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Engineering Education for Sustainability: A Multistakeholder Case Study on ICT and Transportation*

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Under the auspices of the Spanish Royal Academy of Engineering, a large group of academics, civil servants and industry professionals have thoroughly examined the sustainability of the current transportation model and the implications that Information and Communication Technologies (ICT) could have on increasing transportation sustainability. Based on this work, the authors have developed a model to integrate this subject in engineering education.

The research found out the need for additional layers of complexity in the education of engineers. Specifically, engineers need to acquire the corresponding technical competences, the ability to apply them in transportation systems, the transversal integrated competences, and how all this relates to sustainability values.

Truthful to their role in society, engineering schools should be centres of debate for the elaboration of technical solutions to current sustainability problems. In this paper the interplay between ICT, transportation and sustainability, has been analysed showing the role that engineering schools should play as scouts of the future and facilitators of social debate.

Keywords: information and communication technologies (ICT); transport sustainability; transversal competences.

1. Introduction

The importance of including non-conventional disciplines in engineering programs to facilitate that engineers are aware of their responsibilities towards society in a broad sense, has been widely recognized. One of these essential responsibilities is the protection of the environment. [1] examined the approaches to teach environmental matters in the USA higher education, showing that they basically range from learning about "knowing" to learning about "caring".

Until now, engineering education has focused mostly on the "knowing" end of the spectrum of environmental education, as this seems to be the obvious choice for a profession that is so much based in the application of a wide array of technological knowledge. However, with the recent awareness of the profound and lasting implications of technology on the sustainability of our model of society, the "caring" aspects have taken an increasing importance.

[2] compared different methods to integrate sustainability in engineering education and proposed a reorientation of professional engineering education in a more preventively-oriented direction, so that engineering practice could be more sustainable. In a similar way, [3] asked for a change of the paradigms that would require that engineers be educated to question the sustainability of the current patterns of production and consumption and to consider which practices need to be changed. Table 1 shows a comparison between the traditional and the innovative approaches to engineering education when examined from a sustainability perspective.

The American Accreditation Board for Engineering and Technology (ABET) is conscious of the importance of sustainable development as a dominant economic, environmental and social issue in the 21st century. In fact, the Accreditation Process Principles called for the "understanding of and work toward sustainable development, . . . safety and environmental impact." According to [4], a fundamental change in engineering education is required to help the next generation of engineers learn to design for sustainable development and long-range competitiveness.

This change has to be reflected both in the education that new engineers will receive as well as in the role that universities have to play in the corresponding social debate. For instance, the Association of University Leaders for a Sustainable Future has declared that the University has "a major role in the education, research, policy forma-

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Table 1. Traditional vs. Advanced approaches to integration of sustainability matters in engineering education

Issue	Traditional approach	Advance approach
Learning	Knowing	Caring
Action	Mitigation	Eco-design
Management	Risk-management	Strategic management
Inclusion in CV	Additional to CV	Transversal in CV
Aim of the degree	Educate professionals	Educate responsible citizens

tion, and information exchange'' necessary to create a sustainable future. On the other hand, the Presidents, Rectors, Chancellors, Vice-Chancellors and representatives of leading educational and research institutions in the G8 member nations attending the 2009 G8 University Summit acknowledged the important role that education plays in informing, promoting and implementing sustainable and responsible development.

This transformation will include new global challenges, most notably avoiding climate change, which requires a drastic reduction of global Greenhouse Gas (GHG) emissions, with a corresponding change in the future energy mix and, of particular interest for this paper, in the transportation system. Since transport is the main source of GHG emissions in developed countries [5], special efforts have to be applied in this sector [6]. The measures that have been adopted so far (e.g. Euro standards in the European Union) are helpful in reducing emissions somewhat, but they are clearly insufficient. In fact, GHG emissions from road transport in EU-27 have grown 30 % since 1990. Moreover, road transport is also a human health hazard, mainly due to its impact on urban air pollution [7]. Therefore, the transport sector is crucial in building a sustainable model and engineering schools, in close relationship with industry actors, should participate actively in the research on more sustainable transport systems and in improving the awareness for changes in the social behaviour.

2. Presentation: framework of the case study as conclusions of the multidisciplinary panel of RAI experts

The Spanish Royal Academy of Engineering (RAI) launched in 2009 the study ''ICT contribution to transport sustainability in Spain'', with the participation of a panel of 62 authors (13 academics, 13 university professors, 11 civil servants and 25 professionals from energy, transport and the ICT industry) [8]. The RAI was aware of the strong economic, social and environmental relevance of the transportation sector, as well as the potential of the ICT to enable profound changes in industrial activities and in social behaviour. This is why the RAI decided to launch a multistakeholder, pluridisciplanary debate on the role that ICT could play in finding solutions to the negative sustainability impact of the transport sector.

The study identified and examined three areas where the ICT could be helpful: reduction of mobility needs, mitigation of transport impacts and facilitation of behavioural changes. The role of ICT was analyzed from a multidisciplinary approach. This triple thematic perspective—transport, ICT and sustainability—were the main challenge in this study, because the knowledge and experience of the experts was, at most, in two out of the three topics. The RAI organized general focus groups for all the participants and specialized focus groups by chapter. The work was organized by means of several thematic sessions, conducted by the coordinators, where the experts could discuss preliminary findings and contributions: discussion papers, case studies, etc.

The case studies constitute an important methodological contribution of this research. The support from public and private organizations allowed to include actual industry experiences, pioneer technologies, solutions and tendencies for sustainable transport from public institutions (the Madrid city hall and the Spanish ministerial area responsible for ICT), and private organizations (Alcatel, Telefónica, Iberdrola, REE, Alsa, Nissan, RENFE, Indra, Telvent, Cepade, UOC and Fundación Ceddet). At the same time, they identified the main roles of each stakeholder in promoting sustainable transport. These roles are summarized in Fig. 1.

One of the findings of the study is the need for additional layers of complexity in the education of engineers. Sustainability should be a major pillar in today's engineering education and therefore has to be present somehow in the curriculum. In order to be well equipped to address the challenges of present transportation systems in a comprehensive manner, engineers need to acquire the corresponding technical competences, the ability to apply them in transportation systems, the transversal integrated competences such as the potential of utilization of ICT, and how all this relates to sustainability values.

This finding motivated the authors of this paper to undertake a research project on the development and implementation of a competences model minded to include, in the academic curricula of

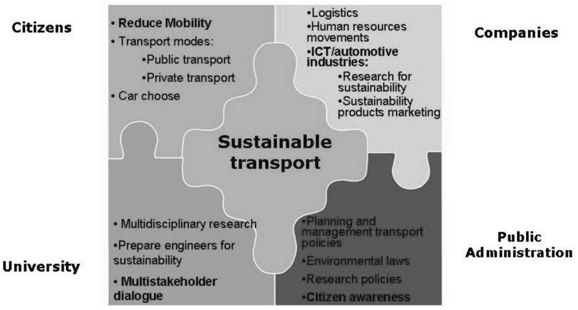

Fig. 1. Stakeholders role in sustainable transport.

engineers—especially of those specialized in transport—the key issues identified by the RAI research group.

This multidisciplinary research and the multistakeholder dialogue are expected to have a positive impact through the transformation process of the professor's knowledge and the institutional approach to sustainability issues. But the focus of this paper goes further, because it uses the outputs from the research to educate engineers for sustainability by introducing adequate changes in the present academic plans.

3. Objective and methodological approach

As indicated above, the objective of this paper is to develop and to apply a competences model to examine the potential integration of the key issues identified by the study of the RAI into the academic curricula of engineering schools. Experts' contributions, as well as the specific case examples that had been used in the RAI study, jointly provide the framework and the legitimacy source for the analysis to be performed here. It is to be noticed that the RAI is a much respected institution, with a direct influence not only in the professional domain, but also in academia. In fact, the focus groups agenda included the role of engineers and the challenges for university as a major concern.

In the RAI study, a competences model for an engineer with a particular emphasis on sustainability is proposed. Its main features are described in Table 2.

A competence is defined as a set of conduct patterns that leads the person to perform efficiently his/her tasks and functions, and is built on three components: knowledge, ability and expected behaviour [9]. A competence model corresponds to a group of competences that is required in a particular professional profile.

Taking these inputs as a first step, the research presented in this paper was structured into three different phases:

1. Exploitation and systematization of RAI research findings that could be related to sustainability competences for engineers, following the framework presented above. The main result is a "competence matrix" that could be used for other programmes.
2. Contrast and validation of the competence matrix through focus groups with university professors, at one of the largest technical universities in Spain (UPM).
3. Development of indicators to evaluate the viability of implementing the competences in education for transport engineers for sustainability including an application to one of the programmes at the abovementioned university.

The process and results for these phases are presented in the next sections.

4. Discussion—phase one: exploitation and structure of results

The RAI study contemplated three approaches to improve the sustainability of transport with the help of the ICT: reduction of mobility needs, mitigation of transport impacts, and changes in citizen behaviour. This perspective sheds a new light on the interactions between transport and sustainability as transport policies should focus on improving accessibility or "creating proximity" but avoiding environmental, social and economic costs derived from an increment of the transport activity.

In the model, every block has different competence requirements from the engineers' education (Fig. 2). Reduction of mobility needs and changing citizen behaviour are mainly related to transversal technical integrated competences and values, while reduction of transport impact is closer to basic technical and applied competences and, therefore,

Table 2. Competences model

Competence category	Definition	Example in transport sector
Basic technical	Related with basic subjects for engineers	Mechanical engineering
Applied technical	Orientation to provide technical solutions to industries	Transport
Transversal technical	Comprehension of technology areas that have impact in a given sector not being part of its core technologies	ICT
Values	Background attitudes that establish implicit priorities while taking decisions	Sustainability implications

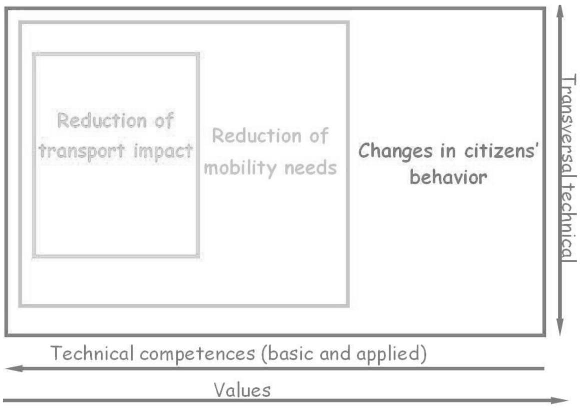

Fig. 2. Model framework.

fits more easily into traditional engineering curricula.

The identification of competences has been made according to the four categories previously defined: basic technical competences, applied technical competences, transversal technical competences and values. The method applied to identify the adequate competences suggested by the RAI expert groups consists of the following steps:

- Consider a theoretic prototype for a mechanical engineer focused on transport systems. The student would be any industrial engineer with interest on transport issues. It has no correspondence with any existing grade.
- Select the key ideas from the reports to identify the competences that the experts have suggested. Some of the competences are clearly pointed, while others are deducted indirectly.
- Match each competence to one of the four groups defined in Table 2.
- Define in detail the selected competences.

Results for each category are shown in the following paragraphs. A table summarizing the findings is also presented and it constitutes the starting point for the focus groups with professors and it helps to complete the evaluation of indicators.

Basic technical competences

The competences for this level of the framework are not identified here in an exhaustive way, since this job has been done elsewhere and it has to be done for each one of the required key basic technical competences. These competences could amount to more than one hundred, and they respond to a very high technical expertise profile that is usually covered at engineering schools.

Applied technical competences

The more innovative competences, which are related to technological trends in transport, at the time that are related to ICT, are shown in Fig. 3 as well as the evaluation of those areas with higher sustainability impact. It highlights the technological innovation which is more relevant for every transport mode (road transport, train, plane and ship), considering different categories for passengers and goods. There are three rows for the application of technology to vehicle, infrastructure or traffic management. ICT innovation is also relevant at technical competences level, particularly for those related with collaborative platforms, web 2.0, etc.

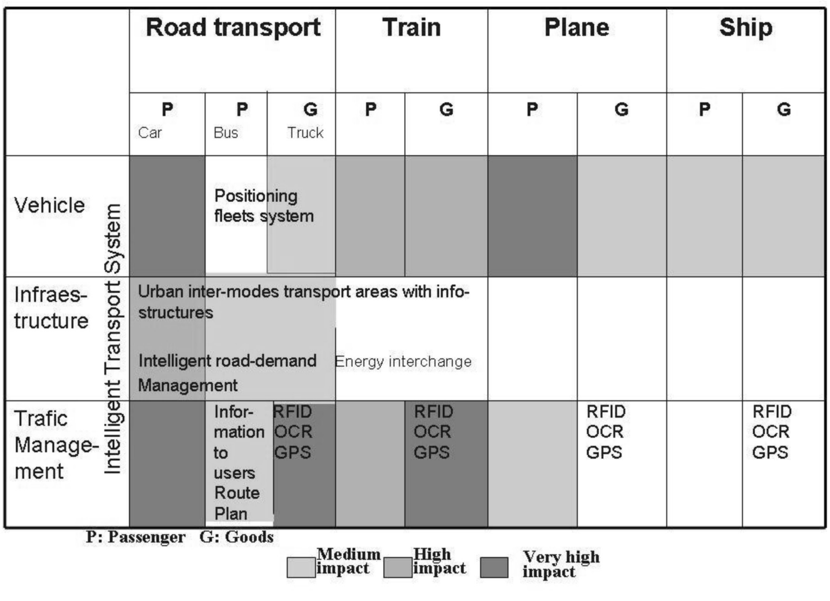

Fig. 3. Key technical trends (RAI, 2009).

Transversal technical competences

Competences identified at this level are:

- Holding a vision that includes:
  - Transport Systems as new paradigm (vs. transport modes).
  - ICT as tools to change mobility schemes.
  - New service models (e-models).
  - e-work, e-learning, e-cooperation opportunities.
  - Awareness on reduction of mobility needs.
- Understanding the roles of the different actors:
  - Companies.
  - Public administration.
  - R&D in universities.
  - Academic plans for students.
  - Multistakeholder approach.
- Leadership skills that combine:
  - System vs. detailed technical approaches.
  - Analysis capability.
  - Relationship capabilities.

Values

The competences included in this level are:

- Strategic vision.
- Innovation.
- Sustainability awareness.
- Cooperation ability.
- Positive change management.
- Pluridisciplinar capability.
- Open and interactive communicating orientation.

The results of the complete process are summarized in Table 3, where both the four categories and the three perspectives are explicitly considered.

5. Discussion—phase two: validation of the competence matrix

With this set of competences as the starting point, a focus group with professors from one of the largest technical universities in Spain has been formed. The objective was to jointly examine the identified competences and their potential application to a pilot project in an Industrial Engineer School.

Discussions from this focus group were divided into two different parts:

- A general debate on the competences identified in Table 1 in order to explore the innovation that ICT could bring to the existing subjects.
- The development of indicators to evaluate the viability of the implementation of the identified competences in the curriculum of transport-oriented engineers, particularly to the subjects they teach in the master degree.

The conclusions of the focus group on the competence matrix (Table 3) can be summarized as follows:

- University professors have a major role to play introducing sustainability topics in their subjects, such as environmental impacts and the role of technologies for finding solutions.
- As a first step to be able to comply with the task in the previous bullet is that these sustainability values are internalized by the professors themselves, what presently is not the case in general at the technical universities. Values, moreover, need to be part of the institutional culture.
- From a theoretical point of view this set of competences are interesting for mechanical engineering, industrial engineering and environmental engineering. Nevertheless, the process to adapt this competence model to the current subjects would not be easy. On one hand a more detailed definition for each competence is needed, and the number of the competences model should not be higher than 10. On the other hand, the subjects would need a strong revision, to introduce new contents and, what is more difficult, to leave apart others considered equally important.
- Changes required to gradually introduce these competences in the curriculum, are related to contents, methodologies and coordination mechanisms among the subjects.
- Many of the identified competences consist of technical knowledge that should be complemented with practical contents and, therefore, can be managed separately by each lecturer.
- Applied technical competences and transversal technical competences need a consistent work with students during several years, with incremental learning of the identified competences.
- The framework is useful as a model for other areas of engineering, adapting the specific competence for each technology or discipline.

6. Discussion—phase three: indicators

Since a major outcome of the debate was the difficulty in implementing the required changes in the curriculum, each competence was individually examined and three indicators were selected to evaluate the viability of its gradual implementation. The three characteristics of each competence to be appraised by the indicators are:

- The level of maturity or internalization in the present culture of the engineering school.
- The relevance for the students in the process of incorporating sustainability concepts in the revised curriculum.

Table 3

	Transport and sustainability		
Competences	**Reduction of mobility need**	**Reduction of transport impact**	**Changing citizen behaviour**
Basic technical competences	Specific for each technology	Specific for each technology	
Applied technical competences	ICT sector innovations	Intelligent Transport Systems Infrastructure-vehicle communication RFID OCR Positioning fleets system Electric vehicles New technologies for propulsion . . .	Web 2.0
Transversal integrated competences	Holding a **vision** which includes: • ICT as tools to change mobility schemes • New service models (e-models) • e-work, e-learning, e-cooperation opportunities. Understanding **roles** of different actors: • Companies • Public Administration • R&D in universities • Academic plans for students • Multistakeholder approach **Leadership** skills to combine: • System vs. detailed technical approach • Analysis capability • Relationship capabilities	Holding a **vision** which includes: • Transport Systems as new paradigm (vs. transport modes)	Holding a **vision** which includes: • Reduction of mobility needs awareness
Values	• Strategic vision • Innovation • Sustainability awareness • Cooperation ability • Positive change management	• Pluridisciplinar capability	• Open and interactive communicating orientation

- The operational difficulty of implementing this competence in the master subjects.

Table 4 shows the results of the analysis of the indicators applied to the bachelor and master of industrial and chemical engineering as well as some suggested pedagogical innovations, in particular for the first steps in the incorporation of each one of the competences. It will also be used for priorizating those competences with higher relevance and lower maturity and suggesting actions in the future. For instance, actions to promote pluridisciplinar capabilities appear as the most interesting for a first step.

7. Conclusions

There is no doubt that sustainability, from an environmental—but also social—point of view, is today a major concern in engineering activities.

Nevertheless, the consideration of sustainability topics in the curriculum of the future professionals is still insufficient in the majority of high education programs. It requires much more actions than including an additional set of themes and subjects in the ‘‘traditional’’ curriculum. Dealing with sustainability in engineering is not only a question of knowing ‘‘green’’ technologies, it also has to be with the interaction among technical, social and natural systems, what leads to consider competences and values. In short, it implies to manage a real change process that needs the commitment of academic authorities, teachers and stakeholders (among which private sector and non-profit organizations should have a main role).

In order to guide this change process, a conceptual framework and a related methodology for its application has been developed with a multistakeholder approach. It has also been applied in the main Spanish technical university (UPM), where the traditional degrees and masters are experiencing a deep revision to be adapted to EEES requirements. A specific case—the sustainability of transportation with the help of ICT—allows illustrating the implementation of the proposed methodology.

Table 4. Competence indicators

Competence category	Competence name	Maturity (1)	Relevance (2)	Operational difficulty (3)	Pedagogical innovation suggested
Basic technical competences	**Specific basic technologies**	C	Medium	E	Research papers as part of the subject materials
Integrated and applied technical competences	ICT sector innovations	T	High	E	Research papers as part of the subject materials
	Intelligent Transport Systems	T	High	E	
	RFID	T	Low	E	
	OCR	T	Low	E	
	Positioning fleets system	T	High	E	
	Web 2.0	I	Low	M	
Transversal integrated competences	Holding a **vision** which includes: • ICT as tools to change mobility schemes • New service models (e-models) • e-work, e-learning, e-cooperation opportunities.	I	Medium	M	Annual workshop for lecturers on sustainability trends
	Holding a **vision** which includes: Transport Systems as new paradigm (vs. transport modes)	T	High	M	Annual workshop for lecturers on sustainability trends
	Understanding **roles** of different actors: • Companies • Public Administration • R&D in universities • Academic plans for students • Multistakeholder approach	T	High	H	Case studies for different organization profiles
	Leadership skill: System vs. detailed technical approach	T	Medium	H	Classroom debates (cases, papers, videos)
	Leadership skill: Analysis capability	C	Medium	H	
	Leadership skill: relationship capabilities	I	Medium	H	
Values	Strategic vision	I	Medium	H	Workshops (blended learning) for lecturers, researches and students.
	Pluridisciplinar capability	I	High	H	
	Open and interactive communicating orientation	I	Medium	H	
	Innovation	T	High	H	
	Sustainability awareness	T	High	H	
	Cooperation ability	I	Medium	H	
	Positive change management	I	Medium	H	

(1) Innovation—I, Transition—T, Consolidated—C.
(2) High, Medium, Low relevance to deeply understand sustainability.
(3) Easy to implement—E, Normal—N, Hard to implement——H.

This practical experience has included the discussion of preliminary results by means of a focus group with faculty. It has confirmed the adequacy of the methodology as a tool for systematizing the different tasks constituting the process of change towards a curriculum adequate to give answer to new sustainability requirements. At the same time, it has highlighted the necessity of tools to facilitate the comparison and prioritization of actions. In this sense, a preliminary set of competence indicators has been developed and applied to particular case examples.

In conclusion, this work has proposed and tested a methodological framework that can guide the decision to change the process of adaptation of engineering degrees and masters to the new requirements of sustainability, according with academic and industry requirements. It can be easily adapted to the particular circumstances and context of many universities and high education institutions that, in many countries, have already accepted the challenge of contributing to a more sustainable society.

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