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Guest Editorial

Emerging Technologies for Engineering Education: Flexibility, Consistent exploration, Realism, Integration, and Sustainable Development for Active Learning

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In our era of the technology-enabled entrepreneurship and technology-driven innovation, engineering education has a key role to promote a sustainable model for educating leaders and for creating new contexts for experimental and experiential learning. One of the key challenges modern Engineering Education faces is the fast integration of knowledge to curricula and the design of participatory and student-centered learning models. The nature of engineering problems requires a variety of skills and competencies that have to be developed. This editorial serves as a position paper for the role of ICTs for the provision of personalized learning in Engineering Education. The main contribution is the provision of an integrated model which requires five success factors as prerequisites for the design of any STEM Curriculum and more specifically of engineering curricula.

Keywords: Engineering education; active learning; personalized learning.

1. Active Learning and Action research in STEM with emphasis on Engineering education

In the global context, STEM (Science, Technology, Engineering, and Mathematics) Education is in an era of transition. The core knowledge in all programs is reconsidered in order to meet the fast changing needs of a world that requires quick responses to various and new problems. Engineering education especially is called to provide solutions to pressing problems of contemporary societies and contribute—if not lead the way—to the transition to sustainable societies, with a more balanced relationship between people and the environment. Computer Engineering Education is facing similar challenges. In an era where a number of emerging technologies are evolving, the design of teaching curricula and academic programs requires an integrated learner-centric strategy. In this visioning article we are elaborating on the main aspects of a strategic adoption model of personalized learning environments in STEM education. The justification of a one-fits all pedagogic model to engineering education sounds like an unreasonable effort, given the special features of Engineering context. To the relevant debate a number of complementary approaches have been proposed; active learning [1], experiential learning [2], transformative learning, critical education, flipped classroom [3], blended learning are some examples. Here, we will focus on active and experiential learning on the one hand and action research on the other, as we consider these to be particularly relevant to this discussion. Active learning is about promoting interactions of learners with the learning context and the learning content. The notion of the learners' community is also significant as well as the role of technologies.

The integrative approach of Active and Experiential Learning, Technology driven learning innovation and Teaching Strategies for STEM disciplines in general and more specifically in Engineering is inevitable for the next generation of STEM education, where critical Learning Objectives, Assessment Methods and Program Outcomes should be reconsidered and integrated with the learning process and portfolio management of students.

One of the main problems of past teaching methods is that STEM students have too much information to remember and traditionally they were expected to retain too much where as in Active Learning and Problem-based learning it is the type of learning which results from the process of working towards the understanding of, or resolution of, a problem. Barrow and Tambling [4] provided an interesting context for the use of ICTs for the provision of Active Learning (see Fig. 1).

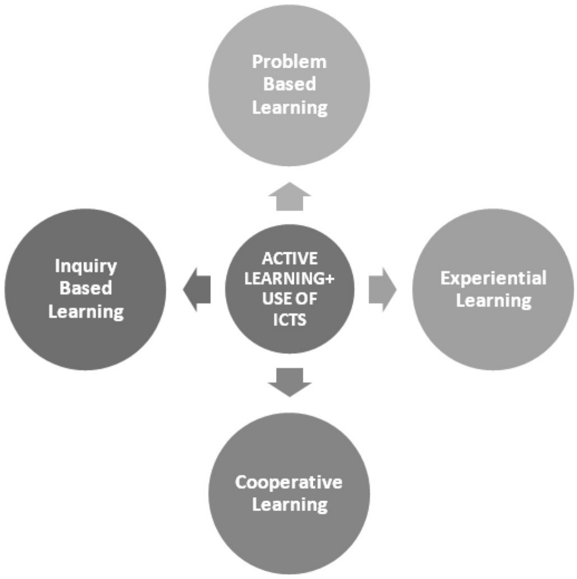

Fig. 1. A context for Active and Experiential Learning [4].

Active Learning in STEM disciplines requires full engagement from the part of the student utilizing an integrative approach via Problem Based Learning, various ICTs, and more direct contact with the Professor and full engagement. So, how do we do it? A brief comparison of the *bottle traditional theory vs Active Learning* shows the benefits but also the drawbacks. According to the *bottle traditional theory* the bottle (student) is already filled with knowledge and is ready to go practice as a STEM specialist. However, given the fact that there is too much information in the STEM disciplines and since information is generated at an exponential rate the main concerns to be addressed is whether the student has acquired the right knowledge, whether it has been remembered accurately and whether the acquired skills will help the graduate solve problems. It is now well accepted that students learn best and retain knowledge when they are actively engaged in the learning process as long as coverage of basic concepts and principles needed to use the knowledge responsibly is not sacrificed on the expense of *Active Learning.*

So what is the overall purpose of introducing new *Active Learning Strategies* and how it should be done?

When an instructor/facilitator employs active learning strategies, he or she will typically spend greater proportion of time promoting deep learning and a lesser proportion of time transmitting information. In addition, the instructor will provide opportunities for students to apply and demonstrate what they are learning and to receive immediate feedback. For such a strategy to be successful, the instructor should include a wide range of strategies and activities (see bullets below) that share the common element of involving students and at the same time self-valuate the things they have done [5].

- Increase student participation by having the instructor pausing for structured activities.
- Increase student engagement by having the instructor requiring responses or by using clickers as an example or a short structured in-class activity is assigned.
- Increase student retention by encouraging student-to-student talk and more practical student collaborations as partners or groups.
- Encourage student ownership in course.
- Less lecturing by instructor so student comprehension during the lecture is assessed directly.
- Find ways to make more exciting the classroom experience and offer opportunities to correct misunderstandings.
- Higher level thinking.

All these traditional guidelines about the promotion of active learning in classroom requires a fresh refinement under the new promises of modern tools and applications related to technology enhanced learning [6, 7]. Several traditional active learning teaching methods and techniques including Think-pair-share (pair-share), Role playing, simulations, Muddiest point/clearest point, Group quizzing, Generate lists, Cooperative learning, Minute papers and writing assignments, PBL and case studies, Concept maps require a more detailed analysis about their impact in class enabled by a number of novel ICTs like Social Networks, Micro content and Micro Blogging Platforms, Learning Management Systems, Intelligent Classroom tools etc.

Additionally in Engineering Education the critical linkage to problem solving orientation increases the complexity of any applied strategy for Active learning since there must be a problem based learning component. In other words any consideration of the learning context in Engineering Education should take seriously into account with realistic and feasible services the following characteristics of Problem Based Learning: Uses stimulus material to trigger discussion, Presents the problem as a 'real life' situation, Guides students' critical thinking, Requires students to work in a group, Encourages the students to identify their own learning needs, Encourages evaluation of the learning process, Graduates are able to enter the next stage of education and development, Graduates are satisfied, well informed and active citizens, and Graduates are adaptable to the needs of community and industry.

Given the character of engineering as a realist discipline and its mission to provide solutions to real, pressing and heavily socio-politically-laden problems of contemporary societies, issues like practical solutions, functionality, safety, aesthetics, imagination, social value/sustainable development constitute primary concerns of the engineering practice and thus of engineering education as well. These issues point to some of the required skills engineering study programs should cultivate in new engineers.

Table 1 summarizes some of these (not claiming to be all inclusive) and includes some of the questions that engineering students need to consider for effective and sustainable solutions. This table can be used as a collaborative working matrix for strategizing the justification of ICTs role in Engineering Education. In fact provides a consultation document for the strategic adoption of engineering education teaching strategies with the use of ICTs.

2. An integrated model for Personalized Engineering education

The main focus of our analysis, in this visioning article, is to examine the strategic fit of emerging Technologies for Engineering Education and how those would lead towards personalized learning environments. We therefore examine a number of parameters setting the following goals:

- To help clarify the role of Active Learning, Technology enabled teaching Methodologies and Social Networks as a key response to the need for effective Engineering Education.
- To help design guidelines for new Engineering Education programs.
- To propose the integrative approach of Active Learning, Technology driven learning innovation and Teaching Strategies for Engineering Education as inevitable for the next generation Engineering Education, where critical Learning Objectives Assessment Methods and Program Outcomes should be reconsidered and integrated with the learning process and Portfolio management of students.

Table 1 Engineering Education: Issues to take into account, skills for new engineers, questions to consider

Engineering—issues of concern	Engineering education—skills	Questions to consider	Teaching methods
Practical solutions	Problem solving Interdisciplinary Investigation of diverse sources of knowledge Research methodology	What is the problem? Who defined it? What excluded? Which are the relevant bodies of knowledge? How can they be integrated? Whose knowledge is relevant? Implications for future generations?	Problem based teaching Case studies Group projects Group discussions Community-based research Role playing Games Simulations Labs
Functionality	Integration of different needs & interests Listening	For whom? For what use?	Survey Discussions with stakeholders Role playing
Safety	Knowledge Foresight Consideration of diverse criteria	Which are the risks? When are they expected? Which are the extreme conditions? Which are possible consequences? Who will get affected and how?	Group imagining exercises Discussions with stakeholders
Aesthetics	Artistic evaluation Consideration of culture	What is beautiful? According to whom?	Survey Human Computer Interaction Virtual Reality and Augmented Reality Projects
Imagination	Creative thinking skills Free thinking / exploration Considering alternatives	What if? Why not?	Imagining exercises Internet searches Brainstorming sessions Collaborative wikis
Social value/sustainable development	Problem posing / critical questioning Democratic dialogue Ethical dimensions—Quality of life Social justice—knowledge and questioning	Why? Why this instead of that? What is "good"? For whom? How has the perception of "good" changed over time? Any negative impacts? For whom?	Investigation of socio-political context Role playing Sustainability projects Societal Value Startups Business Plans Green Computing

- To demonstrate techniques & activities using also ICTs in Engineering Education.
- To help incorporate active learning into our future teaching of Engineering.
- To clarify the need of student empowerment and active citizenship in the field of Engineering.
- To provide critical guidelines for Program Directors of Colleges and Universities for reconsidering the priorities in designing new Engineering Curricula.
- To increase awareness of a key conclusion in that investment in STEM education serves as a key response in order to foster Innovation and Sustainability.

To our understanding, five success factors—and their integration (see Fig. 2)—are prerequisites for the design of any STEM Curriculum and they provide a holistic approach to the issues raised in previous paragraphs:

- **Flexibility**. STEM programs should recognize different learning needs and learning outcomes should be designed with different learning styles in mind. Flexible STEM programs imply a modular design and mechanisms that promote adaptability. Flexibility refers to both the learning content and the learning contexts, using different modes and platforms of learning. New technologies like augmented virtual reality, immersive virtual reality labs, MOOCs technologies, social networks and mobile technologies are used. In our perception, monolithic approaches to the diffusion of STEM education are no longer acceptable. In the near future, a tremendous shift in the design of modular, adaptive curricula, with qualitative (along with quantitative) evaluation criteria will be the standard. From a research point of view, this flexibility in STEM curricula will require extensive experimentation in new *out of the box* learning scenarios.
- **Consistent exploration**. The core knowledge that needs to be transferred in STEM education is a matter of inquiry. In our hyper-connected world, knowledge is available in different repositories and via different sources, and the effort to integrate it in sequential learning scenarios is not adequate for cultivating holistic approaches. Instead, the key challenge for STEM education is to reconsider the capacity of STEM curricula to initiate exploratory journeys to discovery, evolution and creation of knowledge, using—but not limited by—already available one. Engaging students to the exploration of knowledge and to the critical positioning to any knowledge artifact and any problem should be a main aim. It is the next big challenge for STEM education to provide fora for critical questioning in relevance to real world problems.
- **Realism.** The necessity to develop integrated engineering study programs and challenging learning environments that respond to real world problems has to depend on a realistic appraisal of all aspects of learning organizations/academic institutions. The exploitation of infrastructures and the consideration of time and space limitations should inform the design of curricula. Furthermore, realism should also inform the outputs (e.g. proposed designs or products) of engineering educational activities; functionality and safety concerns are important in any engineering work. The challenge engineering education needs to address at this point is the contextualization of this realism. In other words, the political, social, cultural and economic context in which the engineering activity—educational or other—takes place should also be studied in order to propose effective and sustainable realistic solutions.
- **Integration**. Given the hyper-connectivity of our world and the many bodies of knowledge that have been developed, integration of knowledge and approaches is a requirement for present STEM/engineering education. Different disciplines and different knowledge sources should inform engineering education. Such integrative learning requires cooperative learning processes, as well as cooperation of the academic environment, the industry and communities. The challenge STEM curricula designers have to face today is how to achieve a balance between industry-driven demands, student empowerment to

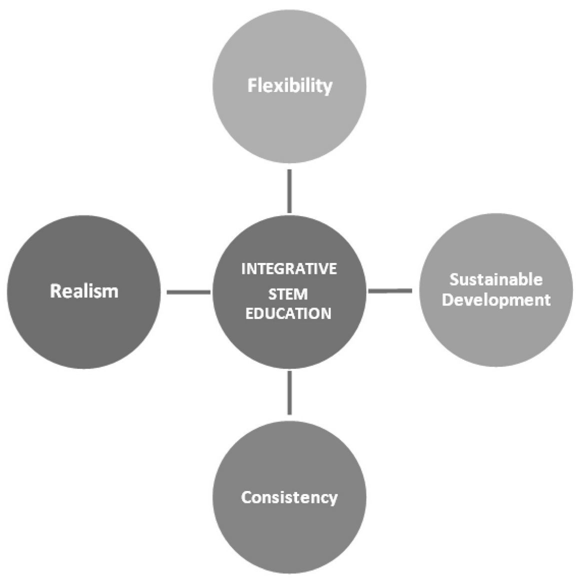

Fig. 2. Five integrated success factors in STEM education.

Table 2

Success factors for STEM education	**Engineering education—desired skills**	**Characteristics of active learning**	**ICTs emerging methods**
Flexibility	Integration of different needs & interests Listening Consideration of culture	Student-centered Experiential learning Personalized learning environments	Content and Context Awareness
Consistent exploration	Creative thinking Exploration Considering alternatives	Inquiry-based learning	Learning Paths discovery Personalized Learning Processes Modular Learning Environments
Realism	Problem solving	Problem-based learning	Cost Effectiveness through Open Source Solutions Promotion of cost effective Cloud computing Virtual Labs
Integration	Interdisciplinary Diverse sources of knowledge Artistic evaluation Democratic dialogue	Cooperative learning	Industry-Academia collaborations Capstone Projects Monitoring Software
Sustainable development	Problem posing/critical questioning Ethical dimensions Quality of life Social justice	Action research—class as research site for community problems	Smart Cities Projects Innovation driven brainstorming tools Entrepreneurship Hubs in Engineering Depts.

become critical thinkers, and socially responsible solutions.

- **Sustainable development**. The flexibility, realism and exploratory character of any STEM program should aim to development at three levels—individual, community, and innovation—as well as their integration. Individuals should promote their knowledge, skills and competences; individuals should work in teams to exploit group dynamics and develop synergies for the benefit of the community; and all these should be with a dedicated orientation to innovation for quality of life and sustainable communities. This is a critical radical change of our times. The engineering discipline is called to become one of the key drivers of innovation offering sustainable solutions worldwide through advanced applied research; to work for the social good, for all people today and for future generations.

Combining the proposed five success factors for STEM education, the important issues and skills for engineering education and the discussion on active learning provided above, we propose the following model for engineering education that can prepare? realist—visionary new engineers, able to design and propose effective solutions to existing problems and simultaneously ways towards sustainable societies (Table 2).

3. Conclusions

The current era of Engineering Education is an era of transition. Sooner or later Engineering Educators all over the world will be asked to reconsider the traditional structures for the provision of curricula and programs. A key shift towards flexible, consistent and sustainable education programs need to be realized. One of the greatest aspects of this shift will be the collaborative emphasis and the requirement to promote a learning culture that incorporates active and experiential learning. Within this new context a number of ICTs will gain critical significance as key vehicles for the provision of academic value. Our contribution refers to the provision of Flexibility, Consistent exploration, Realism, Integration, and Sustainable development as five critical hermeneutic factors for the cultivation of personalized engineering education focusing on active and experiential learning. Early 2017, we are planning a special issue for the Informatics in Education Journal with a more detailed discussion of these factors.

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