that frames educational technology as effective when it is pedagogically aligned, carefully selected, and embedded in inquiry, scaffolding, and formative assessment [46], [47]. However, the present study adds that this alignment becomes more demanding in Gifted STEAM Education, because teachers must simultaneously address high cognitive challenge, interdisciplinary integration, and inclusive participation.

The distinction between attitudes, perceptions, and practices is also relevant here. Teachers' attitudes reflected a cautious openness towards technology. Their perceptions emphasised the need for purposeful design, explicit digital skills goals, ethical restrictions, and differentiated guidance. Their practices included the use of tablets, projectors, collaborative digital platforms, multimedia materials, video and image resources, digital file sharing, printed guides, peer support roles, and equivalent non-digital alternatives. This combination shows that positive attitudes did not necessarily translate into unrestricted digital use. Instead, teachers attempted to regulate technology use through guidance, role allocation, access management, and backup strategies. The discrepancy between enthusiasm for digital tools and caution about their practical use constitutes one of the most important findings of the study.

This understanding is supported by recent international literature on teachers' digital competence. Contemporary approaches move beyond a technocentric understanding of digital tool use and emphasise the pedagogically oriented integration of digital technologies, the development of critical thinking, and the use of digital practices that support measurable learning outcomes [58]. Teachers' professional digital competence is similarly conceptualised as an integrated set of knowledge, skills, and pedagogical practices associated with the design, implementation, and evaluation of learning across all stages of instruction [59]. In the same vein, the DigCompEdu framework and related studies identify digital competence as a distinct and assessable educational capability encompassing digital instructional design, digital assessment, and support for active learning through technology [60], [61]. The OECD also highlights that teachers' digital competence is validated through effective pedagogical use that benefits students, rather than through technological familiarity alone [54]. The findings of the present study support this position, but also suggest that digital competence in Gifted STEAM Education should be understood as an ecological competence distributed across teachers, students, tools, tasks, and institutional conditions.

In relation to the second research question, the main parameters for integrating digital educational technologies into Gifted STEAM Education were pedagogical alignment, explicit goal-setting for digital skills, structured guidance, STEAM coherence, access management, ethical safeguards, formative assessment, and implementation resilience. These parameters show that technology integration in this context is not merely a technical decision, but a complex pedagogical and organizational process. Teachers had to decide which tools were appropriate, how students would access them, how digital skills would be taught and monitored, how gifted and non-gifted students would collaborate, and how the learning activity would continue if technical problems emerged. In this sense, digital technology integration became a matter of instructional design, classroom management, ethical judgment, and contingency planning.

The STEAM-specific contribution of digital educational technologies became visible when teachers described technology as a means of connecting disciplinary practices within a common project. In the learning scenario, digital tools supported scientific inquiry through environmental observation, the organization of evidence, and discussion of ecological problems. Technology was addressed both as a tool and as an object of learning through the use of tablets, projection devices, video materials, file sharing, and multimedia production. Engineering was activated through design, assembly, testing, and problem-solving activities. The Arts were central through documentary production, image composition, poster design, music, cinema, and aesthetic decision-making. Mathematical reasoning was embedded in measurement, sequencing, proportionality, spatial organization, time planning, and the structuring of final products. Therefore, the role of digital technologies was not simply to make the activity more attractive. Their value lay in supporting movement from observation to representation, from representation to design, and from design to public communication.

This finding responds to a central concern in STEAM research: the risk that STEAM becomes a loose thematic label rather than a coherent interdisciplinary learning framework. Previous scholarship has emphasised that educational technologies in STEAM can enable modelling, simulation, design, and exploratory meaning-making in ways that make authentic problem-solving pedagogically feasible [49]. It has also shown that these tools may strengthen scientific creativity by allowing learners to compare hypotheses, test alternatives, and explore multiple solution pathways [50], while enhancing visualisation and real-world mathematical modelling in technology-rich STEAM contexts [51]. The present study extends this discussion by showing that, in mixed-ability Gifted STEAM Education, digital tools become STEAM-relevant only when they are embedded in a sequence of inquiry, design, creative production, and reflection. When digital tools were disconnected from this sequence, their contribution risked becoming merely operational or decorative.

The findings also show that teachers' subject specialization shaped their interpretation of technology integration. The ICT teacher tended to conceptualise technology as both a medium of differentiation and a field in which advanced problem-solving could become visible. The physics teacher placed stronger emphasis on representation, demonstration, and the explanation of abstract scientific ideas. The primary teachers emphasised guidance, participation, role distribution, and the affective management of mixed-ability groups. The philologist highlighted the social, communicative, and collaborative function of technology in shared production. The economics teacher was more cautious about equating Gifted STEAM Education with intensive digital use and stressed that technological thinking can also be cultivated through analogue design, construction, and authentic problem-solving. These differences indicate that technology integration is filtered through teachers' disciplinary identities and professional experiences. This point adds nuance to general models of teacher digital competence, which sometimes understate the extent to which subject background influences pedagogical interpretation.

The pedagogical value of technology use also emerged through its contribution to collaborative and organizational learning practices. Research in STEM education contexts highlights that digital technologies provide a framework for interdisciplinary collaboration, enabling the co-design of learning activities and the development of coordinated pedagogical practices among teachers from different disciplinary backgrounds [62]. Similarly, teachers' professional digital competence is associated with collaborative practices that jointly shape and co-construct the learning process [63]. Digital learning communities have also been shown to strengthen reflective skills, collaborative knowledge construction, and the implementation of diverse pedagogical approaches [64]. Contemporary research further suggests that digital platforms and collaborative digital tools enhance the exchange of teaching practices and foster cooperation through interdisciplinary activities [65], while the effectiveness of digital learning depends primarily on the collaborative pedagogical practices developed through technology use [66]. The present findings confirm these insights while specifying that collaboration is particularly important in Gifted STEAM Education, as the teacher must coordinate disciplinary content, differentiation, technological tools, ethical rules, and the management of heterogeneous student groups.

Regarding equity, the findings show that digital educational technologies can support inclusion and differentiation, but only under specific pedagogical conditions. Teachers did not support a segregated or elitist model in which technology serves only already high-performing learners. Instead, the study points towards a model of mixed-ability learning in which gifted and non-gifted students participate in a common high-challenge framework with multiple entry points, differentiated pathways, graded levels of support, and alternative modes of expression. This is especially important in the Greek context, where gifted education has historically been institutionally underdeveloped and often entangled in ideological tensions around excellence, equality, and inclusion [22].

The study, therefore, contributes to the conceptualisation of equity in Gifted STEAM Education. Equity did not refer only to equal access to devices. Teachers also used the term in relation to meaningful participation, structured role distribution, peer support, differentiated guidance, safe digital practice, and equivalent non-digital pathways. This broader understanding is consistent with the literature associating digital technologies with multiple forms of representation, engagement, and expression, which closely align with the principles of Universal Design for Learning [67]. In inclusive education, digital tools can facilitate the adaptation of content and learning activities to students' diverse needs [68]. At the same time, technology-supported environments can contribute to the personalisation of learning through knowledge representation modes that respond to the cognitive and developmental needs of younger learners [69]. Moreover, technology can enhance students' participation, regardless of diverse cognitive and linguistic backgrounds, by enabling differentiated access to knowledge and interaction with both the subject matter and peers in collaborative settings [70]. The present findings refine this literature by showing that, in Gifted STEAM Education, access and challenge must be designed together. Differentiation cannot mean reducing the complexity of the learning task for some students, nor can enrichment mean isolating gifted learners from the rest of the class. The pedagogical challenge is to preserve a common high-level learning core while providing multiple routes towards participation and expression.

A particularly important tension concerned the technological role of gifted students. Some teachers viewed gifted learners as potential peer supporters, especially when they demonstrated stronger digital skills or faster problem-solving. Others were cautious about assigning gifted students a special technological role, because such a role could reinforce hierarchy or disrupt group balance. This tension is theoretically significant. It shows that the advanced competences of gifted learners can become a collective resource, but only when role allocation is carefully managed. Otherwise, peer support may unintentionally reproduce unequal participation, where some students become technical leaders and others passive assistants. This finding adds a relational dimension to discussions of differentiation, since the issue is not only how the teacher adapts the task, but also how students' different abilities are socially organised within the group.

Another important interpretive dimension concerns teacher knowledge and professional development. The findings suggest that digital technology integration in Gifted STEAM Education emerges from the interaction of technological, pedagogical, and content knowledge. This helps explain why participants placed strong emphasis on guidance, technical support, co-teaching, preparatory planning, and reflection. The need for sustained support indicates that teachers' technological knowledge must continue to develop to be meaningfully integrated with pedagogy and disciplinary content during instructional design and implementation. This interpretation is closely aligned with foundational TPACK scholarship, which argues that meaningful technology integration requires context-sensitive pedagogical and curricular judgement [71]. It also resonates with empirical work showing that teachers often struggle to operationalise technological pedagogical knowledge in real educational settings without targeted preparation and support [72].

However, the present study also suggests that TPACK-oriented approaches require further specification when transferred to Gifted STEAM Education. In this context, teachers do not simply integrate technology into a single subject or standard lesson. They must connect multiple STEAM fields, design cognitively demanding activities, support gifted and non-gifted students within the same task, manage different levels of digital readiness, and respond to ethical and infrastructural constraints. Therefore, the integration of technology requires a context-sensitive, inclusive, and interdisciplinary form of technological pedagogical content knowledge. This interpretation constitutes one of the study's theoretical contributions.

Regarding the third research question, teachers identified several enabling factors that supported the integration of digital educational technologies. These included targeted professional development, collaborative planning, participation in online learning communities, access to model teaching materials, technical preparation, opportunities for reflection, and coherent institutional support. These factors helped teachers transform general positive attitudes towards technology into more deliberate pedagogical practices. The findings also underline the value of professional development programs that do not remain at the level of theoretical instruction, but include collaborative design, implementation, feedback, and revision. Such a structure appears particularly suitable for Gifted STEAM Education, where teachers need to coordinate gifted education principles, STEAM integration, digital tools, and differentiated learning. This finding can also be connected with broader research on readiness for technology-mediated learning, which suggests that self-directed learning, metacognitive awareness, and 21st-century skills are associated with readiness to engage effectively in online learning environments [73]. In the present study, this point is interpreted cautiously at the level of professional preparation and implementation readiness, rather than as a direct measurement of teachers' online learning readiness.

In relation to the fourth research question, the challenges identified by teachers operated at multiple levels. At the individual level, teachers' confidence, previous experience, subject background, and familiarity with digital tools shaped their practices. At the pedagogical level, implementation depended on the clarity of instructions, the coherence of the task, the availability of differentiated support, and the capacity to balance participation among gifted and non-gifted students. At the infrastructural level, outdated equipment, unstable internet access, lack of software licences, incompatibility problems, limited devices, and the need to use personal equipment shaped what could realistically be implemented. At the institutional level, ambiguity around responsibility, limited support structures, and the absence of a stable framework for Gifted Education in Greece created further uncertainty. These levels interacted with one another. For example, a teacher's willingness to use technology could be constrained by infrastructure, while a technically available tool could fail pedagogically if students lack guidance or the task lacks STEAM coherence.

The ethical dimension of technology integration is particularly important in this context. Contemporary literature emphasises that the increasing use of artificial intelligence and digital platforms raises challenges related to transparency, accountability, fairness, student autonomy, and the protection of personal data [74], [75]. In this regard, the use of digital tools in learning should be accompanied by the systematic cultivation of ethical practices and responsible data management [76]. The ethical use of educational technologies extends beyond privacy protection and also concerns the prevention of exclusion, the avoidance of new inequalities, and the assurance that technological applications enhance the learning experience in pedagogically justified ways [77], [78]. The present study confirms these concerns, but also shows that teachers experienced ethics as part of everyday classroom management. Their ethical practices included deleting browsing history, disabling cameras, restricting camera and microphone use, checking devices before and after activities, using safe file-transfer procedures, managing software licences, and preparing offline alternatives.

This practical understanding of ethics is important because it connects digital responsibility with implementation resilience. Teachers did not treat ethical practice as separate from lesson design. On the contrary, consent, safety, access control, data protection, licensing, compatibility checks, and backup plans were understood as conditions that allowed the learning activity to proceed safely and coherently. This is particularly relevant in Gifted STEAM Education, where students may work with open-ended tasks, online resources, multimedia production, AI-supported materials, and public-facing artefacts. The findings, therefore, suggest that responsible technology integration should be built into the architecture of the learning scenario rather than added as a general rule after the activity has already been designed.

The sustainable implementation of digital education also requires well-organised support structures, clear funding frameworks, and continuous technical and pedagogical guidance for teachers [54]. The development of institutional mechanisms for technical support, together with organised digital platforms and infrastructures, is considered a critical factor in reducing uncertainty and ensuring the equitable implementation of innovation within school environments [79]. Contemporary educational policy frameworks also indicate that stable funding, systematic teacher professional development, and strengthened school structures are essential prerequisites for the effective integration and use of digital technologies in education [80]. The present study supports this policy-oriented argument by showing that teachers' pedagogical intentions were often limited by infrastructural fragility and institutional ambiguity. In this sense, technology integration in Gifted STEAM Education cannot be reduced to a matter of teacher competence. It is also a question of institutional capacity and educational policy.

The theoretical contribution of the study lies in clarifying the role of digital educational technologies within Gifted STEAM Education as a mediating layer between high cognitive challenge, interdisciplinary learning, and inclusive differentiation. The findings suggest that technology integration in this field should not be understood only through general models of digital competence or educational technology adoption. In Gifted STEAM Education, digital tools acquire pedagogical value when they support enrichment, complexity, creative production, inquiry, differentiated access, and ethical participation. The study, therefore, extends existing discussions of digital competence, TPACK, and Universal Design for Learning by showing how these frameworks need to be adapted to a context in which gifted and non-gifted students participate in the same high-challenge learning environment.

The study also contributes to the conceptualisation of mixed-ability Gifted STEAM learning. It shows that inclusive participation does not require reducing cognitive challenge. Instead, it requires a design that combines a common demanding learning core with multiple entry points, flexible roles, scaffolded digital support, formative assessment, and equivalent routes to the same learning goals. This finding is significant because it challenges the assumption that gifted education and inclusion necessarily pull pedagogy in opposite directions. Within a carefully designed Gifted STEAM framework, enrichment and inclusion can function as complementary principles.

Overall, the discussion suggests that digital educational technologies can serve as a reliable component of Gifted STEAM Education when they are embedded within coherent pedagogical design, inclusive differentiation, ethical safeguards, and sustained institutional support. The novelty of the study does not lie in claiming that technology supports learning, differentiation, or collaboration. These claims are already well established in the literature. Rather, the contribution lies in showing how these general principles are interpreted, negotiated, and enacted by teachers in a specific mixed-ability Gifted STEAM context. The findings therefore provide an empirically grounded account of the conditions under which digital educational technologies can support interdisciplinary learning, equitable participation, and implementation resilience in Gifted STEAM Education.

6. Limitations and Future Research

The findings of this study should be interpreted in light of several limitations. First, the study involved a small purposive sample of six teachers. This sample was appropriate for the aims of an in-depth qualitative case study because the participants were information-rich cases who were directly involved in the professional development program, collaborative planning, implementation, reflection, interviews, focus groups, and observed activities. However, the sample does not allow for statistical generalization to the wider teacher population. The findings should therefore be understood as transferable insights grounded in a bounded educational case, rather than as representative claims about all teachers who integrate digital technologies into Gifted STEAM Education.

Second, the study was conducted within a specific annual professional development program on Gifted STEAM Education. The participants had already shown interest in educational innovation, STEM/STEAM Education, Gifted Education, and/or the pedagogical use of digital technologies. Their views and practices may therefore reflect a higher level of pedagogical readiness, motivation, and openness to innovation than those of teachers with limited prior experience or lower initial interest in these areas. This self-selection should be considered when interpreting the generally positive, although conditional, attitudes towards technology integration identified in the study.

Third, the implementation took place in a non-formal primary education context rather than in the everyday conditions of formal schooling. This setting enabled flexible implementation of an interdisciplinary, technology-rich Gifted STEAM learning scenario, but it may not fully reflect the constraints of ordinary school classrooms. In formal school settings, curriculum pressure, timetable limitations, assessment requirements, administrative routines, school policies, class size, and unequal access to technological infrastructure may shape teachers' opportunities for implementation in different ways. Further research is therefore needed in formal primary and secondary school environments to examine how similar practices operate under more institutionally regulated conditions.

Fourth, the study relied primarily on teachers' perspectives and observed practices. Although interviews, mini focus groups, observations, field notes, and textual documents were triangulated, the perspectives of students, parents, school leaders, and policymakers were not systematically examined. In addition, the study did not measure student learning outcomes, creativity, collaboration, digital competence, or socio-emotional development through independent assessment instruments. The findings therefore provide insight into teachers' interpretations and practices, but they do not establish causal claims about the effects of digital technologies on students' learning or development in Gifted STEAM Education.

Fifth, the researcher occupied a dual role as designer and facilitator of the professional development program and as collector and analyst of the data. This position provided close access to the case and supported contextual understanding, but it may also have influenced participants' responses or behavior through social desirability, reactivity, or awareness of being observed. The study addressed this risk through triangulation, systematic field notes, reflexive memoing, participant feedback on initial interpretations, and comparison across interview, focus group, observation, and document data. Nevertheless, the possibility of interpretive bias cannot be fully excluded.

Sixth, coding was conducted by the researcher rather than by multiple independent coders, and intercoder agreement was therefore not calculated. Analytical consistency was supported through iterative coding, the development of a coding index, repeated comparison across data sources, within-case and cross-case analysis, and the maintenance of an audit trail. Future studies could strengthen methodological rigor by involving multiple researchers in the coding process, comparing coding decisions, and documenting intercoder agreement or negotiated coding procedures.

Seventh, the study examined one specific learning scenario and one specific mixed-ability group. Although the scenario provided rich opportunities for analyzing technology integration, interdisciplinary STEAM learning, differentiation, equity, and implementation challenges, the findings may have been shaped by the particular theme, structure, tools, student composition, and professional development conditions of this case. Other Gifted STEAM scenarios, age groups, subject emphases, technological tools, or classroom arrangements may generate additional or contrasting findings.

Finally, the study did not examine the long-term sustainability of the practices developed during the program. It remains unclear whether teachers continued to use digital technologies in Gifted STEAM Education after the program ended, how their practices evolved over time, and whether similar approaches could be sustained without the support of a structured professional development environment. Longitudinal research is therefore needed to examine the durability, adaptation, and institutionalization of technology-rich Gifted STEAM practices.

Future research could extend the present study in several directions. Larger and more diverse participant groups would allow comparisons across subject specializations, educational levels, school types, geographical regions, and degrees of experience with Gifted Education, STEAM Education, and digital technologies. Studies in formal school classrooms would help clarify how curriculum demands, assessment systems, school leadership, infrastructure, and policy frameworks affect implementation. Comparative research across countries or educational systems would also be valuable for examining how different institutional approaches to giftedness, inclusion, teacher professional development, and digital education shape the possibilities of Gifted STEAM Education.

Future studies should also include students' perspectives and learning outcomes so that teachers' accounts can be examined alongside evidence of student engagement, collaboration, creativity, problem-solving, digital competence, and differentiated participation. The perspectives of parents, school leaders, teacher educators, and policymakers could further enrich understanding of the systemic conditions required for sustainable implementation. Finally, future research could examine the ethical dimensions of digital technologies and artificial intelligence in Gifted STEAM Education more explicitly, particularly in relation to data protection, transparency, access, authorship, student autonomy, and the equitable use of emerging technologies in mixed-ability learning environments.

6. Conclusion

This study examined teachers' perceptions and practices regarding the integration of digital educational technologies into Gifted STEAM Education within a mixed-ability learning context involving gifted and non-gifted students. The findings indicate that teachers understood digital technologies not as neutral additions to instruction, but as pedagogical mediators whose value depended on clear learning aims, interdisciplinary coherence, differentiated participation, ethical safeguards, and feasible implementation conditions. Meaningful integration therefore required deliberate design connecting digital tools with inquiry, creativity, collaboration, multimodal production, and differentiated learning pathways.

Teachers' attitudes towards digital technologies were generally positive but conditional. They valued digital tools when these supported authentic inquiry, collaborative project work, documentation, multimedia creation, communication, and creative expression, but resisted tool-centred uses disconnected from the learning activity. Their use of tablets, projection devices, collaborative platforms, multimedia resources, printed guides, peer-support roles, and non-digital alternatives showed that educational value arose from alignment among the tool, pedagogical purpose, student readiness, and intended learning outcomes rather than from technological novelty.

Equity emerged as a multidimensional design concern encompassing access to devices, meaningful participation, differentiated guidance, balanced group roles, digital safety, data protection, and alternative pathways when technical conditions or digital readiness were limited. Inclusive Gifted STEAM Education therefore did not require reducing cognitive challenge; instead, it required a shared high-challenge learning core supported by multiple entry points, flexible roles, scaffolding, formative monitoring, and equivalent routes towards common goals. Implementation also depended on the interaction among teacher agency, professional development, collaborative planning, infrastructure, and institutional support, while outdated equipment, unstable internet access, software incompatibility, limited licences, time pressure, and institutional ambiguity constrained what teachers could enact.

The study contributes by clarifying how digital technologies can mediate interdisciplinary inquiry, differentiated participation, ethical practice, and authentic production in a mixed-ability Gifted STEAM setting. It also extends discussions of digital competence, Universal Design for Learning, and Technological Pedagogical Content Knowledge by situating them within a pedagogical ecology that includes learner variability, group interaction, advanced cognitive challenge, ethical decision-making, and material implementation conditions. For practice, the findings support professional development that combines theoretical grounding, collaborative design, implementation, reflection, and ethical awareness, alongside stable infrastructure and coherent institutional support.

Because the study was based on a small qualitative case in a non-formal professional development context, its findings should be interpreted as analytically transferable rather than statistically generalisable. Future research should examine more diverse participants, formal school settings, different educational levels, student perspectives and learning outcomes, and the long-term sustainability of these practices through comparative and longitudinal designs. Overall, digital technologies can contribute meaningfully to Gifted STEAM Education when they are embedded in coherent pedagogical design, inclusive differentiation, ethical digital practice, and sustained institutional support; their value lies less in sophistication than in their capacity to support rich interdisciplinary learning and flexible participation for both gifted and non-gifted students.

DECLARATIONS

Author Contributions

Emmanouil D. Milakis: Conceptualization; Methodology; Investigation; Data Collection; Data Curation; Writing – Original Draft Preparation. **Constantina Corazon Argyrakou:** Validation; Theoretical Framework Development; Writing – Review & Editing. **Eleni Chantzouli:** Validation; Theoretical Framework Development; Writing – Review & Editing. All authors have read and approved the final version of the manuscript.

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Ethical Approval

This study was conducted in accordance with ethical standards. Approval was obtained from the Research Ethics Committee of European University Cyprus under approval number **2023.65**.

Informed Consent

Written informed consent was obtained from all human participants involved in this research. For studies involving minors, consent was obtained from both the participants and their legal guardians.

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Data Availability Statement

The data supporting this study's findings are not publicly available to protect the privacy of study participants. Summary data are included in the manuscript, and more detailed information can be requested from the corresponding author under strict confidentiality agreements.

Competing Interests

The authors declare that they have no competing interests related to the content of this article.

Generative AI and AI-Assisted Technologies Statement

During the preparation of this manuscript, the authors used ChatGPT 5.5 to assist with language editing. After using this tool, the authors carefully reviewed and edited the content to ensure accuracy and integrity, and they take full responsibility for the published work.

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