**IOSUD - Polytechnic University Timișoara**
**Doctoral School of Engineering**

# INNOVATION AND TECHNOLOGY TRANSFER, MEANS TO MAKE EDUCATION IN SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS

**Doctoral Thesis - Abstract**

to obtain the scientific title of doctor at
Polytechnic University Timisoara
in Engineering and Management

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The PhD thesis is in line with the current trends on interdisciplinarity, fitting into the complex and dynamic space of engineering and management. The generation of the proposed research outcomes is presented through a visual model, inspired by the "black box" concept, adapted to the context of STEM education. Figure 1 illustrates how knowledge, material, human and financial resources contribute to innovation and technology transfer to make STEM education more effective. Feedback plays a central role in iterating and refining research goals, activities and results, and supports publicizing and dissemination activity.

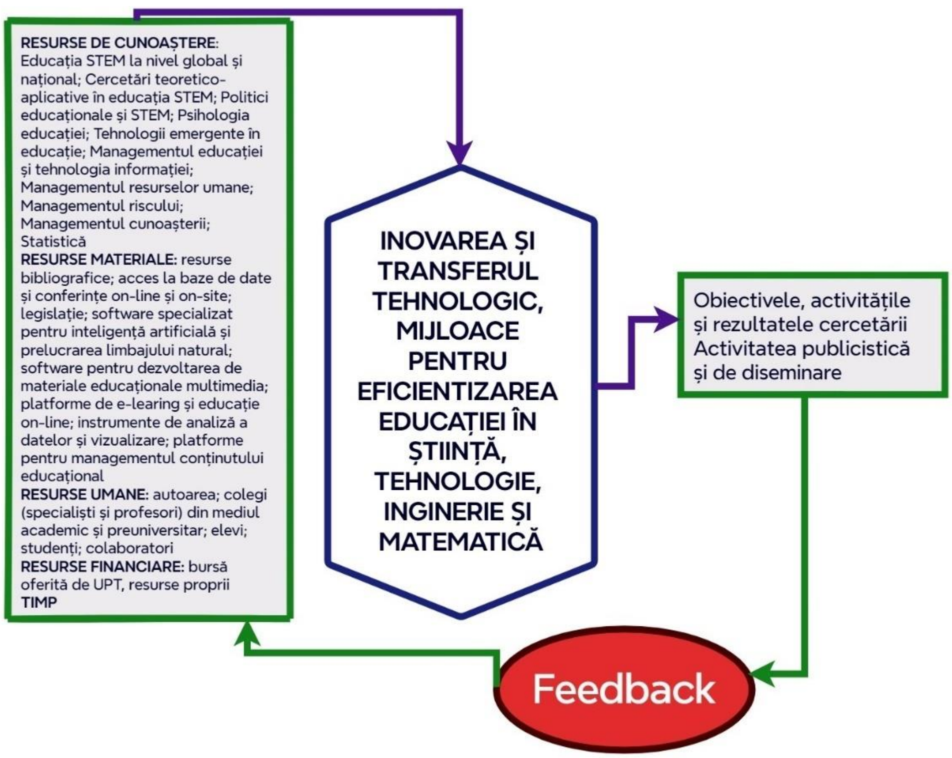


*Figure 1. Black box visual model, adapted to the context of STEM education .*

The doctoral research theme is illustrated in Figure 1.4 and has as its central objective the integration and implementation of STEM education through innovation and technology transfer. In this research, STEM education is approached as a "meta-discipline", aiming to identify, characterize and provide methodological, experimental and applied foundations for methodological, experimental and applied strategies to make education more effective. These strategies are centered on the process of innovation, the identification of sources of innovation and the facilitation of technology transfer in the educational context. Figure 2 presents the research theme schematically, detailing the main components and directions of study.

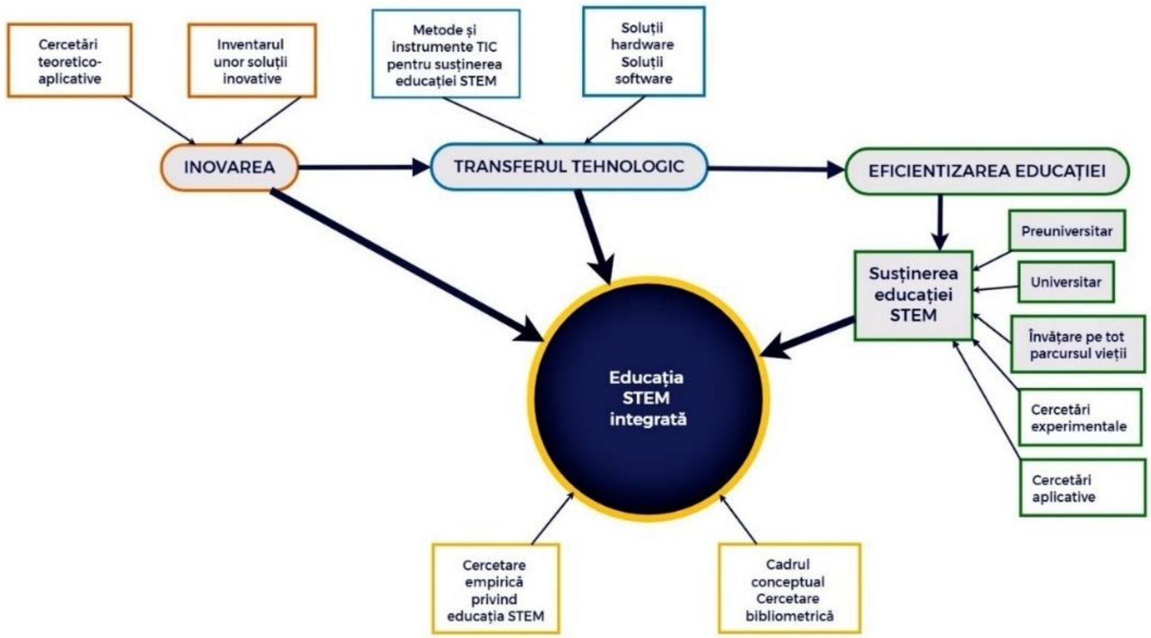


*Figure 2 Schematization of the research topic .*

***The PhD thesis totals 338 pages (including 12 appendices that provide significant details of the research carried out, examples of application of the proposed computational relationships and supporting documents), structured in an introductory chapter, 4 chapters dedicated to the analysis and development of the research problem, and 2 final chapters: one dedicated to the conclusions of the research on STEM education in Romania, with reference to strategies, successes and challenges, and the second dedicated to personal contributions and future research directions. The paper includes 81 figures (of which 63 are included in the thesis chapters and 18 in the Appendices) and 50 tables (of which 29 are included in the thesis chapters), as well as a list of 532 bibliographic titles consulted and cited***

Figure 3 outlines the key interactions between the components of the education system and the external environment, and highlights how the education system defines itself in relation to its main objectives. The diagram illustrates the correlation between available resources and technology transfer actions, especially in the context of accelerated digital transformation. These interactions help direct resources towards innovative scientific fields, ensuring their optimal use and maximizing efficiency, in line with the needs of the labour market and global economic requirements. Thus, the education system becomes an important vector in training a skilled workforce that is adaptable to current economic dynamics.


*Figure 3. Interaction of the education system with the labor market and the economy in the context of digital transformation.*

Integrated STEM education has been identified as a platform for the development of professional as well as soft skills, which include research, problem solving, critical and creative thinking, entrepreneurship, collaboration, teamwork and communication. Further Falloon et al. (2020) argue the potential of STEM education to engage the community and businesses (through public-private partnerships) so that the student-teacher-teacher (or other human resource in the training process) relationship leads to support for business or industry projects and processes. The premises of doctoral research are revealed by the fact that, while interdisciplinarity is seen as the dominant attribute of STEM education today, there are differing views on how STEM disciplines should be positioned and prioritized within STEM-related curricula (Padua, 2017; Bybee, 2010; Falloon et al., 2020). Thus, the research area addressed aims to analyze the importance of the development of an innovative educational system at all levels of education, its capacity for improvement, its direction of development and involves the definition and measurement of educational effectiveness from the perspective of STEM integrated education.

A proverb says that "*It takes a village to raise a child*", (*Farlex Dictionary of Idioms*, 2015), an idea that has inspired communities in Romania dedicated to educational integration through STEM. These communities, often supported by foundations, focus their efforts through projects designed to emphasize the importance of education as a collective responsibility. For example, initiatives such as the Republic Community, with Cristian Tudor Popescu as founding member (2019), or the Academy of Leadership and Pedagogy through Teach for Romania and Community Immersion (2020), are representative in this sense. This collective responsibility becomes even more evident in the context of the integration of STEM education, given the specificity of Generation Z - digital natives who were born and raised in the age of technology. In an age of accelerated transformation, constant adaptability is essential to survive and thrive. Digital natives are thus prepared for the future of work, where digital skills are essential for more than 93% of today's jobs (according to the latest EU-wide surveys).

The influence of technology is profound and has a critical impact on the labor market. As stated by Frey and Osborne (2017), *"As technology advances, its impact on the labor market is vast and inevitable"*. This observation emphasizes the enduring relevance of technological progress in shaping and defining the future of work in various industries, particularly in those areas where automation and digital tools are indispensable. Such insights emphasize the importance of continuously adapting skills and competences to remain competitive in a changing technological landscape

In summary, the representation in Figure 4 highlights ideas about current transformations and trends in education:

- It highlights the significant transformations in education, reflecting the shift from traditional approaches focused on standardization and limited expertise to modern, individualized and integrated methods in the digital age. While the past was marked by a rigorous, conformist and discipline-oriented education, the future proposes a flexible education system centered on complex competences, critical thinking and continuous lifelong learning. The growing role of machines and artificial intelligence, which complement and transform the educational process, is also very important. This transition underlines the need for educational reform to prepare both educators and students for the challenges and opportunities brought by the industrial age and the rapidly changing labor market. Essentially, the education of the future must be adaptable, collaborative and geared towards developing the competencies essential for success in professional and personal life .[1]
- Open and collaborative innovation, carried out through public-private partnerships and based on previous experiences (including hardware and software solutions validated in diverse educational contexts), is a key area for optimizing the STEM education process. Thus, through theoretical and applied research, we aim to develop a successful scenario for integrated STEM education in Romania.

[1] European Commission: Directorate-General for Education, Youth, Sport and Culture, (2019). *key competences for lifelong learning*, Publications Office. https://data.europa.eu/doi/10.2766/569540. https://data.europa.eu/doi/10.2766/569540

| TRECUT | | COMING SOON |
|---|---|---|
| **Over 50% of children in Europe have no access to early education** | **1** | **Early education, the earlier the better** |
| Less than 11% of Europeans aged 25-64 are engaged in some form of training | 2 | The key to career success is lifelong learning |
| Literacy process for math, writing and reading skills | 3 | New forms of literacy, including STEM (digital) skills |
| Only humans can learn | 4 | In the new industrial age (Industry 5.0), machines are learning faster than ever before |
| Learning methods based on standardization | 5 | Individualized learning methods |
| Education centered on curricular areas and subjects of expertise | 6 | Project-based education, e-learning and focusing on complex competences |
| Education based on the knowledge of a small number of providers (e.g. state, church) | 7 | Education based on diversification of providers and partnerships for all stakeholders (stakeholder group) |
| Education - your guarantee for a job | 8 | The difficult transition from school to working life |
| Education is about obedience and submission, obedience and conformity | 9 | Critical thinking - complex competence of the future |
| Europe's higher education institutions top in the world | 10 | Fierce global competition and competition between universities worldwide |

*Figure 4. Trends transforming education .*

**The objective of the PhD thesis** is to conduct bibliographical, theoretical and applied research (in different educational contexts at pre-university, university or lifelong learning level) for the streamlining of STEM education, following the design and implementation of innovative solutions and/or technology transfer to support accelerated digital transformation.

**Operational objectives** pursued during the thesis are:

**OP1.** Research and build a bibliographical synthesis on the theme of efficiency, innovation and technology transfer as means and solutions for the integration of STEM education in education at all levels, which will constitute a foundation not only for the current PhD thesis, but also for further research in the field;

**OP2.** Theoretical background on the approach to make STEM education in education more effective;

**OP3.** Propose a theoretical-applicative approach (a scheme, a scenario and/or a recipe for success) or an innovative solution to make STEM education more effective;

**OP4.** Model the design - implementation of innovative solutions and/or technology transfer to facilitate accelerated digital transformation;

**OP5.** Test, validate and operationalize the research methodology, the proposed solutions;

**OP6.** Conduct a comparative analysis between global and national STEM initiatives to identify successful models and propose strategies adapted to the Romanian context;

**OP7.** Investigate the impact of emerging technologies, including artificial intelligence, on the effectiveness and accessibility of STEM education and propose models for integrating them into the curriculum;

**OP8.** Adapt and test educational models, such as the Nadler-Tushman model, in the context of STEM education to assess their effectiveness in supporting digital transformation;

**OP9.** Extend applied research on making STEM education more effective at the national level, in order to gain a more detailed and representative picture of its implementation in different educational contexts.

The general objective achievement and the operational objectives has been realized systematically and gradually, demonstrated by the scientific research described in each chapter of the PhD thesis.

**Chapter 1, INTRODUCTION. COMPARATIVE PERSPECTIVES ON STEM INITIATIVES AT GLOBAL AND INTERNATIONAL LEVELS** describes the framework for the emergence and development of the research topic, as well as its motivation and importance. The research domain is identified and the main objective and operational objectives associated with the adopted research approach are stated. At the same time, an overview of the content of each chapter is provided in order to demonstrate how the objective of the PhD thesis has been achieved.

In **Chapter 2, BIBLIOGRAPHICAL RESEARCH ON STEM EDUCATION**, a synthesis of research on the current literature is presented. At the same time, clarifications related to the concepts of education, education system, efficiency, innovation, technology transfer, STEM education have been made and trends and/or approaches to their management have been identified.

In the following chapters of the doctoral thesis, the testing and validation of the proposed methodology has been carried out on its *sequences*.

**Chapter 3,** entitled **THEORETICAL-APPLICTIVE RESEARCH ON SUPPORTING STEM EDUCATION THROUGH INFORMATION AND COMMUNICATION TECHNOLOGY,** explores how information and communication technology can support STEM education and examines the impact of technological transformations, as well as the role of digitization in the evolution of education and its integration into educational processes.

In **Chapter 4, THEORETICAL-APPLICATION RESEARCH ON CHARACTERIZING AND IMPROVING KEY ASPECTS OF STEM EDUCATION**, methods and strategies for improving STEM education are addressed, with a focus on technology transfer and the integration of digital platforms. Global trends are analyzed, including in competitive countries, as well as prospects in various regions of the world. This chapter is devoted to applied research and in-depth analysis of methods to improve STEM education and highlights the essential elements for integrating emerging technologies into the education system. It explores methods and tools for technology transfer, which play a key role in developing the skills needed in a digitized society. The section on identifying methods and tools for technology transfer in STEM education, provides a detailed analysis of how emerging technologies, such as artificial intelligence, augmented reality and integrated educational platforms, can support STEM education and facilitate the connection of theory with practice. Various educational platforms and strategies for successfully integrating STEM education into pre-university and university education are examined. In terms of the interlinking aspect of platforms and STEM education, it emphasizes the importance of interlinking technology platforms, which is necessary to facilitate effective technology transfer between educational institutions and business. Comparative analysis of the various platforms used in competitive countries (such as those in Asia, the MENA region, and highly competitive countries) contributes to understanding the success factors in integrating STEM in diverse cultural and educational contexts.

This chapter also presents the context of the applied research carried out in Romania, with a focus on the adaptation of the methodology to local realities. The research included data collection by means of questionnaires based on the PISA model and needs analysis for the development of essential competences for distance work in the context of STEM education. This section presents the structure and dynamics of the competences needed in Romanian pre-university education and how they are influenced by new technologies. This chapter also provides an integrated analysis of the skills acquired in STEM education and distance work, based on data collected through questionnaires. The quantitative and qualitative analysis emphasizes the importance of key competences for adapting to new digital realities and professional development solutions in the context of distance education, with comparisons between university and pre-university environments.

Chapter 4 concludes with important conclusions on making STEM education more effective in Romania and identifying future research directions, including adapting education to telework and digitization, and implications for implementing STEM strategies and improving educational competences in the future are discussed.

**Chapter 5. CONSIDERATIONS AND PERSPECTIVES ON STEM EDUCATION IN ROMANIA. STRATEGIES, SUCCESSES AND CHALLENGES** presents a scientifically substantiated debate on the originality and impact of STEM education in Romania, realizing a comparative evaluation with other international educational systems. The challenges and successes in implementing educational strategies in this field are also presented.

**Chapter 6. PERSONAL CONTRIBUTIONS. FUTURE RESEARCH DIRECTIONS. CONCLUSIONS** presents personal contributions to the field of STEM education, including innovative proposals for educational streamlining and adaptations of the STEM concept for distance education. Future research directions and conclusions on the role of STEM education in the context of global challenges are discussed. In summary, the original contributions made by the doctoral research are:

1. To synthesize the literature on efficiency, innovation and technology transfer as means and solutions for the integration of STEM education in all levels of education (**OP1**). as presented in chapter 2.
2. Theoretical and applied underpinning of the approach to making STEM education more effective in education (**OP2**) as outlined in Chapter 3.
3. In the context of achieving **OP3**, an innovative approach has been developed that combines theoretical elements with practical aspects, proposing an adaptation of Nadler-Tushman (1999), an integrated model that can be applied in various educational contexts. This approach was designed both to respond to the current requirements of the education system and to anticipate future developments in STEM education in an increasingly digitalized environment. In this context, it links to the operational objective: **OP5.** However, the effectiveness of any theoretical-applicative model needs to be validated, through future research, in a rigorous process of testing and adaptation to concrete educational realities;
4. Personal contributions are not limited only to the theoretical formulation of the model but also include its implementation in a concrete experimental setting, aiming at adapting and optimizing the solutions according to the results obtained. Thus, the experiences gained in the testing were integrated to refine the initial model, bringing improvements that increased the relevance and applicability of the proposed solutions. Ultimately, the validation of this approach will confirm the theoretical feasibility of the model, its practical effectiveness and contribute to the consolidation of new methodologies that can be widely adopted in the educational system. This link between (**OP3**) and (**OP5**) reflects the interdependent nature of theoretical and applied research, emphasizing the importance of a continuous cycle of development, testing and implementation to optimize STEM education. All these aspects emphasize how the two objectives (**OP3** and **OP5**) are interlinked and illustrate the candidate's personal contribution through the development and validation of innovative solutions applicable in STEM education.
5. A structural equation model has been proposed, with direct and latent observable variables: quality of education (Q), student motivation (M) and academic performance (P). Also, (Figure 4.25) a Nadler-Tushman (1999) congruence model has been proposed (Figure 4.25), a model that responds to the dynamic requirements and facilitates rapid adaptation to the complex context of both distance education and integrated STEM education.

6. A simplified mathematical relationship has been defined for determining the effectiveness of STEM education as a ratio of outcomes achieved to resources used. This formula could consider both aspects related to the optimal use of resources and aspects related to the achievement of the set objectives

$$Efficiency = \frac{Outcomes}{Resources\ used}$$

where:

- Outcomes could be measured in terms of targets achieved or performance in a particular area, e.g. standardized test scores, graduation rates, level of skills acquired, etc.
- Resources used could include financial resources, time, human effort, infrastructure, teaching materials, etc.

This formula provides a simplified way to value efficiency in each context, allowing performance to be assessed and compared in terms of resources invested. It is important to note that the relationship can be adapted and adjusted according to the specifics of each domain or situation. A clear definition of the outcome indicators and resources used is also necessary to ensure accurate assessment. Both parts of the fraction, the numerator and the denominator, must be expressed in quantities that can be summed (must be homogeneous). This is an important requirement in calculating efficiency to ensure clarity and consistency of measurement.

7. To extend the efficiency formula in the context of STEM education, external influences that can significantly affect long-term outcomes were considered. In this regard, compared to the proposed general formula, several specific factors are critical for assessing effectiveness in STEM education:

- Educational outcomes, which measure immediate success in STEM education through test scores and graduation rates. It is a direct indicator of academic performance.
- Educational resources - the financial, material, and human resources used in the educational process that are the foundation on which the success of STEM programs is built. Effective management of these resources is vital for good educational outcomes.
- Skill development, by measuring skills acquired in STEM fields, is essential to assess the impact of education on students. It is these skills that prepare them for future careers and technological challenges.
- The quality of instruction and the effectiveness of teaching methods directly influence skill development and educational outcomes. Innovative and well-structured teaching methods can make a difference in how students assimilate and apply STEM knowledge.
- Long-term impact is perhaps the most risky and variable factor. The long-term impact of STEM education includes career preparation and contribution to social progress, which are strongly influenced by a range of external factors such as economic, technological, social, political and environmental changes. For example, rapid developments in technology or changes in the labour market can directly affect the relevance of acquired STEM skills, while fluctuations in funding can limit the resources available for education.
- The initial investment, i.e., the initial funding and resources allocated to STEM programs, determines the program's ability to achieve the desired goals. This factor must be well managed to ensure long-term sustainability.

8. These factors are integrated into an advanced formula for evaluating the effectiveness of STEM education, considering both the internal aspects of the educational process as well as

external influences that may affect the long-term impact. This approach provides a holistic and integrated framework for evaluating and optimizing STEM education programs, ensuring that they remain relevant and effective in the context of constant changes in society and the economy. Combining the six factors leads to the proposal of a broad and specific formula for STEM education:

$$STEM\ Efficiency\ =\ \alpha\left(\frac{Educational\ outcomes}{Educational\ resourses}\right)+\beta\left(\frac{Skills\ development}{Training\ quality}\right)+$$
$$+\gamma\left(\frac{Long\ term\ Impact}{Initial\ Investment}\right)$$

where (α, β, γ) are coefficients that reflect the relative importance of each component and can be adjusted to reflect specific needs and priorities. The formula has potential for practical application, although its implementation requires precise definition and measurement of the variables. Each component of this specific formula addresses an important aspect of STEM education, namely: efficiency of resource utilization, quality of instruction and skill development, and long-term return on investment.

9. It extended the formula for making STEM education more effective to include factors specific to distance education by proposing the following mathematical relationship:

$$Distance\ STEM\ education\ Efficiency\ =$$
$$=\alpha\left(\frac{Digital\ Resources}{online\ outcomes}\right)+\beta\left(\frac{Virtual\ training\ quality}{Digital\ skills\ development}\right)+$$
$$+\gamma\left(\frac{Investment\ in\ technology}{Long\ term\ Impact}\right)$$

10. In the context of this thesis, the efficiency of STEM education is addressed by developing formulas that quantify as precisely as possible the relationship between resources used and outcomes achieved, with attention to the specificities of the field. The detailed comparison between the classic STEM education efficiency formula and the formula proposed for distance STEM education emphasizes the key differences resulting from adapting the educational process to a digital environment. The differentiation of "***STEM efficiency***" vs. "***distance STEM efficiency***" formulas is central to this research and reflects methodological adaptation and a deep understanding of how the educational context influences efficiency factors. The structural divergence between the two formulas is not accidental, but reflects an adjustment necessary to adequately capture the specific dynamics of distance education. In the traditional formula, the ratio between outcomes and resources is used to emphasize classical efficiency, in which the main objective is to maximize educational outcomes with minimizing resources. This approach is typical in conventional education, where the quality and quantity of physical and human resources are the determinants of success.
11. Modeling the design - implementation of innovative solutions and/or technology transfer to facilitate accelerated digital transformation (**OP4**), as presented in Chapters 3 and 4.
12. Conducting a comparative analysis between global and national STEM initiatives to identify successful models and propose strategies adapted to the Romanian context (**OP6**), as presented in chapter 4;
13. Investigate the impact of emerging technologies, including artificial intelligence, on the effectiveness and accessibility of STEM education and propose models for integrating them into the curriculum (OP7), as outlined in chapter 3.5;

14. Adapting and testing educational models, such as the Nadler-Tushman (1999) model, in the context of STEM education to assess their effectiveness in supporting digital transformation (OP8), demonstrated through the research described in Chapters 3.4 and 4;
15. Extend applied research on making STEM education more effective at the national level to gain a more detailed and representative picture of its implementation in different educational contexts (OP9), as discussed in Chapters 5 and 6.

All research objectives have been achieved, and future research may extend to investigating how STEM education can contribute to the development of future skills required by the labour market and to further analysing the effectiveness of different STEM teaching methods.

The research carried out within the doctoral program has been valorised through the publication of 18 scientific papers, of which: 4 articles indexed in the Web of Science (WoS) database, and the other articles being indexed in other databases.

**Selected bibliography:**

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