NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY POLITEHNICA BUCHAREST

DOCTORAL SCHOOL OF ENTREPRENEURSHIP, BUSINESS ENGINEERING AND MANAGEMENT

SUMMARY OF THE DOCTORAL THESIS

A conceptual framework for the early identification of weak STEM signals: Applications and implications in choosing an engineering career

Doctoral supervisor,

Prof. Dr. ing. SCARLAT Cezar

PHD student,

PÎRVU (GRIGORESCU) Florentina Alina

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List of abbreviations

2D	*Two-Dimensional*
3D	*Three-Dimensional*
ADHD	*Attention-Deficit/Hyperactivity Disorder*
AI	*Artificial Intelligence*
ANFR	*Agriculture, Food, and Natural Resources Education*
CBE	*Competency-Based Education*
EPCOT	*Early Preschool Children Observation Tool*
EWS	*Early Warning Indicators*
IRT	*Item Response Theory*
IT	*Information Technology*
LMS	*Learning Management System(s)*
MBTI	*Myers–Briggs Type Indicator*
PBL	*Problem-Based Learning*
RA	*Augmented Reality*
REMA-Full	*Research-based Early Mathematics Assessment*
REMA-SF	*Research-based Early Mathematics Assessment Short Form*
RIASEC	*Realistic, Investigative, Artistic, Social, Enterprising, Conventional*
RV	*Virtual Reality*
SCCT	*Social Cognitive Career Theory*
SSRP	*Summer Student Research Program*
STEM	*Science, Technology, Engineering and Mathematics*
STEMi	*STEM Identification Instrument*
TEMA	*Early Mathematics Ability Test*
TIC	*Information and Communication Technology*
URM	*Underrepresented Minorities*
VET	*Vocational Education and Training*
W-GCTA	*Watson–Glaser Critical Thinking Appraisal*

List of figures

Figure 1. The logical structure of the doctoral research: questions, objectives, and empirical studies ……..……..... 9

Figure 2.1. Domains where weak signals are used ……..……...……. 11

Figure 3.1. Stages of early identification of weak STEM signals ….……....……. 14

Figure 4.1. Research methodology (diagram)...……....……. 15

Figure 4.2. Conceptual framework for identifying weak signals of STEM aptitudes ……..……..……..……..……. 15

Figure 5.1. Logical structure of the doctoral research: Pilot study on 8th-grade students …. 16

Figure 6.1. Logical structure of the doctoral research: Pilot study on 12th-grade students … 19

Figure 7.1. Logical structure of the doctoral research: Pilot study on university students ……...…….. 21

List of tables

Table 1. Correspondence between research questions and doctoral research project objectives ……..……. 7

Table 3.1. Psychometric tests and variables that may indicate weak STEM signals ……..… 13

Table 8.1. Link between research questions, achieved contributions, and degree of objective fulfillment …….……..……..……... 23

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INTRODUCTION

This work focuses on the early identification of weak STEM (science, technology, engineering, mathematics) signals and leveraging them in guiding young people toward engineering careers, considering the context of economic, technological, and social transformations in contemporary society. The rapid pace of technological development generates a high demand for STEM specialists, highlighting the need to strengthen the educational system—particularly regarding career guidance and counseling for youth—in order to effectively discover and support their vocations.

The originality of this thesis lies in introducing the concept of the weak STEM signal as a key determining factor in the early orientation of students toward engineering careers. The main objective of this study is to develop a conceptual framework applicable to the Romanian educational system aimed at the early detection of indicators of interest, aptitude, and potential. This framework serves to enhance the efficiency and personalization of academic and career guidance in alignment with students' needs and interests, as well as the actual requirements of society and the labor market.

Table 1. Correspondence between research questions and doctoral research project objectives

No.	Research Questions	Research Objectives	Research Methods	
			Secondary (Theoretical)	Primary (Applied)
1.	How does technological education influence the youth career guidance process?	**O1.** Highlighting the role and impact of technological education on the youth training and orientation process.	Review of the literature *(Theoretical Purpose)*	-
2.	How can the concept of the weak STEM signal be defined and operationalized in an educational context?	**O2.** Defining the theoretical framework regarding the concept of weak STEM signals and early warning systems.	Review of the literature *(Theoretical Purpose)*	-
3.	What methods and tools can be used in the process of early identification of weak STEM signals in the educational system?	**O3.** Establishing a set of methods and tools useful for the early identification of weak STEM signals.	Review of the literature *(Applied Purpose)*	-
4.	How can a conceptual framework for the early identification of weak STEM signals be grounded and structured to guide students toward engineering careers?	**O4.** Proposing a conceptual framework for the early identification of weak STEM signals aimed at guiding students toward an engineering career.	Review of the literature *(Theoretical and Applied Purposes)*	-
5.	To what extent can weak STEM signals support	**O5.** Highlighting how weak STEM signals can	Review of the literature	Survey, descriptive

	the educational and career guidance process for school and university students?	support the educational and career guidance of school and university students.	*(Theoretical and Applied Purposes)*	analysis *(Applied Purpose)*
6.	To what extent is the proposed instrument applicable and useful for the early identification of weak STEM signals in the Romanian educational system?	**O6.** Proposing and evaluating the applicability of a tool for the early identification of weak STEM signals.	-	Survey (pilot validation), descriptive analysis *(Applied Purpose)*
7.	How do high school students' perceptions of the engineering profession influence their interest and orientation toward a future engineering career?	**O7.** Analyzing high school students' perceptions of the engineering profession and highlighting their influence on orientation toward an engineering career.	Review of the literature *(Theoretical Purpose)*	Survey, descriptive analysis *(Applied Purpose)*
8.	What are the main factors influencing university path choices and students' orientation toward engineering careers?	**O8.** Highlighting the factors that influence the choice of university path and students' orientation toward an engineering career.	Review of the literature *(Theoretical Purpose)*	Survey, descriptive analysis *(Applied Purpose)*
9.	What recommendations can contribute to improving the process of early identification of STEM potential and guidance toward engineering careers?	**O9.** Formulating a set of recommendations to improve the process of early identification of STEM potential and educational/career guidance toward an engineering career.	Literature synthesis *(Applied Purpose)*	Leveraging the results of empirical studies *(Applied Purpose)*

Source: *Author*

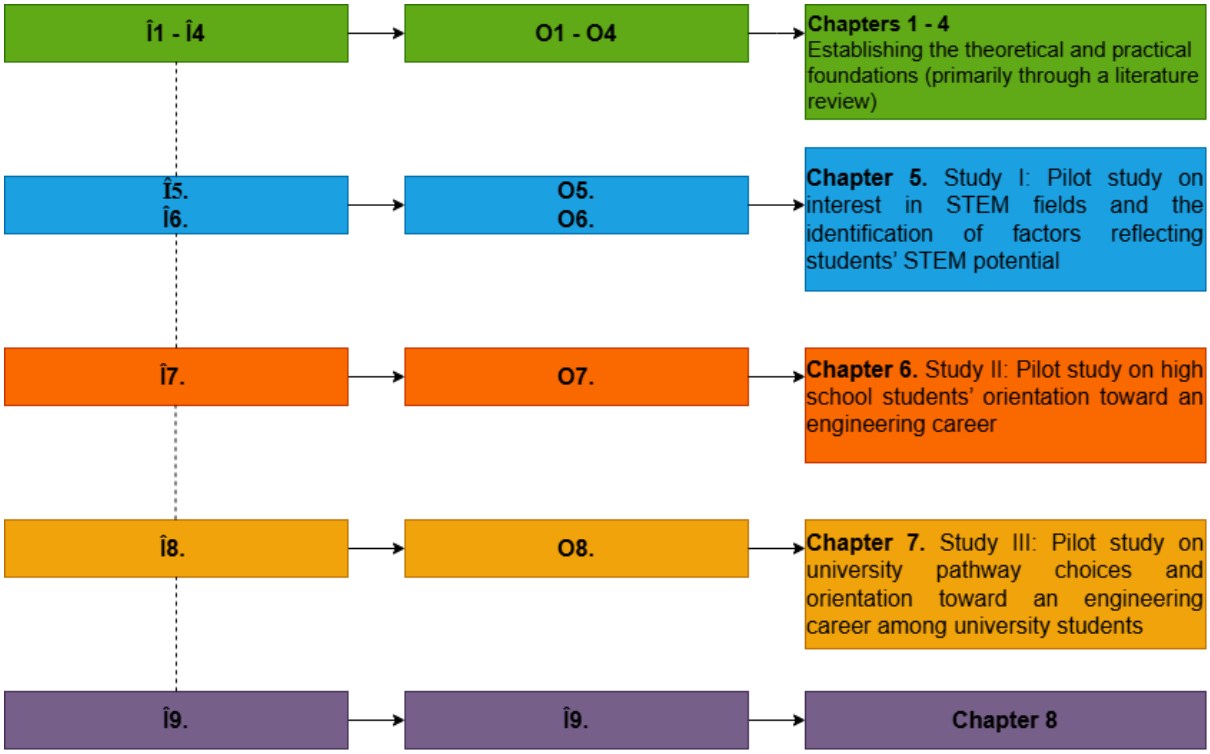


Figure 1. The logical structure of the doctoral research: questions, objectives, and empirical studies

Source: *Author*

Chapter 1 – Context of the study: Educational technologies and technological education

1.1. Technological transformations and their impact on education

> *With the sudden transition to online schooling for all educational institutions in 2020, the entire education system underwent major changes. The pandemic caused by the novel coronavirus forcibly introduced digital technologies into the teaching-learning-assessment process worldwide. Despite the fact that teachers and students were not sufficiently prepared for exclusively online learning, they managed to adapt, overcome the challenges posed by the online environment, and utilize numerous applications, websites, and communication platforms in a relatively short period* (Pîrvu, 2022, p. 343).

Digital technology has transformed all relationships within the school environment. With the help of digital platforms, teachers and students engage with tools that support informal conversation, reflective dialogue, and collaborative work, allowing access to a wide range of ideas and representations (McLoughlin & Lee, 2010).

The digital transformation of society and the rapid development of technologies offer countless opportunities, including in education. It is important that the ethical dimension of digitalization and AI be taken into account. Digital technologies must serve as a tool to provide quality education accessible to all, and the need for digital skills will grow in the future, which must be reflected in the school curriculum (Girigan, 2021).

1.2. Educational technologies and new learning paradigms

In the current context, characterized by the rapid evolution of the digital society and the extensive integration of technologies into the educational environment, the learning process takes on new dimensions and restructures itself according to the new available tools and resources. Educational technologies become essential elements that influence how students interact with information, collaborate, learn, or assess their knowledge.

Scarlat (2021) argues that the educational system is currently at a critical juncture, and the role of the teacher must shift from being a repository of knowledge to being a qualified expert, explorer, and identifier of knowledge. In the future, teachers will continue to exist, but in a different role. First and foremost, they must be familiar with new teaching technologies (including AR – augmented reality, AI – artificial intelligence, VR – virtual reality) and teach students how to use them.

1.3. Benefits, limitations, and challenges of using technology in education

Aleksandrova et al. (2021) state that the effective and pedagogically balanced use of digital technologies can help students, including those with disabilities, to actively engage in the teaching-learning-assessment process and develop individualized educational strategies tailored to their needs.

A study conducted by Tokarska et al. (2020) highlights a series of advantages of using technology in education, such as the formation of skills and abilities necessary for creative activities, the ability to send and receive information quickly, objectivity in assessment, the development of skills and competencies, the intensification of the learning process, and the involvement of students in research activities. Regarding the disadvantages, the same authors list: the lack of digital devices among both students and teachers, teacher workload/overload, lack of digital literacy, the difficulty of integrating digital technologies into lesson structures, and the absence of physical interaction.

Chapter 2 – Theoretical Framework on the Early Identification of Weak STEM Signals

2.1. The concepts of "weak signal" and "early warning"

Weak STEM "signals" are represented by early warning indicators of a behavioral, cognitive, and attitudinal nature. These may be subtle or inconsistent, suggesting a potential vocational orientation toward the sciences without explicitly representing specific career decisions or well-defined vocational interests. "Weak signals appear daily, but we fail to observe their significance," states Kerin (2023).

Weak signals are not merely *"weak evidence of changes to come,"* ready to be uncovered by experts who are sufficiently prepared to observe them (Rossel, 2012). These "weak signals" can be observed as manifestations of individuals' curiosity about specific technical or scientific phenomena, preferences for activities involving experimentation and exploration, or the desire to investigate how certain devices or technologies function.

Early Warning Systems (EWS) take into account multiple data sources to provide timely information to stakeholders. These are also used to identify students who are at risk and require academic support. In the literature, the warning process is described in three stages: (1) signal perception, (2) signal interpretation, and (3) signal enactment as a result of interpretation (van Veen & Ortt, 2021).

2.2. The concept of weak STEM signals and the importance of associated early warning systems

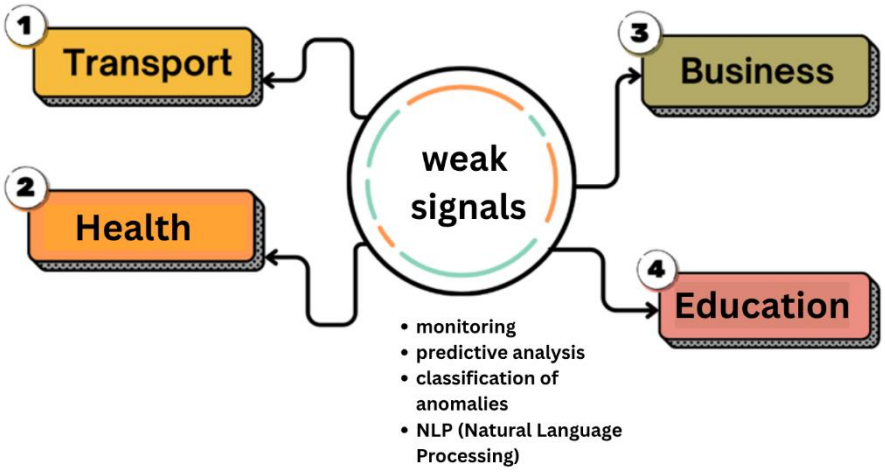


Figure 2.1. Domains where weak signals are used

Source: *Author*

> *The methods currently used by teachers must be adapted to identify students' talents as early as possible, helping them develop skills and competencies that will be useful for their future. If this is achieved, students stand a higher chance of becoming young adults whose skills and competencies align with their natural talents, ultimately attaining professional success and fulfillment, as well as a sense of well-being in the workplace* (Grigorescu & Scarlat, 2025, p. 290).

> *Using early warning systems alongside practical tests and experiments could provide teachers with valuable tools to support these skills* (Grigorescu & Scarlat, 2025, p. 290).

2.3. Enabling factors for the early identification of weak signals in the educational system

Integrating STEM education from the earliest years of life is essential for developing generations prepared to meet the challenges of a competitive global economy. Evidence-based, age-appropriate STEM instruction stimulates curiosity, creativity, collaboration, and critical thinking—fundamental skills for both academic and professional success (Struyf et al., 2019).

STEM potential can be recognized not only in technical capacities but also in the critical thinking abilities of individuals who have developed their skills (Fadlelmula, 2022). STEM literacy, defined as the understanding of and familiarity with the foundational principles of each discipline, is considered an educational priority for all students (Thibaut et al., 2018).

2.4. Methods for the early identification of weak STEM signals

Before they begin to speak or think consciously, children start to perceive and interact with the world around them. The starting point of cognitive development consists of the experiences a child has in and with the physical world. In early childhood education, STEM does not involve explaining abstract laws or concepts to children, but rather guiding them and engaging them in experiences that incorporate certain concepts, such as gravity. Young children do not appear interested in reproducing statements about the world, nor is it effective for them to do so.

In the early years, the process through which a child learns about the material world inherently involves STEM learning. Furthermore, questions posed by children that can be scientifically explored, as well as technological problems solved through engineering and design, form an integral part of science learning. STEM teaching should begin at as early an age as possible, and the specific disciplines must be grounded in a solid foundation of physical or informative evidence (Hanno, 2018; Statman et al., 2026).

2.5. Tools and technologies for the early detection of weak signals and engineering potential

One of the most well-known and useful tools available for identifying career interests is John L. Holland's theory of vocational choice. The proposed model is widely known as the RIASEC model, named after the initials of the six identified vocational interest types. The greater the congruence between an individual's profile and the professional environment, the higher the probability of job satisfaction, stability, and work engagement (Nauta, 2013).

The Watson-Glaser Critical Thinking Appraisal (W-GCTA) serves as a primary instrument for assessing cognitive abilities in professionals, as it directly measures critical thinking skills (Watson & Glaser, 2010).

Additionally, virtual laboratories and simulations can significantly impact the shaping of students' STEM identity and foster their curiosity about science. They also provide teachers with opportunities to observe interested and talented students in this field, enabling early detection of weak signals pointing toward a potential STEM educational and career pathway. Interactive simulations allow students to explore complex theoretical concepts in a visual and interactive manner, facilitating conceptual understanding and the development of analytical thinking.

Chapter 3 – Determinants of Guidance Toward an Engineering Career

3.1. Relevant theories and models regarding the identification of students' STEM aptitudes

The three basic hypotheses of weak signals theory are: (1) weak signals are emerging issues, (2) emergence is linear[1] (more precisely, it moves linearly from a rudimentary stage to an advanced or progressing one), and (3) issues possess universal characteristics that help identify weak signals. The authors propose that weak signals usually concern not only the identification of linear emergence, but also the changing contexts and positions of observers (Ahlqvist & Uotila, 2020).

Table 3.1. Psychometric tests and variables that may indicate weak STEM signals

No.	Psychometric Test / Instrument	Signal Type	Measured variables	Examples of observable weak STEM signals	Reference
1.	PISA Tests (Mathematics & Science)	Cognitive-behavioral	Problem-solving, applied reasoning, knowledge	Unusual or original solution strategies, even if the answers are only partially correct	Hencke et al., 2022
2.	Torrance Tests of Creative Thinking (TTCT)	Cognitive-affective	Divergent thinking, conceptual flexibility	Providing original answers to scientific or technical tasks; unusual combinations of concepts	Almeida et al., 2008
3.	Science Motivation Questionnaire (SMQ/SQI)	Affective	Intrinsic motivation for learning science, STEM self-efficacy	Sustained interest in experimental activities or empirical research, even in the absence of external rewards	Glynn et al., 2011
4.	Big Five Inventory (NEO-PI-R / BFI)	Affective-behavioral	Openness to experience, conscientiousness, perseverance	A curious, persistent student willing to self-teach STEM content	Costa & McCrae, 1992
5.	Behavioral Observations in STEM Tasks (portfolio, problem-solving, coding tasks)	Behavioral	Perseverance, metacognition, self-regulation in the face of failure	A student who reformulates strategies and persists after minor errors	Zimmerman, 2002

[1] *linear emergence* - a succession of developmental stages in which the phenomenon is perceived as evolving from an initial stage into a future issue or a fully defined trend.

6.	STEM Career Interest Survey (STEM-CIS)	Cognitive	Interest, perceived value of science	Interest in and recognition of the strengths of STEM disciplines	Kier et al., 2014
7.	Adaptive Learning Analytics Tests	Cognitive-behavioral	Response time, learning patterns, progress	Atypically accelerated trajectories in specific domains (e.g., geometry, physics)	Allensworth, 2013

Source: *Author*

The steps to follow for the early identification of weak signals based on this model could be structured as follows: *(a) focusing conversations and efforts on identifying weak STEM signals among students; (b) identifying students for intervention; and (c) utilizing indicator frameworks to address students' weak signals and further develop them.*

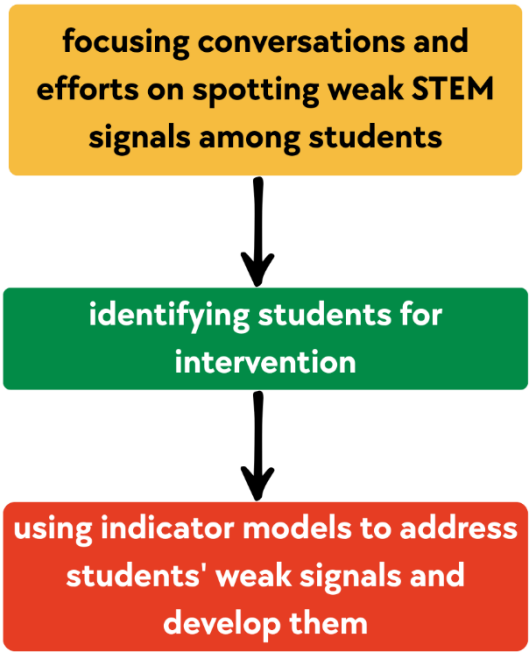


Figure 3.1. Stages of early identification of weak STEM signals

Source: *Author*

Chapter 4 – Conceptual Framework for the Early Identification of Weak STEM Signals for Engineering Career Choices

4.1. Justification and structure of the proposed conceptual framework *(data sources, methods and tools, evaluation and validation criteria)*

Figure *4.1* presents a proposed diagram of a research methodology aimed at the early identification and evaluation of emerging STEM-related competencies. The role of this proposed framework is to facilitate student preparation in order to identify STEM skills and develop them into competencies that will support students throughout their educational and professional pathways.

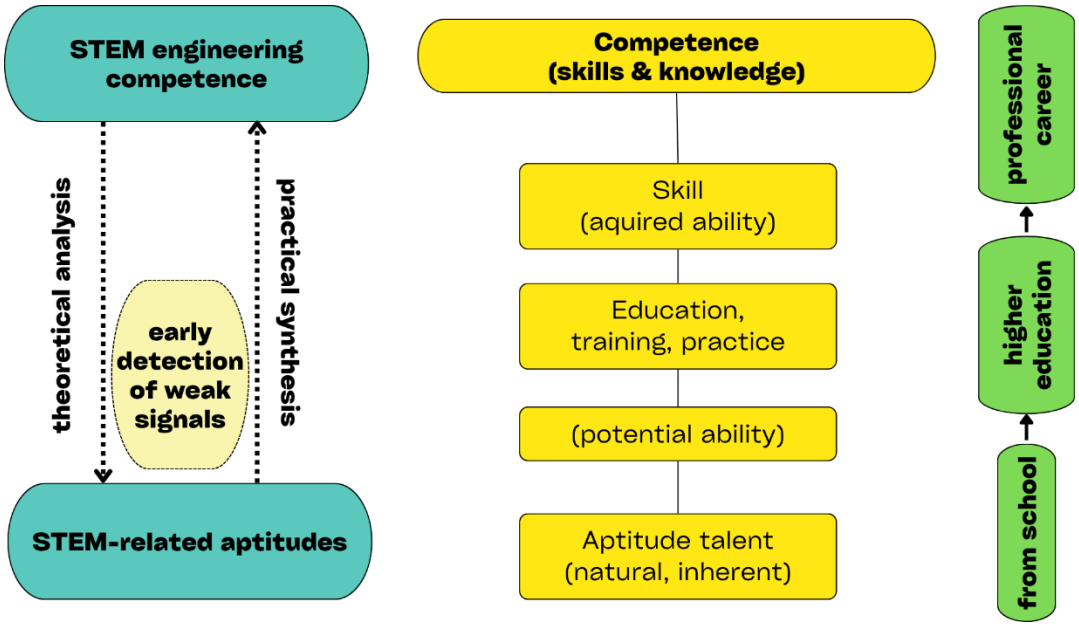


Figure 4.1. Research methodology (diagram)

Source: *Grigorescu & Scarlat, 2025*

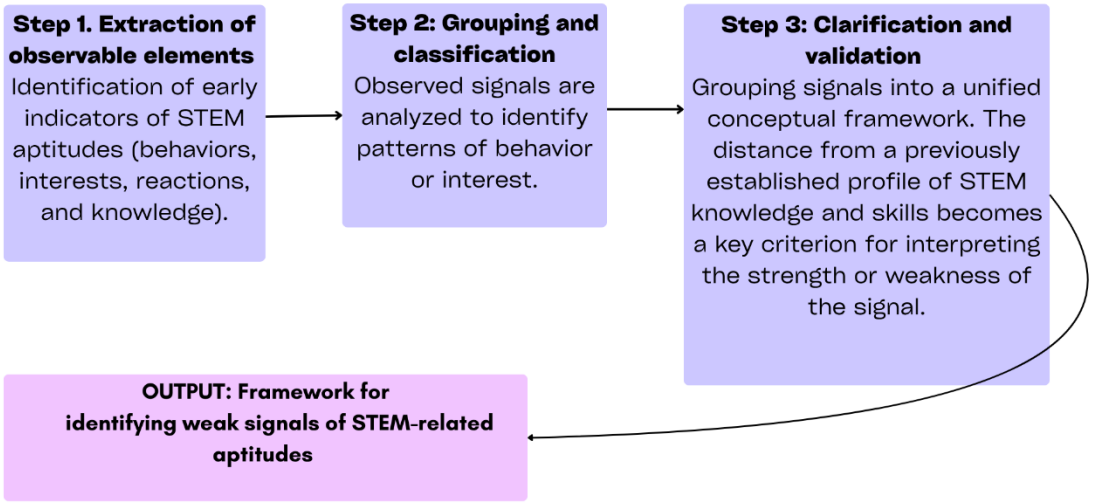


Figure 4.2. Conceptual framework for identifying weak signals of STEM aptitudes

Source: *Grigorescu & Scarlat, 2025*

Chapter 5 – Pilot study on interest in STEM fields and the identification of elements reflecting students' STEM potential

5.1. Research objectives and methodology

This study was conducted to assess students' interest in STEM fields and to identify the elements that reflect STEM potential (such as mathematical reasoning, problem-solving, critical thinking, and technical skills).

> *Applying the theory of weak signals in education, particularly in engineering education, can positively support the process of guiding students toward technical careers by identifying and highlighting their potential* (Grigorescu & Scarlat, 2025).

A mixed-methods approach was used in this study, combining quantitative and qualitative data collected via an instrument administered to a sample of 130 eighth-grade students from four schools during the 2025–2026 academic year. The instrument, hereinafter referred to as STEMi (STEM identification instrument), consisted of four parts corresponding to the research objectives: identifying students' interest in science-specific activities, identifying elements that reflect STEM potential, evaluating 21st-century skills, and analyzing career intentions. The study focused on Romanian eighth-grade students, with the sample comprising 130 participants across four schools.

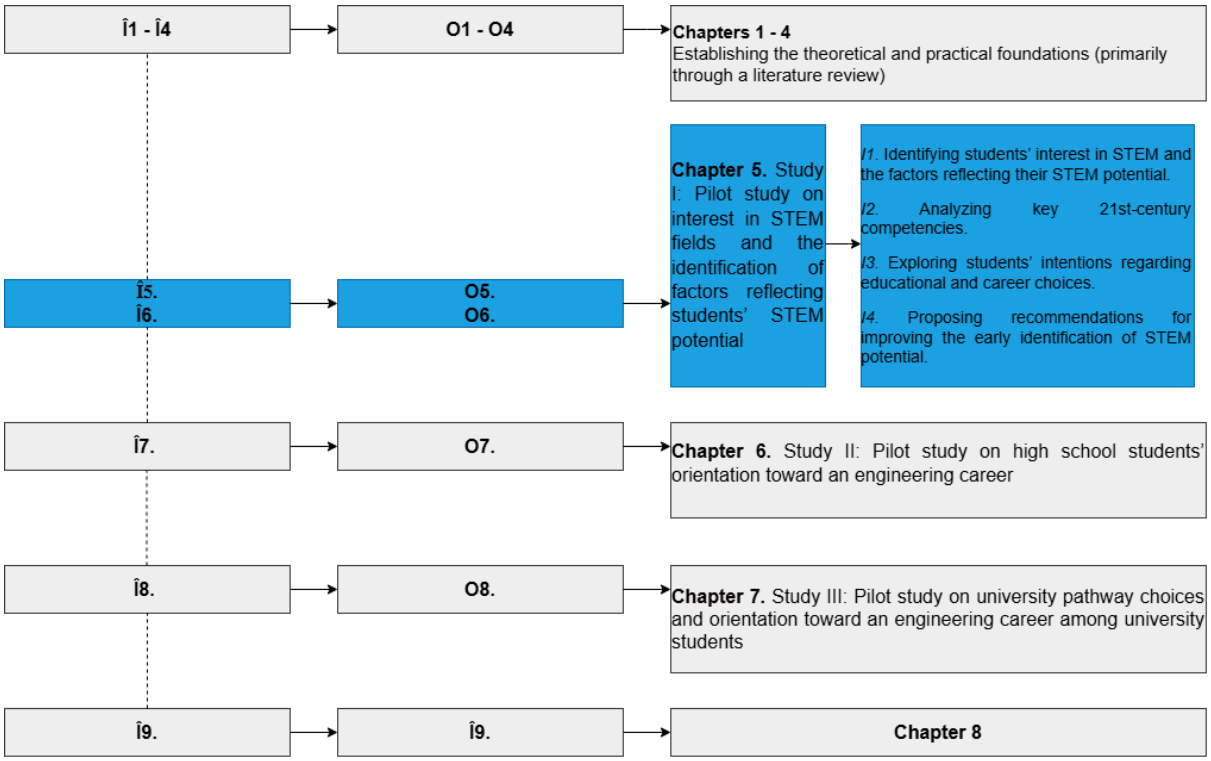


Figure 5.1. Logical structure of the doctoral research: Pilot study on 8th-grade

Source: *Author*

5.2. Data Analysis and Interpretation

Identification of students' interest in STEM activities

The results indicate that the majority of participants, specifically 70.77%, expressed a preference for outdoor activities at the playground, suggesting a general tendency toward exploration and active social interaction. Among the students, there is a predisposition for spatial thinking, problem-solving, and an interest in hands-on projects, as well as engineering itself. Emerging and multidimensional interests were observed, which could be leveraged to guide students toward STEM and foster specific technical skills.

Across all four student groups, high percentages were observed for responses demonstrating functional curiosity—that is, young people wish to discover how a given device works. Interest in the structural/construction aspect was lower across all four groups. Students in the second group recorded the lowest proportion at 6.45%, whereas the highest proportion was observed in the third group at 29.73%.

Interest in participating in science-related activities was also measured, with the highest percentage recorded among students in the first group (48.48%) and the lowest among respondents in the fourth group (24.14%).

Clear differences among the four schools emerged as follows: *students in the first group are more STEM- and innovation-oriented; those in the second group are more balanced and pragmatic; those in the third group exhibit diverse aspirations focused on exploration; and students in the final group aspire to personal utility and work-life balance.*

Identification of Elements Reflecting STEM Potential

Students demonstrated a high level of applied reasoning skills (up to 96.97%–100% correct answers in the first group), solving simple mathematical tasks with ease. However, increasing the level of difficulty significantly reduced performance. On the geometric modeling task, only 45.45% of responses were correct in the first group, indicating that advanced cognitive skills are less commonly developed. Conceptual transfer (e.g., the energy-time relationship, consecutive percentage applications) revealed major difficulties. Energy-time conversion was performed correctly by fewer than one-third of the students. The capacity for physics- and calculation-based argumentation was best represented in the fourth group (48.28%), whereas other groups recorded very low success rates (down to 9.68%).

These results indicate that cognitive weak STEM signals are well-defined at the level of elementary mathematical reasoning, but become uncertain during complex tasks involving spatial thinking, interdisciplinary transfer, and logical argumentation. Furthermore, a high task-abandonment rate was observed (missing responses reaching up to 83.78% in the third group) as the degree of abstraction increased.

Evaluation of 21st-Century Skills

Regarding students who prefer collaboration, the highest percentage was recorded in the first group (81.8%), while the lowest score was found in the third group (40.5%). These results support the notion that the majority prefer collaboration; however, this preference is most prevalent among students in the first two groups and the fourth group, suggesting an influence of the educational environment on the development of collaborative competence.

Students who stated that they prefer to communicate with peers to find a solution ranged between 10.81% (third group) and 21.21% (first group). As for students who prefer working independently until they arrive at a solution, the highest percentage was observed in the third group (48.65%) and the lowest in the first group (18.18%).

Analysis of Students' Intentions Regarding Career Choices

Students in the first group stood out with the highest levels of interest in the field of science (48.48%). Most of their positive responses were substantiated by a strong interest in mathematics, physics, biology, or programming, a desire to become engineers or work in technical fields, and the perception that STEM is valuable for personal development and represents a "field of the future."

Respondents in the first group held the best perception regarding their preparation for the STEM field, as well as the clearest responses. Students in the second group demonstrated a moderate yet fragmented perception; those in the third group exhibited a weak and rather vague perception; and students in the final group had a very poorly defined perception, dominated by non-responses.

Students in the first group were the most STEM-oriented. In contrast, responses from the second group revealed the highest level of indecision regarding career direction, with their perception of school preparation being generalist and diffuse—seeing school primarily as a space for general training for any career path rather than a clearly outlined professional trajectory.

Chapter 6 – Youth perceptions of engineering careers

6.1. Theoretical foundations and empirical perspectives on youth perceptions of engineering careers

The low level of students' aspirations toward STEM fields, along with low youth participation in educational programs within these domains, represents a global concern. A recent study maintains that erroneous perceptions of STEM professions are correlated with negative expectations regarding career outcomes (Luo & So, 2026). The engineering career encompasses multiple dimensions, ranging from the structure of the domain and systemic challenges to youth perceptions and obstacles related to gender and inclusion.

6.2.1. Research objectives and methodology

This study aims to investigate the perceptions of twelfth-grade students enrolled in high schools in the Municipality of Bucharest during the 2024–2025 academic year concerning career counseling and guidance, with a focus on engineering careers.

The research methodology was quantitative, based on the survey method, and the instrument used was a questionnaire administered digitally via Google Forms. This questionnaire was distributed to several teachers working in high schools across Bucharest, who then forwarded it to their students. A total of 52 twelfth-grade students from various high schools (both public and private) in Bucharest completed the questionnaire.

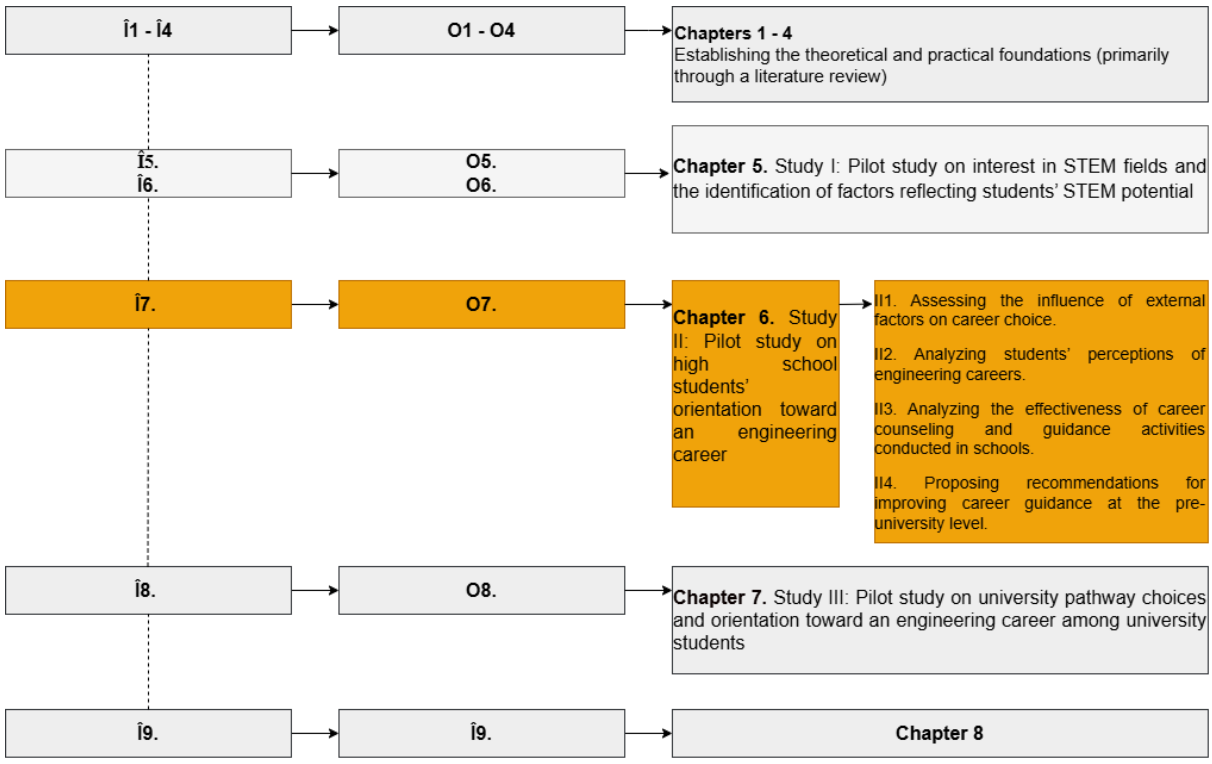


Figure 6.1. Logical structure of the doctoral research: Pilot study on 12th-grade students

Source: *Author*

6.2.2. Data analysis and interpretation

Factors influencing career choice

The majority of respondents, approximately 40%, stated that they occasionally participated in career counseling and guidance activities during high school, 36.5% indicated that they participated regularly, and 21.2% stated that they had not participated in such activities, but would like to do so.

Most young people consider activities such as volunteering, internships, and workshops to be very useful in the career choice process, with few reporting a moderate or non-existent influence. Involvement in these projects significantly influences career decisions, offering students the opportunity to explore new domains, acquire practical skills, and establish direct contact with the labor market.

Participants were asked whether they believe technological advancement could influence their future career choice. Three-quarters of them consider that technological advancement has a significant influence on their career decision-making process, while 21.2% mentioned that they had not thought about it or did not know if technological advancement was a factor that could influence their decision.

Half of the participants selected the option describing the field of engineering as interesting but challenging. Another significant percentage, 30.8%, chose the option "difficult, demanding, and stressful," while 9.8% stated that they view engineering as boring and unattractive.

To determine the level of interest in pursuing an engineering career, participants were asked whether they had considered a career in this field. Nearly half stated that they had not considered an engineering career up to the point of completing the questionnaire, 38.5% said they still needed to do further research, and the remaining 17.3% confirmed that they were considering this career path.

Most respondents stated that the most important reason was their personal passions and interests. This finding aligns with the responses provided to a previous question regarding who or what influences their future career decisions. Other reasons mentioned by students include career opportunities and an attractive salary (9.6%) or family influence. Additionally, 23.1% of the participants stated that they had not researched this field sufficiently, or that they do not like/are not good at the relevant subjects.

Chapter 7 - University pathways of young people and guidance toward an engineering career

7.1. Theoretical foundations and empirical perspectives on guiding youth toward an engineering career

Global population growth and development are driving a high demand for engineering talent, as solutions are urgently needed for challenges such as sustainable energy and efficient material management (Gerryts, 2013). Although graduates possess a solid theoretical background, securing a successful engineering career requires self-knowledge, the development of soft skills (communication, leadership, teamwork), and self-promotion abilities (Millar, 2011). Regarding the stimulation of early interest, participation in engineering education activities does not inherently guarantee a clear perception of the field; without accurate definitions and the building of self-efficacy, the overall impact on professional aspirations remains limited (Broadbent, 2019).

7.2. Pilot study on the choice of university pathway and guidance toward engineering careers among students

7.2.1 Research objectives and methodology

The main objective of this study is to analyze the factors influencing the choice of university pathway and the effectiveness of career guidance provided to young people toward an engineering career. To analyze the factors influencing students' choice of educational and professional pathways, as well as the role of counseling and career guidance activities in the university and future career selection process, a quantitative research methodology based on the survey method was employed. The instrument used was a digital questionnaire developed in Google Forms. The questionnaire was completed by 43 students from universities in Bucharest.

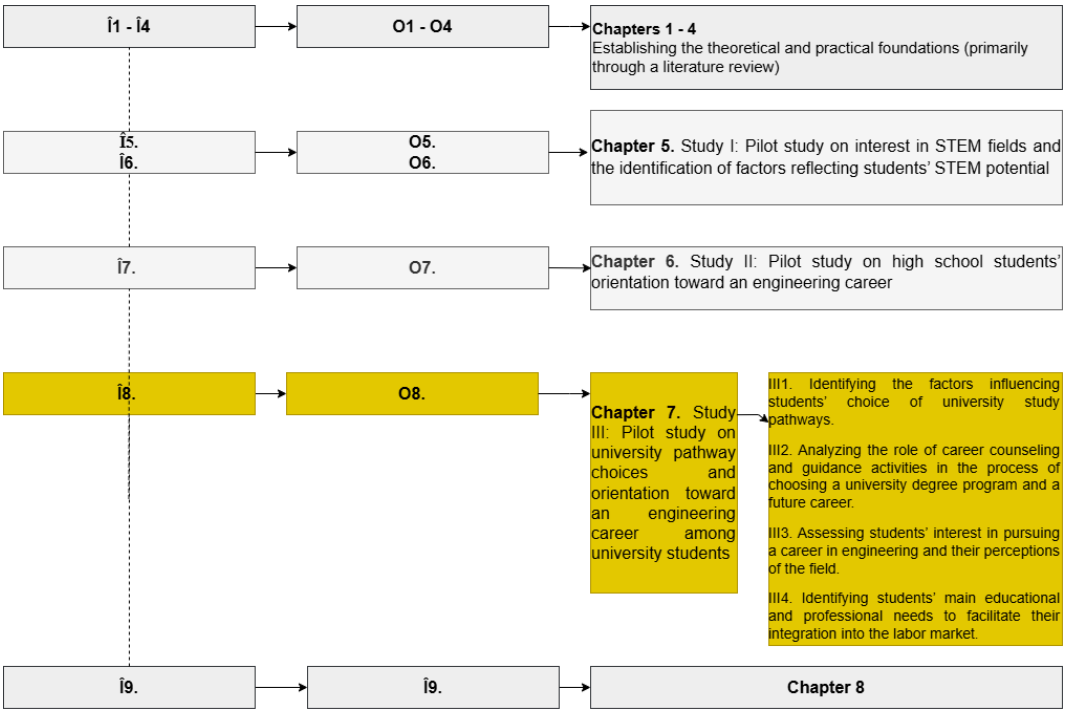


Figure 7.1. Logical structure of the doctoral research: Pilot study on university students

Source: *Author*

7.2.2. Data analysis and interpretation

To highlight the primary reason for selecting their university faculty, students were asked to choose a single option from a list. Most respondents selected passion for the field (46.5%), employment opportunities (35.6%), and financial benefits (14%). Smaller percentages indicated family influence (9.3%), friends, or other opportunities offered by the chosen faculty.

To investigate student perceptions regarding the importance of workshops, internships, and volunteering activities, a Likert scale was used, where 1 represented "not at all important" and 5 represented "very important." As shown in the chart below, more than half of the respondents selected option 5 (very important), while no student selected option 1 (not at all important). These findings suggest that such activities yield tangible benefits for students and should be integrated more frequently into student career counseling and guidance processes.

The distribution of students who wish to pursue a career in engineering was examined using a multiple-choice item. Although only 40% of students indicated in the preceding question that their current degree program could lead to an engineering career, 44.2% of respondents answered affirmatively to this item.

The majority of respondents (41.9%) believe that the field of engineering is insufficiently promoted in secondary education. Only 23.3% of students responded affirmatively to this question, while 34.9% indicated they did not know. These results highlight the low visibility of the engineering field within high schools.

Capitolul 8 – Final Conclusions

8.1. Main findings and the extent of achievement of the research objectives

The synthesis of the main research findings, their alignment with the formulated research questions, as well as the extent to which the research objectives were achieved, are systematized in *Table 8.1*.

Table 8.1. Link between research questions, achieved contributions, and degree of objective fulfillment

Research objectives	Relevant contributions	Chapter	Extent of achievement
O1	Clarification of the role of technology education as a conducive environment for stimulating interest and developing the digital/technical competencies necessary for orientation toward an engineering career.	**Chapter 1, s**ubc. **1.1., 1.2., 1.3, 1.4, pp. 16-22.**	Achieved
O2	Defining the concept of "weak STEM signal" and establishing the theoretical framework of early warning systems transposed into an educational context.	**Chapter 2, s**ubc. **2.1, 2.., pp. 23-29.**	Achieved; Opens up possibilities for longitudinal studies.
O3	Identification, analysis, and methodological grounding of a set of suitable methods and tools for the early detection of STEM potential.	**Chapter 2, s**ubc. **2.4, 2.5, 2.6.** **Chapter 3, s**ubc. **3.1.**	Achieved
O4	Proposal and structuring of an original conceptual framework aimed at the early identification of weak STEM signals and guidance toward an engineering career.	**Chapter 4, s**ubc. **4.1, 4.2, 4.3, 4.4, 4.5.**	Achieved
O5	Highlighting the decision-making role of weak STEM signals; identifying interest, analyzing 21st-century key competencies, and exploring career intentions among high school and university students.	**Chapter 2, s**ubcapitolul **2.3.** **Chapter 3, s**ubc. **3.1, 3.2, 3.4, 3.5.** **Chapter 5, s**ubc. **5.1, 5.2, 5.3, 5.4.**	Achieved; Opens up possibilities for longitudinal studies.
O6	Empirical validation and assessment of the practical applicability of the developed early identification tool, confirming its utility in the	**Chapter 5, s**ubc. **5.1, 5.2, 5.3, 5.4.**	Achieved; Opens up possibilities for

	Romanian pre-university education system.		longitudinal studies.
O7	Determining the impact of external factors, perceptions of the engineering profession, and the effectiveness of school counseling activities on young people's decisions regarding their educational and professional pathway.	**Chapter 6, s**ubc. **6.1, 6.2, 6.3.**	Achieved
O8	Identification of determining factors in choosing a technical faculty, evaluation of interest in engineering, and assessment of students' educational and professional needs.	**Chapter 7, s**ubc. **7., 7.2, 7.3.**	Achieved
O9	Formulation of an integrated set of strategic recommendations and practical measures for decision-makers, teaching staff, school counselors, pupils/students, and their families.	**Chapter 8, s**ubc. **5.4, 6.3, 7.3, 8.3.**	Achieved

Source: *Author*

8.2. Scientific contributions and original elements of the thesis

One of the primary original contributions of this research is the introduction and conceptual foundation of the "weak STEM signal" concept within the educational and professional guidance process for young people.

Furthermore, the operationalization of the weak STEM signal concept and its integration into a conceptual framework applicable to the Romanian educational system represents another significant contribution of this work. This provides a novel perspective on the process of preparing youth for careers in engineering.

The results of the pilot study presented in Chapter 5 highlighted the role of socio-emotional skills alongside collaboration, leadership, resilience, problem-solving, and self-efficacy competencies, representing another key contribution. A further contribution, derived from the pilot studies presented in Chapters 6 and 7, is the finding that the choice of an engineering career is driven more by personal interests and intrinsic motivation than by external influences.

The findings from the pilot studies detailed in Chapters 5, 6, and 7 demonstrated that the educational environment influences the development of interest in STEM fields, that there are discrepancies between students' self-reported interests and their actual competencies, and that personal interests, motivations, and aptitudes are the primary factors influencing career choice.

Finally, a practical contribution of this research consists of the development and evaluation of the applicability of the STEMi instrument. The deployment of this tool in the pilot study demonstrated its utility in capturing subtle indicators of STEM interests and aptitudes.

8.3. Practical implications and recommendations for stakeholders

A. Recommendations for the economic environment and industry

Increasing youth interest in engineering careers is directly influenced by industry and STEM organizations; thus, the following is recommended:

- Developing **sustainable partnerships** between educational institutions and industry.

B. Recommendations for higher education institutions:

- Developing mentoring and career guidance programs for students;
- Facilitating students' access to hands-on, practical experiences;
- Strengthening collaboration with the economic sector and industry.

C. Recommendations for decision-makers and educational policymakers:

- Developing institutional mechanisms such as ***"early warning systems";***
- Formulating national strategies to support the implementation of STEM programs starting from primary education;
- Developing ***standardized instruments*** for assessing interest and potential;
- Training teaching staff and school counselors to streamline the process of recognizing and leveraging weak STEM signals.

D. Recommendations for pre-university educational institutions

Educational institutions are advised to:

- Develop systematic mechanisms for the early identification of students demonstrating weak STEM signals;
- Encourage teachers to utilize dedicated tools when conducting these evaluations;
  Frequently integrate interdisciplinary activities into the curriculum.

E. Recommendations for students and their families

Recommendations for students include:

- Participating in projects, competitions, volunteer activities, thematic camps, and practical experiences that contribute to strengthening their STEM identity and clarifying future career opportunities.

Recommendations for families are as follows:

- ***Supporting children's natural curiosity;***
- ***Promoting exploration and experimentation;***
- ***Avoiding the transmission of stereotypes.***

8.4. Future research directions

Future research should encompass larger and geographically more diverse samples. At the same time, an important objective involves the continued development, refinement, and validation of the STEMi instrument. Furthermore, conducting longitudinal studies to track the evolution of pupils and students over an extended period is recommended. Evaluating the effectiveness of educational interventions designed to develop and leverage weak STEM signals could represent a valuable perspective in this regard.

Additionally, deeper investigation is needed into the factors that influence female participation and success in these fields. Finally, a research trajectory derived directly from the contributions of this thesis consists of the further theoretical development of the weak STEM signal concept.