Best Practices in STEM Education: Using Active Learning and Novel Teaching Methodologies in Education for Innovation and Sustainability

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Abstract

In our days there is a critical debate for the effectiveness of Science, Technology, Engineering and Math (STEM) Curricula and their revision based on flexible active learning didactical approaches. From various sources, it is evident that there is a critical gap in the perception of students and academic directors for the need of STEM education. In our research work we provide a methodological approach that communicates some critical actions required for the integration of STEM Curricula in modern academic programs.

The core knowledge in STEM curricula requires a detailed analysis of effective didactics and teaching methods. The current problems in the effectiveness of teaching in STEM Curricula are related to the diffusion of the learning content and the facilitation of an active learning environment. A detailed desktop literature research provides the input of our methodological approach. We analyzed the literature related to gaps in STEM Education, teaching performance and we informed a research model comprising of critical success factors. These were used in a meta-analysis through a qualitative research facilitated with interviews of STEM Professors from 14 countries. The basic focus of our analysis is the role of Active Learning, Technology enabled Teaching Methodologies and Social Networks as a key response to the need for effective STEM Education.

The main findings are related to design guidelines for New STEM Education programs, Technology Related Success Factors and Active Learning Strategies. The integrative approach of Active Learning, Technology driven learning innovation and Teaching Strategies for Stem is inevitable for the next generation STEM education, where critical Learning Objectives should be reconsidered and integrated with Portfolios management of students.

Our research also provides critical guidelines for Program Directors of Colleges and Universities for reconsidering the priorities. One of our key conclusions is that investment in STEM education is a key response in order to foster Innovation and Sustainability.

1. Critical success factors of STEM education

The provision of qualitative education in the context of STEM undergraduate curricula is a key requirement for the development of skills and competencies of young students, who are the prospective scientists who will be called to play a key role in contemporary knowledge societies. Various gaps in performance have been recorded in literature and a scientific debate is analyzing responsive actions. The following are few of the aspects of a multifaceted phenomenon that has a contribution to the overall quality and impact on the STEM programs worldwide (Fig.1).

- Content and Collaboration Dimension
- Educational Processes and Teaching Quality
- Technological Innovation
- Administrative Quality in Higher Education
- Societal Challenges
- Sustainability

The following figure reflects the significance of these factors, starting from the ones that relate with educational practices (bottom) to their goals (top).

[1] Deree-The American College of Greece, Greece

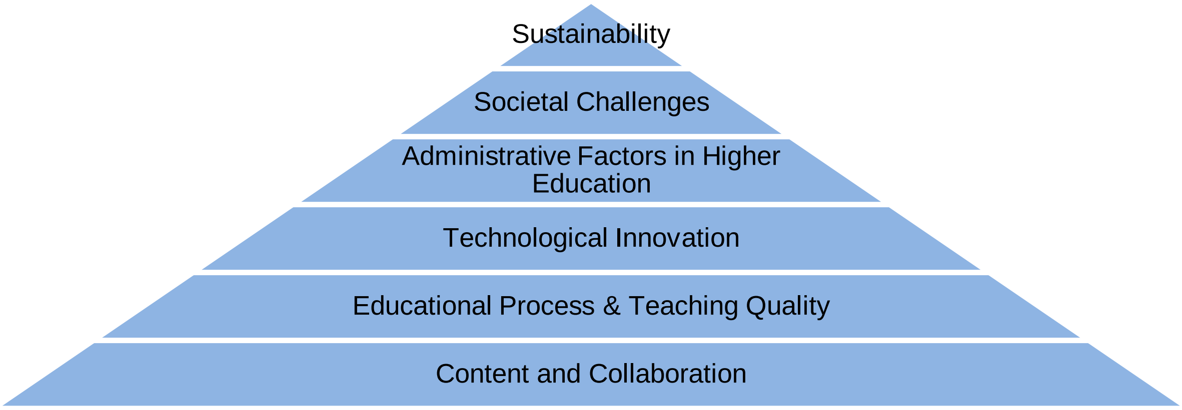

Fig. 1. Aspects of STEM core competencies

In relevance to these dimensions of STEM, various research papers in literature extensively analyzing factors that provide meaningful insights for each dimension [1], [2], [3], [4]. In our perception and methodological approach all these factors should be considered in the design of new STEM programs. In a way these factors provide flexible parameters that have to be defined, measured and incorporated in the full educational process that administers the STEM education. In a forthcoming journal publication we will provide an analytical discussion of these factors as well as a taxonomy of qualitative factors in different scenarios for STEM Education. In a later section in this article we present a first overview of this methodological approach.

Content and collaboration: The first critical consideration in the design of STEM Education programs is the content and the collaboration design.

- Design of Learning Content
- Modularization of Content provision
- Evidence Based Content
- Experimentation
- Theory and Practice Integration
- Community Based Content Creation
- Open Resources
- Lessons Learnt and Best Practices
- Flexible Adoption

Educational process: The second critical pillar in STEM education is related to the justification and provision of effective learning strategies, capable of supporting different learning needs, objectives, and skills development [5], [6], [7].

- Personalized Learning
- Active Learning
- Evidence Based Learning
- Critical Skills development
- Continuous Improvement
- Collaborative Learning
- Special Needs
- Educational Laboratories
- Conceptual Modeling

Administrative factors: The third critical dimension in the design of STEM Education programs is related to the overall strategies for the Administration of the Higher Education.

- Total Quality Management
- New Areas for Development
- Designing of Timely Curricula and Programs
- Interdisciplinary Integration
- Resources Management
- Holistic Evaluation

- Management by Objectives

Technological Innovation: Technology is a key enabler for STEM Education and it should be critically considered in any integrated strategy. The pace of technological evolution is very fast, new technologies appear and change radically the perceptions for the provision of learning content and the enhancement of learning experience [1], [2], [3].

- Integration of Novel Information and Communication Technologies
- Technology Enhanced Learning
- Free and Open Source Tools
- Massive Open Online Courses
- Emerging Technologies Exploitation (Cloud Computing, Big Data, Virtual Reality, Games and Simulations]
- Industry Academia Collaborations [Startups, Competitions, Awards]
- Cognitive Computing

Societal challenges: STEM Education because of its nature should always be capable of addressing critical societal challenges [7]. The following are a few of the societal challenges that STEM education can address with targeted programs.

- Green Economics
- Social exclusion
- Development and Prosperity
- Integration of STEM Outcomes to Society
- Economic austerity
- New Business Models
- Environmental problems

Sustainability: Sustainability is a key philosophical and applied movement towards a better world for all [1], [2].

- Balance between / integration of environmental – social – economic aspects
- Continuous Improvement and longevity
- Community - Industry - Academia Partnerships
- Research Enhancement
- New Knowledge for social innovation
- Performance based on integration of knowledge and affect

2. An integrative methodological framework for effective STEM education

The previous compilation of critical success factors in STEM education proves the complexity of the phenomenon. Undoubtedly any integrated framework for a realistic provision of effective STEM education requires an integrative consideration of the previous factors. On a strategic level, STEM Education should be effective, efficient, motivating, linked to real world problems, providing the required theoretical background to real world problems but also and a clear association to state of the art solutions. At an operational level STEM education should be run on a basis of a smooth plan of measurable, modular objectives, with the integration of didactical stakeholders. In Figure 2, we present a research model that currently guides our empirical research.
The main purpose here is the analysis of qualitative factors that inform learners' performance in STEM education. Towards the development of a value chain model for the design of effective STEM Programs figure 2 is a first visualization of several hermeneutic variables and factors for the perceived value of STEM education. The basic idea is that the aspects of STEM core competencies (and also research variables) depicted in figure 2, and several factors that we will present in a future publication, provide an interesting context for further investigation.

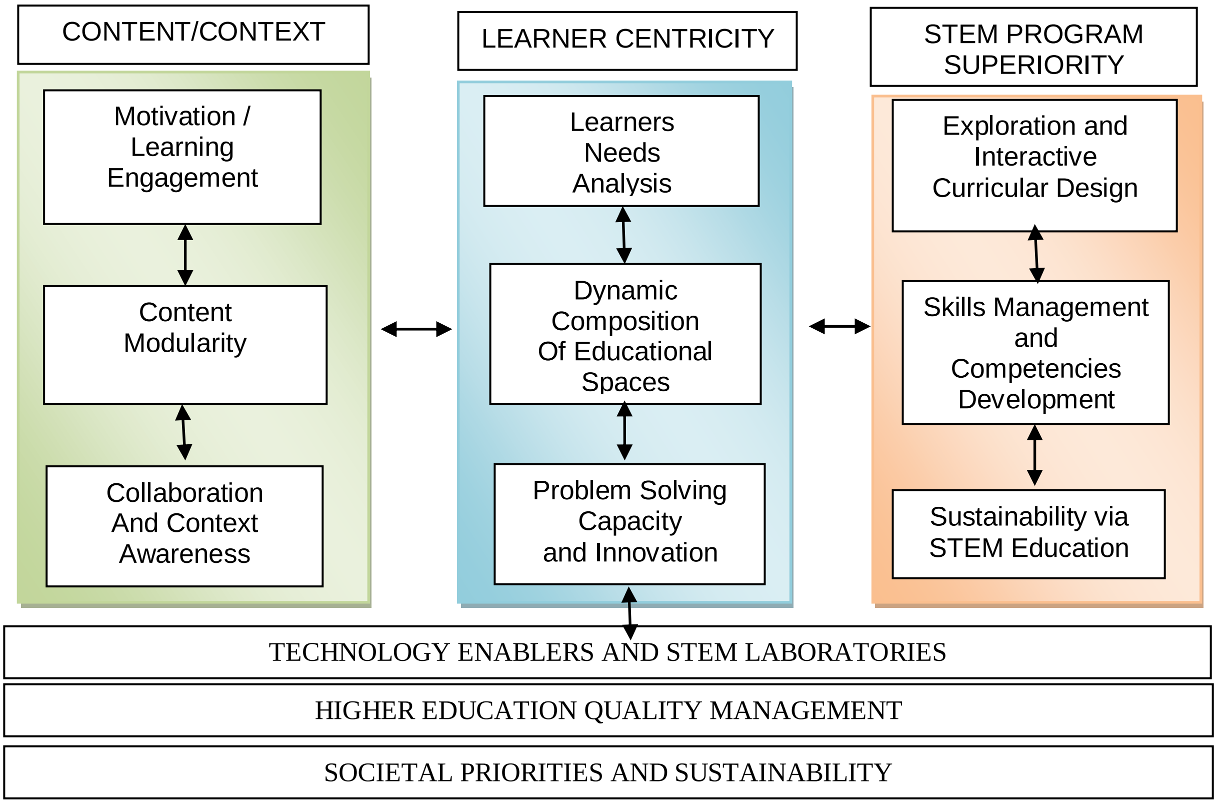

Figure 2. An integrative research model for hermeneutic factors of STEM education excellence

Currently we are in the process of developing a research tool, combining structured questionnaires and in depth interviews with administrators of STEM education, faculty and students. In table 1 we elaborate on a key proposition based on our empirical ongoing research.
The basic philosophy of the model is that a number of hermeneutic factors in each of the 3 pillars of the model provide synergies for value adding components in the provision of STEM Education. The three pillars represented with different colors in Figure 2 are CONTENT/CONTEXT – LEARNER CENTRICITY and STEM PROGRAM SUPERIORITY. Additionally Technology, Quality Management and Societal Priorities are considered as the supportive synergistic approaches that contribute significant value to STEM Programs. The next important question of our research is to operationalize these abstract conceptualizations models and methodologies into practical, easily adopted guidelines for the design of STEM Programs.
Table 1, is providing a first effort for academic consideration. It serves as a model for design of good practices in STEM education. In fact it is an alternative way to strategize the design of STEM Curricula by facilitating a modular approach to the objectives of these programs. We differentiate four critical areas for STEM effectiveness and for each one of them we provide the basic portfolio based critical objectives - novel learning and teaching methodologies, content/context, awareness, learning technologies, and innovative and social responsible STEM education. The integration of these areas set the context for the design of programs as well as the basis for the evaluation of the learning process, the administrative process and for the analysis of the effectiveness of STEM.

Scenario / Strategy	**Novel Learning/ Teaching Methodologies**	**Content/ Context Awareness**	**Learning Technologies**	**STEM for Innovation & Sustainability**
A.	Group Learning	Content Discovery	Collaborative Platforms	Social responsibility
B.	Exploratory Learning	• Open Educational Resources	• Question and Answering Systems • Collaborative Filtering Platforms • Social Networks	• Innovation with a purpose
C.	Concept Modeling / Associations	• Industry Driven Requirements • Literature Studies	• Concept Maps Software	• Integration and multidisciplinarity

D.	Synthesis and Analysis	• Conceptual Modeling • Interdisciplinary integration	• Question Answering Systems • Recommender Systems	• Experiential learning • Critical study • Real problem solving
E.	Active Learning	• Engagement based on personal needs • Profiling	• Educational Games • Simulations • Virtual Reality Environments • Labs • Haptic Technologies • Dynamic Profiling • Recommender Systems	• Experiential learning • Action research • Lab activities • "Green" design
F.	Capstone Mentoring	• Research Based content • Problem Solving • Research Models review	• Research Software • Groupware • Cloud Shared Applications • Brainstorming tools	• Action research • Field work • Problem solving
G.	Peers Mentoring	• Peers Profiling, Skills Profiling	• Collaborative Platforms • Workflow Systems	• Group work & collaboration

Table 1. Model for design of STEM education programs

3. Future research and conclusions

The next steps in our research include four major research initiatives:

- An empirical study related to the perceptions of qualitative factors in STEM education programs. This is going to run in summer 2016. The main focus of the study is to reveal connections between the hermeneutic factors presented in the previous section
- A focused study on dimensions of Active Learning and Teaching Strategies
- The design of three pilot courses integrating the key propositions of our research
- The preparation of a project proposal for Active Learning for STEM education

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