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# HIGH SCHOOL GRADUATES' PERCEPTIONS OF SPACE STUDIES IN FORMAL EDUCATION

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**Abstract:** Science, technology, engineering, and mathematics (STEM) subjects are a significant concern in educational systems worldwide. Students who learn these subjects acquire skills and knowledge that enable countries to develop advanced technological infrastructures in industry and academia, ultimately driving local and global economies toward a more advanced future. However, many countries have reported reduced student interest in STEM studies. While students become interested in STEM subjects after joining space education projects, these are often informal activities that occur outside schools. Space education allows students to explore several subjects simultaneously through a multidisciplinary approach and facilitates the development of important skills required in the knowledge-intensive industry and academia. Hence, this research aimed to analyze the perceptions and attitudes of high school graduates exposed to school-based space studies within the formal educational framework in relation to their motivation to undergo STEM studies and other pedagogical issues. The results reveal students' high degree of motivation to undergo STEM studies through space education, which is an expected but not obvious finding. As for the pedagogical aspect, the issues highlighted by space education include learning activities outside the classroom, the acquisition of skills, and the use of the project-based learning (PBL) approach.

**Key words:** high school graduate perspectives, multidisciplinary learning, space education assessment, STEM engagement

## 1. Introduction

Amid the ever-evolving educational landscape, the inclusion of space studies within the formal schooling system represents a significant stride toward integrating interdisciplinary approaches to learning. Space education, characterized by its unique combination of science, technology, engineering, and mathematics (STEM), not only captivates the imagination of young learners but also prepares them for the complexities of the modern world. Through its diverse contents, workshops, and activities, this educational paradigm seeks to deepen and reinforce students' engagement with STEM disciplines by leveraging the inherently fascinating field of space. The significance of such education extends beyond mere academic curiosity as it has been empirically linked to motivating students to pursue STEM studies at higher levels of education (Afful et al., 2020; Pujol et al., 2006). As we delve deeper into the intricacies of space education, it becomes evident that while the benefits are substantial, the challenges remain significant.

### 1.2 Literature review

Space education stands at the confluence of numerous scientific and technological domains, requiring a broad spectrum of knowledge that includes, but is not limited to, aeronautics, computer communication, astronomy, physics, biology, chemistry, and materials, electrical, electronic, and mechanical engineering. These disciplines are fundamental to the fields of space and aviation engineering, underscoring the necessity of well-rounded STEM education that supports the development of satellites, launchers, aircraft, and space probes (Isaacson et al., 2019). However, the

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multidisciplinary nature of space studies presents considerable teaching challenges within the formal education system, especially given younger students limited prior knowledge of physics, mathematics, and engineering. The complexity of integrating such a wide array of subjects into a cohesive educational experience can hinder the efficacy of space education, making it difficult for educators to impart comprehensive and comprehensible knowledge. Despite the growing attention to and the integration of space studies into educational curricula, a notable gap exists in terms of empirical research conducted to assess its impact. This scarcity of data points to a critical need for thorough investigations into how space education influences student outcomes, including their motivations, academic achievements, and subsequent engagement with STEM fields. Addressing this gap is essential not only for validating the assumed benefits of space education but also for identifying areas for pedagogical improvement and innovation (Afful et al., 2020).

Apart from individual educational outcomes, robust STEM education programs, particularly those incorporating space studies, have profound and multifaceted economic implications. Comprehensive STEM education has been recognized as a crucial driver of national and global economic development by fostering a workforce equipped with the necessary skills in STEM fields. According to the World Economic Forum, effective STEM education is essential not only for cultivating innovation and technological advancement but also for supporting sustainable economic growth and addressing complex global challenges, as outlined in the United Nations' 17 Sustainable Development Goals (SDGs, Schwab, 2020). These goals emphasize the importance of quality education, industrial innovation, and infrastructure development, all of which are intimately connected to robust STEM curricula. For example, advancements in clean energy, sustainable cities, and climate action (SDGs 7, 11, and 13, respectively) are directly reliant on the innovations and skills fostered through comprehensive STEM education (United Nations [UN], 2019). Thus, the integration of space studies within formal education systems prepares students for future careers in STEM by enabling them to acquire the capabilities to tackle these critical issues and ultimately contribute to economic sustainability and resilience.

The current research contributes to this rapidly growing field of study by offering a novel perspective: a retrospective analysis conducted from the view of high school graduates who have experienced space education within the formal education system. This approach provides a unique opportunity to evaluate the teaching processes involved and to assess their effectiveness through the lens of those who have directly benefited from or faced challenges with it. By capturing the insights of graduates, this study aims to shed light on the actual impact of space education and, in doing so, offer valuable feedback that can inform future educational strategies and policymaking.

Furthermore, the interconnection between space education and broader STEM competencies cannot be overstated. In an age where technological advancements and scientific knowledge form the backbone of the global economy, preparing students with the skills and insights required to navigate this landscape is paramount. By virtue of its ability to inspire and engage, space education plays a crucial role in this preparatory process. Specifically, it fosters a deeper understanding of fundamental scientific principles and cultivates critical thinking, problem solving, and innovative skills, which are essential for the workforce of tomorrow. Thus, evaluating the efficacy of space studies in enhancing STEM readiness among K–12 graduates is a critical aspect of the current research, which aims to provide a comprehensive understanding of how education in this field can serve as a catalyst for future success in an increasingly complex and technology-driven world (Isaacson et al., 2019).

An integral component of effective STEM education, particularly within the realm of space studies, is the presence of role models who can inspire and guide students. The existing research has underscored the profound impact of educators and professionals acting as role models on students' attitudes toward STEM disciplines. In particular, role models in STEM fields help demystify the pathway to STEM careers, enhance student interest, and improve self-efficacy among learners, all of which are critical for sustained student engagement in these areas (Cheryan et al., 2017). The impact of role models extends beyond mere academic motivation; in fact, they influence students' self-concept and broaden their career aspirations (Dennehy & Dasgupta, 2017). In the context of space studies, where interdisciplinary learning and innovative thinking are paramount, the role of educators as carriers of knowledge and exemplars of STEM applications becomes even more crucial. They not only convey

content but also embody real-world applications of that knowledge, thus playing a pivotal role in fostering a highly capable and diverse STEM workforce (Packard & Wong, 2018). Furthermore, the effectiveness of role models in STEM education has been linked to increased diversity within STEM fields. In particular, diverse role models representing different genders, races, and backgrounds can increase engagement in space studies among traditionally underrepresented student groups, potentially leading to more inclusive and equitable outcomes in STEM education (Smith et al., 2016). This aspect of role modeling is essential for developing a talent pool that can contribute to and thrive in a globally competitive economy.

Upon examining the broader impacts of STEM education, studies have shown that early exposure to STEM disciplines significantly influences students' interests and career paths in these fields. For example, the longitudinal perspectives provided by alumni surveys reveal that students who engage deeply with STEM during their K–12 education are more likely to pursue STEM-related degrees and careers (Maltese & Tai, 2011; Tai et al., 2006). These retrospective analyses underscore the pivotal role of implementing comprehensive STEM curricula in cultivating a robust foundational skill set among students, which is crucial for both academic success and workforce readiness. For instance, Tai et al. (2006) found that early interest in STEM, developed through engaging and interactive STEM education, predicts a higher likelihood of students obtaining a STEM degree and entering careers related to these fields. Further supporting these findings, Maltese and Tai (2011) highlighted the importance of active learning experiences in STEM, such as participating in science fairs and engaging in hands-on laboratory experiments, which are significantly correlated with sustaining students' interest and ensuring their success in STEM fields beyond their college years. Among others, these outcomes emphasize the need for dynamic STEM education programs in schools and highlight the critical nature of these programs in preparing students to meet the challenges of the modern technological and scientific landscape. By fostering an early interest in STEM and providing students with a solid foundation, educational institutions play a crucial role in shaping the future of our scientific and technological workforce.

The integration of space studies into formal education systems represents significant opportunities and challenges. Leveraging the inherent interest and potential of space education can enhance students' STEM learning and equip the next generation of scientists, engineers, and innovators with the necessary knowledge and skills. However, while such integration is promising, to be truly effective, this process must be driven by innovative teaching strategies and curricula informed by robust empirical research. In this regard, the current study's retrospective analysis of high school graduates' experiences and perceptions sheds light on the practical impact of space education. These invaluable insights offer guidance for refining educational practices and strategies that support the evolution of the educational framework. Such efforts contribute directly to preparing students not only for academic success but also for active participation in a global economy driven by scientific innovations and technological advancement. By addressing the pedagogical challenges and capitalizing on the motivational impacts of space studies, educators and policymakers can significantly enhance the alignment between educational outcomes and the competencies required by the UN's SDGs. Moreover, this research underlines the need for a sustained commitment to improving space education as a critical component of comprehensive STEM education initiatives, thus ensuring that future educational practices can meet the demands of an increasingly complex and technology-driven world.

## 2. Constructing the Research Framework: Problem Statement, Study Purpose, and Objectives

### 2.1 Problem statement (Knowledge gap)

Previous studies have described various types of informal space education offered by space agencies globally (Haubold, 2003). Evaluations of these informal education programs indicate that space education through such programs can rouse students' curiosity; motivate them to pursue courses in science, technology, or engineering; and eventually establish careers in these fields. These informal education programs have been positively viewed by science and technology teachers, who often utilize them to teach students about space (Khan et al., 2005). Despite the positive impacts of informal space

education programs (Thrash, 2004), their full potential has yet to be universally realized across all societal segments—a phenomenon that can be attributed to several factors, including the sporadic financing and localized availability of these programs. Many informal space education activities rely on funding that is not fully assured, thus affecting their sustainability and reach. Moreover, these programs tend to be concentrated in geographical areas that are often inaccessible to students in rural or underserved communities. There is also a widespread lack of awareness among broader audiences regarding these opportunities, further limiting their reach. Despite the significant advantages offered by these informal programs, the challenges they face (e.g., accessibility and financing) mean that space education has not yet been broadly integrated into formal education curricula. Indeed, the lack of formal education in this field is the principal reason for the general lack of knowledge about space education. Furthermore, the exposure (or lack thereof) of K–12 graduates to space education within the formal education system influences their decisions regarding their entry into the scientific technological labor market and, consequently, their future career paths. This underscores the need for a more systematic incorporation of space studies into formal education in ways that address the benefits and current limitations of informal space education initiatives.

### 2.2 Purpose of the study

The current research aims to investigate the perceptions and attitudes of K–12 graduates exposed to space studies through their schools' formal educational framework, analyze their relationship to students' motivations to undergo STEM studies, and assess other pedagogical outcomes in relation to space education.

### 2.3 Research goals and objectives

This study aims to systematically investigate the impact of space education on high school graduates by focusing on three core areas: attitudes toward STEM and space studies, self-efficacy, and pedagogical outcomes. By integrating quantitative assessments and qualitative insights, the research is structured around the following objectives: (1) to examine the effect of space education on high school graduates' attitudes toward STEM and space studies; (2) to assess the impacts of space education on high school graduates' self-efficacy; and (3) to evaluate the effects of space education on high school graduates in terms of learning methods, skills acquisition, and other pedagogical aspects.

## 3. Methodology

### 3.1 Participants

Using social media, space studies program coordinators distributed anonymous questionnaires to high school graduates throughout Israel via the formal education system. A total of 47 participants who were exposed to the topic of space in their schools completed the survey. Of these, 31 (66%) were male and 16 (34%) were female. Among the 47 participants, 32 (68.1%) reported having graduated from K–12 within the past three years, while 15 (31.9%) indicated that they had graduated more than three years ago. At the time of the survey, 26 participants (55.3%) either held a university degree or were currently pursuing university-level studies, whereas 21 (44.7%) had not yet engaged in university-level education.

### 3.1 Tools

A questionnaire was developed specifically for this study, following a structured process that began with a comprehensive literature review. The formulation of the questionnaire was further informed by insights gained from two focus groups of space educators currently employed within the formal education system. This preliminary stage was enhanced by in-depth interviews with four high school graduates who had participated in space studies during their K–12 education and subsequently chose to pursue STEM courses at the university level. The initial draft of the questionnaire went through an evaluation process conducted by a panel of experts, including two space teachers with over a decade of experience in the formal education system and two distinguished faculty members from the

university's engineering school. Their feedback was crucial in refining the questionnaire and developing an improved version. After this revision, the finalized questionnaire was distributed for data collection.

The finalized questionnaire for high school graduates consisted of three parts: Part A - Background Characteristics, Part B - Core Assessments, and Part C - Exploratory Queries. Part A collected essential information about the graduates, including their gender, the amount of time since they finished K–12 education, confirmation of their exposure to space content during their formal education, and their current educational level. Part B included four categories encompassing 23 Likert-scale questions designed to comprehensively evaluate the participants' perceptions of space education and its impacts. Each category targeted specific dimensions relevant to space studies within the school curriculum. Furthermore, the statements in each category were paired with their respective Cronbach's alpha values to indicate the internal consistency and reliability of the scales used. The response scale for each statement ranged from 1 ("never or almost never") to 5 ("very often"), with an additional option for respondents to mark the item as "not applicable" if the question did not pertain to their experiences.

Category 1: Stakeholders' Perceptions of Space Education (Cronbach's alpha = 0.752) assesses the perceived importance of space education among various stakeholders, including the Ministry of Education, students, parents, school administrators, and the graduates themselves. This category reflects the collective stance on the value of integrating space studies into school curricula. Sample statements were as follows: "As a school graduate, I get the impression that the integration of the field of space within the framework of the school is important [in the eyes of the Ministry of Education]" and "As a school graduate, I get the impression that the integration of space within the school is important [to the students]".

Category 2: Personal Impact and Satisfaction with Space Education (Cronbach's alpha = 0.824) examines the personal satisfaction experienced by graduates with space education and its impact, focusing on aspects such as meaningfulness, inspiration, enjoyment, personal security, and the ability to tackle difficulties encountered during their educational experiences. Example statements include the following: "As a school graduate, to what extent do you agree with the following statements: [I am satisfied that space studies are possible]" and "As a school graduate, to what extent do you agree with the following statements: [The lessons that dealt with space are full of meaning and purpose]."

Category 3: Educational Potential of Space Studies (Cronbach's alpha = 0.899) evaluates the perceived educational potential and impact of space studies, examining aspects including the capacity to inspire students, clarify scientific concepts, provide challenges, and enhance overall comprehension of the subject matter. Example statements include the following: "As a school graduate, how do you rate the potential of studying space at school in doing the following? [Inspire students to study space]" and "As a school graduate, how do you rate the potential of studying space at school in doing the following? [to explain scientific concepts or principles by conducting scientific experiments]".

Category 4: Pedagogical Approaches in Space Education (Cronbach's alpha = 0.640) reviews the effectiveness and relevance of various pedagogical methods used in the teaching of space education, focusing on research methods, information and communication technologies (ICT), and project-based learning (PBL). Sample statements include the following: "As a school graduate, how do you rate the potential of studying space at school in doing the following? [teach space through research methods]" and "As a school graduate, how do you rate the potential of studying space at school in doing the following? [teach space through ICT]." Notably, the statement, "As a school graduate, how do you rate the potential of studying space at school in doing the following? [teach space through working in groups]," was originally included in this category but was dropped during the analysis to improve reliability, raising Cronbach's alpha from 0.54 to 0.64.

Upon examining the correlations between the categories of the questionnaire, it was evident that each category contributed distinctively to our understanding of space education within the formal schooling system. Notably, Categories 2, 3, and 4 ("Personal Impact and Satisfaction with Space Education," "Educational Potential of Space Studies," and "Pedagogical Approaches in Space Education," respectively) exhibit significant intercorrelations ranging from moderate to high ($r = 0.57$ to $0.78$).

Such values reflect a substantial interconnectedness in how personal impact, educational potential, and pedagogical approaches relate to one another. In contrast, Category 1 ("Stakeholders' Perceptions of Space Education") shows no significant correlation with Categories 2 and 4, suggesting that stakeholder perceptions may operate independently from the personal and pedagogical aspects assessed in the questionnaire. However, there is a low yet significant correlation between Category 1 and Category 3 ($r = 0.368$), which could imply that while stakeholders' perceptions are somewhat related to the educational potential of space studies, they are not as closely aligned with personal satisfaction or pedagogical methods. These findings indicate that despite some overlap in the constructs measured by the questionnaire, each category largely captures a unique aspect of the space education experience. This result highlights the multifaceted nature of space education and its impact on graduates. Furthermore, it affirms the questionnaire's robustness as a measurement tool, demonstrating its capability to distinguish between different facets of educational experiences in space studies.

Part C of the questionnaire consisted of two open-ended questions aimed at augmenting the interpretation of the quantitative data: "Please provide a detailed description of a memorable event from your school's space studies program that has had a lasting impact on you" and "In your opinion, should space studies be incorporated as a compulsory subject within the formal education curriculum?" These questions sought to garner rich qualitative insights into the phenomenon being investigated to complement the numerical responses from the other sections of the questionnaire.

## 4. Results

To evaluate the efficacy of space education within the formal educational framework, a structured analysis of the high school graduates' responses was conducted. Such an analysis helped elucidate the participants' collective perceptions and attitudes regarding their experiences with space studies during their formal schooling years. The gathered data, as summarized in the table below, offer quantitative insights into the levels of satisfaction across different facets of participants' space education. These metrics provide a foundational basis for understanding the impact of space studies and inform subsequent discussions and conclusions drawn from the study.

**Table 1.** Mean scores of questionnaire categories

| Category | # | N | Mean | Std. Deviation |
|---|---|---|---|---|
| Personal Impact and Satisfaction with Space Education | 2 | 47 | 4.4529 | .80939 |
| Pedagogical Approaches in Space Education | 4 | 47 | 4.4255 | .72798 |
| Educational Potential of Space Studies | 3 | 47 | 4.4202 | .91353 |
| Stakeholders' Perceptions of Space Education | 1 | 47 | 3.5660 | .73582 |

The high mean scores in the categories of Personal Impact and Satisfaction, Pedagogical Approaches, and Educational Potential reflect a pronounced level of contentment and perceived benefits among the participants. These scores indicate the enriching experiences students attribute to their space education. Conversely, the category of Stakeholders' Perceptions reveals a need for greater engagement and value recognition among the key influencers and decision-makers within the educational sphere. In particular, this result underscores a potential area for strategic development and enhanced communication regarding the importance of effectively integrating space studies into the educational curriculum.

To determine the differences among the four categories, a one-way ANOVA with repeated measures was employed. The analysis yielded a significant main effect ($F(3,44) = 13.49$, $p < .001$), indicating that not all categories are viewed equally. Bonferroni-adjusted comparisons further reveal that the score for Stakeholders' Perceptions is significantly lower than those for the other categories, underscoring the variance in graduate satisfaction levels across different facets of space education. This specific finding also emphasizes the notion that while personal impact and pedagogical methods are highly regarded, the influence of stakeholders' perceptions is not held in the same esteem. Overall,

these results confirm that high levels of satisfaction among the participants are predominantly associated with the personal and educational potential aspects of space studies.

The comparative analysis of the categories highlights the unique role of each category and their varying degrees of influence on the participants' perceptions of their space education. The clear statistical significance of these results, as illustrated in Table 1, ensures that the observed differences are reliable and convey substantive distinctions in how they value each category. In subsequent analyses, the study examined the potential effects of two background characteristics on graduates' perceptions of space studies: gender and the time elapsed since their graduation. This study specifically examined whether attitudes toward space education varied between male and female graduates and whether these attitudes were subject to change over time, thus distinguishing between those who had graduated up to three years prior and those whose graduation was three years ago or more. As for gender, the statistical analysis did not show any significant differences between males and females, suggesting that gender does not have a notable influence on space education-related perceptions. Similarly, no significant change in attitudes was observed with respect to the time elapsed since graduation. This finding indicates that graduates' perceptions of space education remain stable over time and do not significantly vary, regardless of how much time has passed since they completed their studies.

## 4.1 The effect of space education on high school graduates' attitudes toward STEM and space studies

The open-ended questions from Part C of the survey significantly contributed to understanding the effect of space education on high school graduates' attitudes toward STEM and space studies, addressing the first goal of the study. Through the analysis of their responses, five main themes emerged, highlighting the benefits and concerns associated with space education.

**4.1.1. Value of space studies**. Graduates often praised the intrinsic value of space studies, noting it as a profoundly enriching field that significantly enhanced their knowledge base. One respondent exemplified this sentiment by remarking, "Yes, [it is] an interesting field that enriches you with a lot of knowledge." Such a statement not only reflects the perceived educational benefits but also implies that space studies are instrumental in fostering positive attitudes toward STEM disciplines.

**4.1.2. Academic achievement and recognition**. This theme surfaced frequently, with graduates recalling specific instances in which their accomplishments in space studies, such as presenting projects at significant academic events, were publicly recognized. "Presenting projects at the end of the 12th grade was exciting," mentioned one graduate, illustrating how such recognition could serve as a motivational force that deepens their engagement with and commitment to STEM disciplines.

**4.1.3. International and cultural exposure**. Responses under this theme underscored the global perspective and cultural insights offered by space studies. For example, a memorable account from a graduate involved traveling to Moscow for a space-related educational program: "I flew to Moscow with my major in order to learn about space." Such experiences not only broaden students' horizons but also enhance their understanding of space studies within a global context.

**4.1.4. Concerns about compulsory integration**. Despite the potential advantages, a notable apprehension existed regarding the mandatory inclusion of space studies in the curriculum. A typical concern was articulated by a student, who stated that it should be considered "…[n]ot as a compulsory subject because in order to learn the subject of space, the student is required to think outside the box." This reflects a fear that compulsory integration might not accommodate all learning styles or interest levels, potentially hindering rather than helping students.

**4.1.5. Optionality and student choice**. Aligning closely with concerns about compulsory study, many graduates expressed a preference for optionality in studying space-related subjects. As one respondent stated, they "[p]refer it to remain as an option," suggesting that giving students the autonomy to choose their subjects can lead to more personalized and effective learning outcomes. In addition, this theme directly relates to the present study's focus on evaluating educational methods and the

pedagogical aspects of space education, further emphasizing the importance of adaptability and student-centered learning approaches.

Overall, the abovementioned themes collectively demonstrate how space education influences graduates' attitudes toward STEM. Such themes reveal a general consensus on the value and benefits of space education, characterized by its ability to enrich students' academic lives, provide international exposure, and enhance their overall educational experience. However, mixed feelings about making space studies compulsory suggest a need for flexibility in curriculum design to better cater to diverse students' needs and preferences. The insights derived from these open-ended questions are instrumental in informing future educational policies and practices, particularly in optimizing the integration of space studies into current school curricula and maximizing student engagement and success in STEM disciplines.

### 4.2. The impacts of space education on high school graduates' self-efficacy

The open-ended questions explored the impacts of space education on high school graduates, particularly in terms of their self-efficacy, which is a critical component of educational outcomes, in accordance with this study's second goal. The responses revealed several themes that illustrate the profound effects of space studies on students' confidence and capabilities.

**4.2.1. Interactions with professionals and astronauts**. Many graduates recounted memorable interactions with space professionals and astronauts, which significantly enhanced their self-efficacy. One student vividly remembered "[m]eeting with an astronaut"—an experience that not only inspired them but also solidified their belief in their own potential in the field of space studies. Such interactions often serve as a catalyst for students, boosting their confidence and motivating them to pursue further education and careers in STEM fields.

**4.2.2. Integration with existing subjects**. Another prevalent theme is the potential integration of space studies with other academic subjects. The high school graduates suggested that space education should not necessarily be a standalone requirement but should be integrated with subjects, such as geography and physics, to enhance comprehension and relevance. For example, one graduate proposed, "Maybe not as a requirement but as an elective course; yes, it is important that it be combined with subjects like geography and physics." Such a statement indicates that this interdisciplinary approach could bolster understanding and increase the value of learning space-related content.

**4.2.3. Diverse student needs and interests**. The high school graduates also highlighted the diversity of students' needs and interests, suggesting that space education should be flexible enough to cater to different student groups. A typical response (e.g., "Not everyone connects; therefore no, but definitely invest in it as a quality extended profession") emphasizes the need for educational strategies in space studies to accommodate students' varying levels of interest and connection with the subject matter. This theme also suggests that, while space studies can significantly impact students' self-efficacy, its implementation should be tailored to ensure that it meets the wide range of student profiles and learning styles.

In summary, the abovementioned themes collectively reveal that space education plays a vital role in shaping high school graduates' self-efficacy by providing them with inspiring interactions, practical knowledge integration, and tailored educational opportunities that resonate with their diverse needs and interests. The findings also underscore the necessity of employing a strategic approach in incorporating space studies into the formal education system, thereby broadening students' academic horizons and enhancing their confidence and preparedness for future academic and professional endeavors in STEM fields. This nuanced understanding helps meet the current study's goal of evaluating the pedagogical impacts of space education, particularly in terms of enhancing students' self-efficacy, while providing a strong basis for subsequent analyses related to the additional study goals.

### 4.3 Evaluating the effects of space education in terms of learning methods, skills acquisition, and other pedagogical aspects

The analysis of open-ended questions revealed significant insights into the effects of space education on high school graduates in terms of learning methods, skills acquisition, and other pedagogical aspects. These findings align with the study's third goal of evaluating the educational practices associated with space studies and their impacts on students' preparedness in STEM fields.

**4.3.1. Experiential learning and excursion activities**. Experiential learning through educational trips and industry visits plays a crucial role in enhancing students' understanding of and interest in space studies. In their responses, the participants frequently highlighted the educational value of real-world exposure to space technology and environments. For example, one respondent vividly described a visit to an aerospace industry facility: "An excursion to the aerospace industry to see the Bereishit spaceship before it went to space provided a tangible connection to theoretical knowledge and significantly boosted my interest and understanding of space science." Such experiences not only reinforce theoretical knowledge but also stimulate students' curiosity and lasting interest in the sciences.

**4.3.2. Project-based learning and competitions**. Participation in space-related projects and competitions is another theme that emerged as highly impactful. These activities integrate theoretical learning with practical applications, thus enhancing students' engagement and knowledge retention. A graduate's recollection of "Participating in the Space Olympics in the 6th and 9th grades" exemplifies how PBL and competitive events can excite and motivate students. The use of the PBL approach in space studies encourages collaborative learning, critical thinking, and the application of science and mathematics in solving real-world problems, which are essential skills in any STEM field.

**4.3.3. Classroom learning and curriculum integration**. The foundational role of classroom learning in introducing and elucidating complex scientific concepts, such as the states of matter, including plasma, was also underscored by the high school graduates. As one student shared, "I remember the first time we discussed the states of aggregation in science class; discovering plasma was a revelation." Such educational moments are pivotal in shaping students' perspectives and understanding of science, thereby demonstrating the importance of a robust curriculum that effectively integrates space studies to enrich the standard science education framework.

**4.3.4. Synthesis of pedagogical impact**. These thematic insights from the high school graduates articulate a clear and impactful narrative on the pedagogical advantages of incorporating space studies within the K–12 education system. The hands-on learning experiences, coupled with the stimulation provided by projects and competitions, not only make learning more interactive and enjoyable but also strengthen students' scientific knowledge and problem-solving skills. Furthermore, the effective integration of space studies into the regular curriculum can enhance conceptual understanding and open up new realms of inquiry for students, which are crucial for fostering a skilled and knowledgeable future workforce in STEM.

In general, these findings collectively affirm that space education significantly enhances the educational landscape by providing diverse learning experiences that promote greater engagement and comprehension among students. The integration of interdisciplinary and experiential learning methods into school curricula is essential for developing students' competencies in STEM fields, ultimately preparing them to meet the challenges of the future. This comprehensive understanding of the impact of space education also highlights the need for educational strategies that are adaptable, innovative, and inclusive, thus ensuring that all students benefit from the rich educational potential offered by well-designed space studies. These observations will guide future educational policies and curriculum development efforts aimed at integrating space studies more holistically within the formal education framework. In turn, this can help maximize students' engagement, learning outcomes, and readiness for higher education and careers in STEM.

# 5. Discussion

## 5.1 Overview of the findings and integration with the literature

This study comprehensively explored the impact of formal space education on high school graduates' attitudes toward STEM disciplines, unveiling several critical insights that contribute to the existing literature. In particular, the overall high scores across the categories of Personal Impact and Satisfaction, Educational Potential, and Pedagogical Approaches (M = 4.45, 4.42, and 4.43, respectively) confirm that the integration of space studies into existing school curricula profoundly enhances student experience and engagement with STEM fields. These findings are consistent with Isaacson et al. (2019), who highlighted the multidisciplinary nature of space studies as a pivotal element in fostering comprehensive understanding and skills acquisition in STEM areas. In contrast, the lower scores in Stakeholders' Perceptions (M = 3.57) suggest a critical area for improvement. In particular, such a disparity may indicate potential misalignments between educational policy implementations and stakeholder expectations or a lack of awareness about the benefits of space education among wider educational communities. This finding aligns with Haubold's (2003) observations regarding the sporadic adoption and support of space education initiatives across different regions as well as suggestions of how enhanced stakeholder engagement and clearer communication of the benefits of space studies could bridge this gap. These insights also resonate with the concerns expressed by Pujol et al. (2006), who recommended scaling up space science education to capitalize on its motivational impacts on students' pursuit of STEM careers. Furthermore, Afful et al. (2020) emphasized the role of space education not just in sparking initial interest but also sustaining engagement through high-quality, inspiring educational practices that align with students' needs and curricular goals.

## 5.2. Implications

**5.2.1 Educational policy and curriculum design.** The strong endorsements of the personal impact and educational potential of space studies by the participants in the current study suggest that these programs significantly contribute to students' academic and personal development. This finding corroborates the study of Fraknoi and Roberts (2017), who showed that engaging projects within space studies (e.g., the Eclipse Megamovie Project) can significantly enhance public and educational engagement with science. Therefore, policymakers in the field of education should consider these findings and advocate for the incorporation of space studies into mainstream curricula, ensuring that such programs are comprehensive, continuously evaluated, and aligned with both national education standards and global scientific competency requirements.

**5.2.2. Teacher training and professional development.** As highlighted by the high scores in this category in the current study, pedagogical approaches play an important role in enhancing the effectiveness of space education. Thus, teacher training should focus on equipping educators with the necessary knowledge and skills to help them effectively integrate space science into their teaching practices. This should include professional development in multidisciplinary approaches, the use of ICT, and the application of PBL methods, which are critical for the successful delivery of complex STEM subjects (Slater et al., 2015).

**5.2.3 Role of stakeholders.** The comparatively lower scores for Stakeholders' Perceptions indicate a need for improved advocacy and communication that highlight the value of space education. Stakeholders at all levels, including educational authorities, school administrators, and parents, must be better informed about the significant benefits of space education, which in turn, could enhance their support and engagement with these programs. This approach aligns with the study of Smith et al. (2016), who discussed the importance of having diverse role models in STEM education to attract more diverse students and ensure equitable educational opportunities.

## 5.3. Future research directions

This study underscores the necessity of conducting continuous research to further explore the longitudinal impacts of space education on student outcomes, including their career trajectories and

interest in advanced STEM fields. Longitudinal studies could provide deeper insights into the sustained effects of early STEM engagement, as highlighted by Tai et al. (2006) and Maltese and Tai (2011), who found that early interest and engagement in STEM subjects significantly predicted continued involvement and success in these fields in later educational stages.

In summary, the integration of space studies into formal education holds substantial promise for enhancing student engagement and achievement in STEM fields. By addressing the pedagogical and stakeholder-related challenges, as well as bolstering the role of space studies in school curricula, educators and policymakers can significantly enhance the educational landscape. In this way, they can prepare students for academic success and help them with active and informed participation in the increasingly complex technological world. This study offers a foundational step toward understanding the multifaceted impacts of space education and paves the way for its broader integration into educational systems worldwide.

## 6. Conclusion

This study represents a novel contribution to the field by analyzing the impacts of space education through the retrospective insights of high school graduates, thus providing a unique vantage point that has seldom been explored in previous research. The study's findings confirmed the substantial benefits of integrating space studies into formal educational systems, which extend well beyond enhancing student engagement and performance in STEM fields. Apart from the identified benefits, they also foster a comprehensive understanding and appreciation of space science among students, potentially inspiring future educational pursuits and career paths.

The analysis also revealed consistently high scores across Personal Impact, Educational Potential, and Pedagogical Approaches (mean scores of 4.45, 4.42, and 4.43, respectively), underscoring the effectiveness of space education in boosting student interest and involvement in STEM disciplines. These findings align with those of Isaacson et al. (2019), who emphasized the interdisciplinary nature of space studies, which is essential for developing a robust set of skills in STEM areas. In comparison, Stakeholders' Perceptions scored relatively lower (mean score of 3.57), highlighting a critical area for improvement. This finding also suggests a gap between the potential benefits of space education and its recognition and value among educators, parents, and policymakers, thus indicating the need for enhanced advocacy and communication efforts to more comprehensively integrate space studies into formal school systems.

Moreover, the enduring nature of space education's impacts, as reflected in the students' consistent perceptions regardless of the time elapsed since graduation, suggests that these educational experiences have a long-lasting influence on their educational and professional trajectories. This enduring impact substantiates the need for sustained efforts to integrate space studies into STEM curricula, thus preparing students to meet future challenges in a technologically advanced society.

### 6.1. Strategic implications

**6.1.1. Curriculum integration**. Space studies should be integrated within the STEM curriculum through interdisciplinary, hands-on and project- and inquiry-based learning experiences. This approach can help contextualize space science within the broader framework of STEM education, enhancing both curriculum relevance and student engagement (Fraknoi & Roberts, 2017).

**6.1.2. Stakeholder engagement**. The use of improved communication strategies to enhance stakeholders' perceptions is critical. This involves organizing informational sessions, workshops, and seminars that effectively communicate the benefits and essential roles of space education in fostering critical and innovative thinking capabilities among students.

**6.1.3. Professional development**. Prioritizing the professional development of educators is crucial in effectively delivering space-related content. Furthermore, training should focus on multidisciplinary approaches and the integration of modern educational technologies and methods, which are essential for the comprehensive teaching of complex STEM subjects (Slater et al., 2015).

**6.1.4. Continuous research and evaluation**. There is also a need to conduct ongoing research to assess the long-term effects of space education on student outcomes, including career aspirations and interests in STEM fields at higher educational levels. Future research should include longitudinal studies that can provide deeper insights into the sustained impacts of early STEM engagement (Tai et al., 2006; Maltese & Tai, 2011).

In conclusion, the findings of this study advocate for a robust integration of space studies into formal education to comprehensively enhance student engagement and achievement in STEM fields. By addressing the educational, pedagogical, and stakeholder-related challenges highlighted in this work, space education can be optimized to better serve educational systems and societal needs, specifically in terms of preparing students not only for academic success but also for active participation in a global economy driven by scientific innovation and technological advancement. Finally, the innovative retrospective approach of this study offers foundational insights into the multifaceted benefits of space education, paving the way for its broader adoption and integration into educational frameworks throughout the world.

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