Re-inventing engineering education: a new challenge

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ABSTRACT: Over the last decade, many authors have voiced their concern about the future of engineering education being affected by sweeping changes in the global economy. These changes require an adjustment in the educational policies of institutions that provide knowledge and learning to new engineering candidates. This article provides a framework for the re-design of engineering education in order to fulfil the expectations of employers in the near future. This framework addresses the way in which data is acquired and classified, the curriculum is integrated and inverted, information is visualised and presented, research and development conducted, as well as the collaboration of all parties encouraged. The educational contents and techniques that are required to satisfy the needs of society at large must be decided around a table with the parties involved in the learning process.

INTRODUCTION

Employers, administration, instructors and students are showing increasing discontent in the way engineering education is being implemented today. A possible way to resolve this situation is to introduce more *project-based learning* as a prerequisite. This will assure that students learn what is relevant in their practical life. Unfortunately, this approach seems to have several drawbacks. Many instructors consider that this approach takes too much of their time and it is not always possible to ensure that students behave honestly.

Nevertheless, experience gained in teaching different courses to freshmen students shows that if the learner feels pride with the work they accomplish, a *self learning* habit is developed. This realisation is more important that the extent to which the content is covered and the possibilities of misbehaviour. Ways to deal with this situation have been covered elsewhere [1].

A FRESH LOOK AT EDUCATION

The experience gained during three decades of practice in teaching in the universities and in industry encouraged the author to take the liberty of making ten recommendations for a fresh approach for the enhancement of engineering education. These recommendations are detailed below.

Data Acquisition

It is suggested that learners should acquire knowledge following the chronological order in which the knowledge was originally developed. Motivation to learn can be enhanced if the owners of the knowledge are presented to the learner in the context of the time of the discovery. The experiences gained by a researcher and instructor on environmental sciences is a good example for this proposal.

Prof. Curi devoted all his professional life to finding solutions to the ever-growing problems facing the well-being of our planet. His research work inspired many of his students to do further research and implementation work. His memory is always fresh in the minds of those who had the fortune of knowing him personally. His concern for the environment encouraged him to also research in the field of social sciences and his last contribution was in the field of environmental ethics. Table 1 lists a few of the findings presented at the *1st Environmental Ethics Symposium* he jointly organised with UNESCO. Several well-known international authors had made valuable contributions. Further details of his wonderful accomplishments have been reported previously [2].

Case Classification

Concurrent to the acquisition of data, a classification system must be developed. *Case-based learning* is an excellent tool to help the learner in retrieving information when developing a new project. This new technique provides the means to categorise different cases in accordance with the instances of predefined attributes. An example the author has developed for operation management education can be seen in Table 2. Using the attributes suggested in the table, the cases that best fit the instances of a new project can be selected for current usage.

Although this tool has been mainly used for engineering design purposes, it can also be used in engineering management applications. Previous work presented the experiences gained while developing a *case-based reasoning* scheme in project management. Practice has shown that projects are in most cases delayed and over-costed. Predictions for new projects can be made if enough information is available from completed projects. Collaboration with practitioners is required in this context [3].

Table 1: Selection of recommendations from the *1st Environmental Ethics Symposium*, held in Istanbul in 1996.

#	Summary of recommendations made
1	A report by the IEEP shows that industry, schools, media and other institutions should join efforts to spread environmental *awareness*.
25	Developing the norms to the reverse the deteriorating environmental conditions should start by awakening the consciousness of *human identity*.
35	The rights of non-humans and future generations not able to be represented should be considered.
43	The establishment of an *intergenerational justice* scheme can assure the survival of future generations.
69	Utilising the *Unscrupulous Dinner's Dilemma*, it is questioned whether the future of nature can be left to human will or if a management *scheme of protection* is needed that considers economical, aesthetic and ecological reasons.
83	Although acknowledging the degree of devastation observed in nature, *environmental activism* endangers the institutional balance. Adequate target groups can help in resolving environmental problems.

Table 2: Examples of attributes for operation management activity parameters.

Grp	Item	Attribute 1	Attribute 2	Attribute 3
Character	*Scope*	Simple	Connected	Complex
	Level	Strategic	Tactical	Operational
	Environment	Static	Evolutionary	Dynamic
	Goal	Single	Multiple	Fuzzy
	Data	Small	Large	Huge
Conditions	*Relations*	Simple	Connected	Complex
	Expectations	Low	Middle	High
	Difficulties	Small	Large	Huge
	Techniques	Simple	Connected	Complex
	Solutions	Single	Multiple	Fuzzy
	Results	Single	Multiple	Fuzzy
	Conclusions	Simple	Connected	Complex

Curriculum Integration

Engineering is a profession that requires the synthesis of knowledge that has been already developed by many other disciplines. The engineering candidate must develop skills to deal with the knowledge that is emerging from the natural and social sciences. A very good example of integration can be seen in the now very popular field of *mechatronics*. As shown in Figure 1, electrical and mechanical applications are being integrated from various fields. Developing transport, power and industrial projects require the merger of components, devices and systems that were originally from different fields.

The candidate to the engineering profession should clearly see and understand how the various basic components make up particular devices and how these devices form part of more complex systems. *Softcomputing* helps in the integration for the operation of the products. Breaking the artificial boundaries between self-imposed and perpetuated disciplines is a challenging task that engineering instructors have to face [4].

Programme Inversion

It is recommended here to change the engineering educational programme so that the learner is exposed to different areas of expertise right from the beginning of the studies. Through the years, the learners should develop the habit of *revisiting* the same subjects with an ever-deepening breadth. An example of an undergraduate control engineering *programme inversion* is given in Figure 2. Since the aim of a control engineering programme should be the development of products that are in accordance with the specifications, a closer look to design practice is envisaged in the figure.

In this example, electrical and mechanical components should be brought together with the support of a computer program. Learners should gradually develop skills in the use of basic knowledge of mathematics and physics for the design of systems. This new approach to education should ensure that the learner is capable from the first year to develop relevant projects [5].

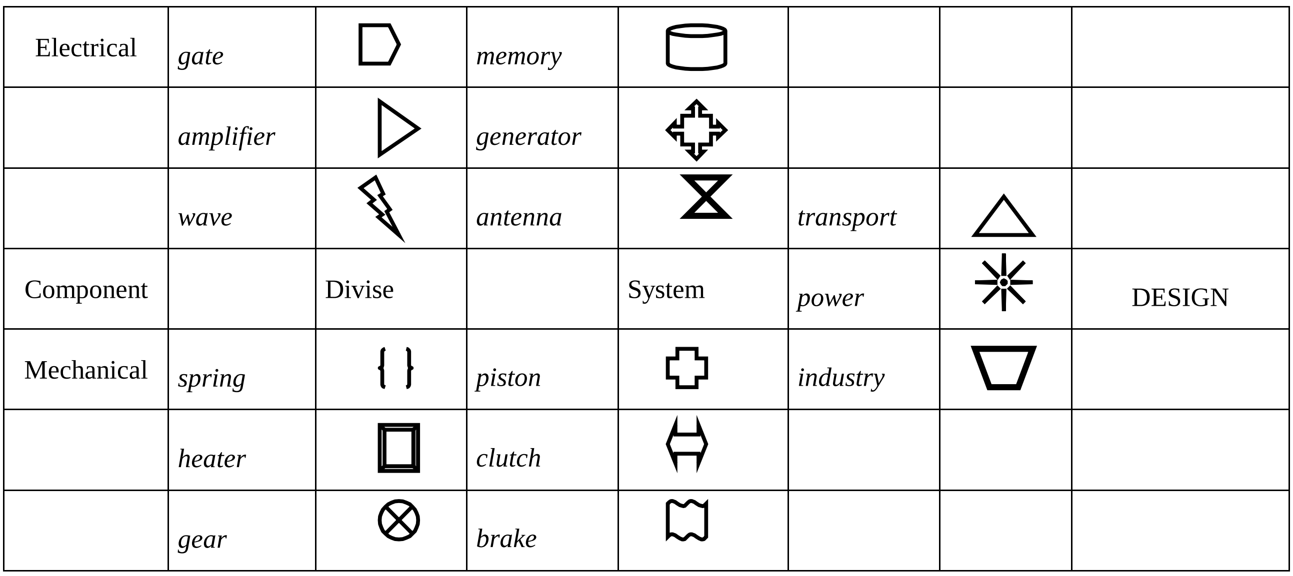

Figure 1: Integration of electrical and mechanical engineering disciplines.

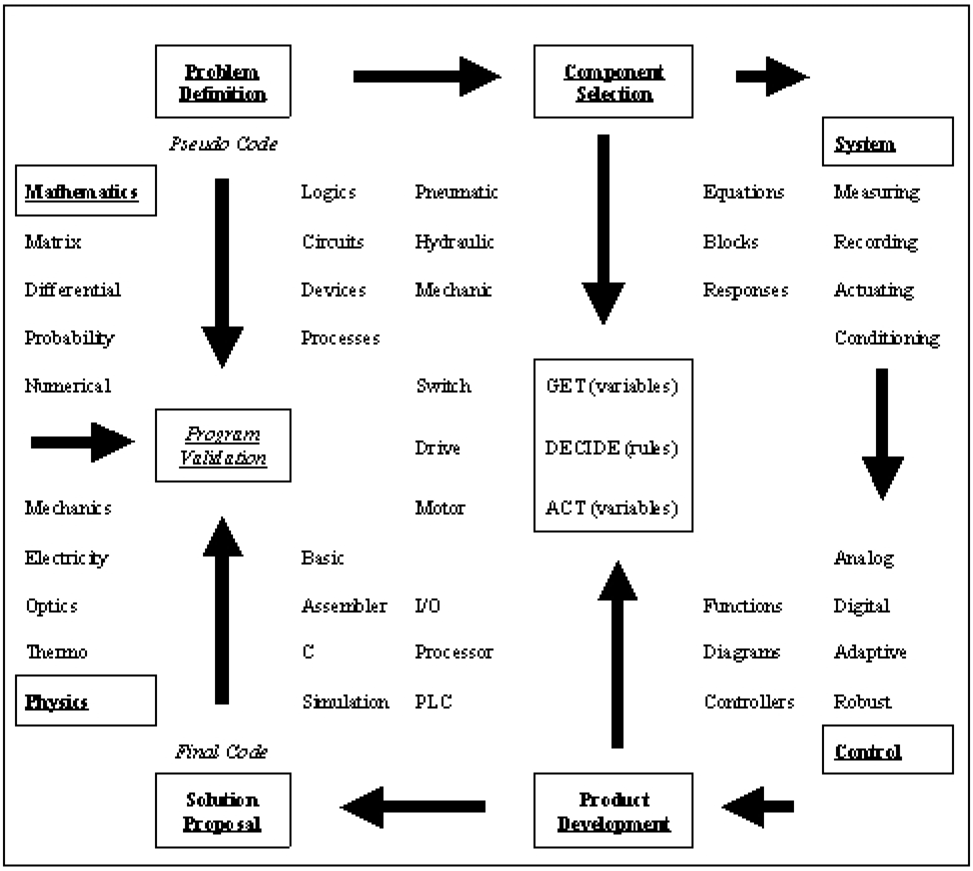

Figure 2: Proposal for an inverted curriculum for an undergraduate control engineering programme.

Symbolic Representation

Although the solution of many engineering problems is based on the crunching of numbers, new ideas can only develop if a symbolic representation is made to help in visualising the problem. Simple symbols for mechanical components are presented in Figure 3 as an example. Complex systems are only the aggregation of the basic components. Over the years, learners should master the practice of combining components within a given framework.

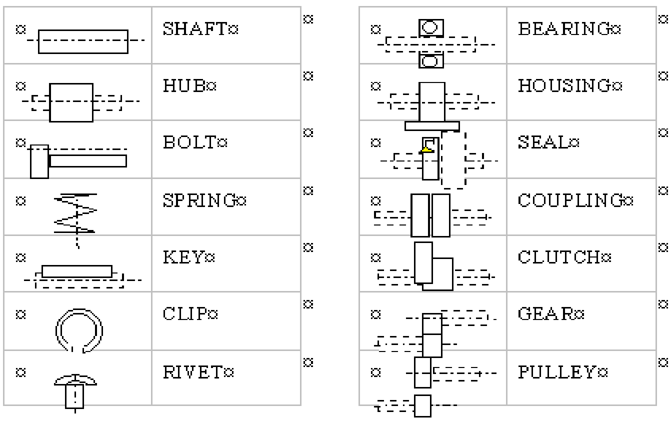

Figure 3: Machine elements symbols used by the freshmen students in the introductory course.

Proper use of industrial catalogues can help in understanding the implications of designing complex systems. Students should always be assigned to unique projects where they can develop hands-on skills. Close guidance has given promising results in a freshmen engineering class; this was reported elsewhere [6].

Oral Presentations

Once the ideas have been developed on paper, an engineer should be able to present them orally to all related parties. Presentation practice requires special skills that should be gradually developed, starting with small projects. Selling the idea is an important stage in the development of a project. Encouraging freshmen students to stand up in front of the class has been the main concern of the author during the last few years (see Figure 4).

Figure 4: Student presenting orally the weekly work.

It is important that all students present their weekly progress at the beginning of each class. The instructor should then make a general overview of the work done and, after giving the grades, make suggestions for the next week. When the individual projects have reached certain maturity, groups can be assigned to work together. At this stage, it is very effective to create an atmosphere wherein students deliver the presentations in groups and then participate in making suggestions to each other [7].

Conceptual Mapping

Research work needs to be related to practical applications. Conceptual mapping provides an adequate tool to make this transition. Learners should develop the skills of synthesising the knowledge created during the research work so that it can be implemented effectively. In Table 3, the work published by Prof. Curi in 1974 is given as an example. Classification of the work by an area of specialisation, design technique and location can help students develop new ideas.

Table 3: Classification of some of Prof. Curi's publications.

#	Area	Design	Location
74-1	Water	Filtration	
74-2	Water	Assimilation model	River
74-3	Water	Pollution	River
74-4	Solid	Collection	Hospital
74-5	Water	Solid-liquid separator	
74-6	Water	Sewage disposal	City
74-7	Water	Filtration mechanism	
74-8	Water	Declining flow rate filter	

The changes in the environmental engineering topics that Prof. Curi made during his career can be seen in full detail in another document. The shift from water treatment to waste water management and finally to research in solid waste disposal can be clearly followed. In all the publications his zeal in protecting nature and human health by developing adequate techniques proves that the reconciliation between the research and educational activities is possible [8].

Innovative Approaches

Transforming new ideas into practical applications is a process that the learner must be exposed to while developing successive projects. Consultation with the client at the right time can save work that otherwise may be wasted. Proper documentation of the process helps in making the necessary changes as required. The author has been working closely with students in developing close-to-real life projects. Personal contact with each student helps in creating an atmosphere of mutual trust.

As shown in Figure 5, a student has developed new ideas using LEGO techniques. This technique allows changes to accommodate the suggestions made by the instructor acting in the role of a customer. Real cases can be reported where students have continued to work on the projects they have started when in school. Integrating out-of-class activities with the mainstream curriculum must be considered [9].

Teamwork

It is impossible to think of today's engineer working in isolation during the whole design process. Skills in dealing with others must be developed so that conflicts are avoided and bright ideas are incubated. In many cases, it is necessary to work with experts in other fields. Only experience can provide the path for self-development and leadership. It is hoped that instructors will also join in collaborative teaching.

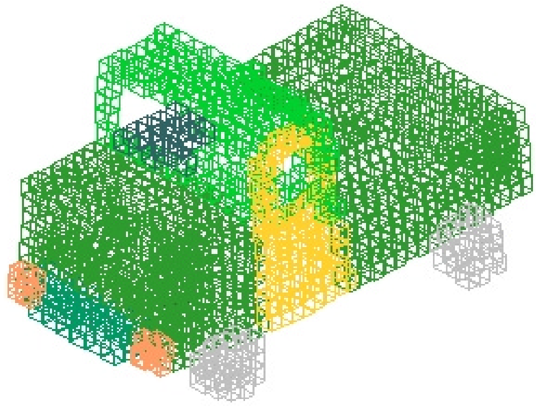

Figure 5: Drawing of a truck using the LEGO technique.

Figure 6 shows students working in a recently completed course on design using LEGO material. Each student was assigned with a different object and was expected to work separately during the first half of the session. However, in the second half, students were asked to match their work in pairs. The need to make changes to fit size and form became immediately clear. Iterative work under the guidance of the instructor helped in creating a real life situation [10].

Figure 6: Students developing LEGO items.

Mutual Cooperation

Engineering education today cannot be possible only within the boundaries of universities. As the costs of various equipment for experimentation increases, support from industry is required more and more. Agencies should act as brokers of knowledge to safeguard the intellectual properties of the owners. Research is possible only if adequate resources are provided. A *spirit of enterprise* must be created if all parties involved are to benefit from the joint ventures.

Figure 7 shows a potential model for cooperation between government, industry and universities. An independent overarching institution (named *academy*) can help in facilitating dialogue between the three parties. Government agencies can help in the development of sound policies for cooperation in the centres where industry has a liaison office. Foundations, unions, associations and trade chambers can also assist in the mutual exchange of human and other resources [11].

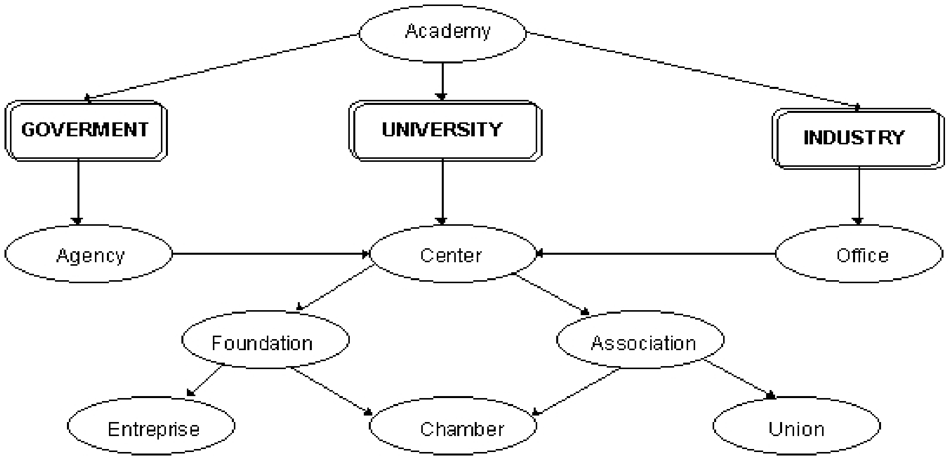

Figure 7: Model for collaboration between government, university and industry institutions.

CONCLUSION

A framework for the implementation for the reform of engineering education has been presented in this article. The framework includes issues that cover both the content and the methods in which the curriculum should be designed in order to satisfy the needs of a changing world.

As shown in Figure 8, the parties involved in the educational process should come together to ensure that implementation in the classroom is in fact in tune with the policies mutually agreed upon [12].

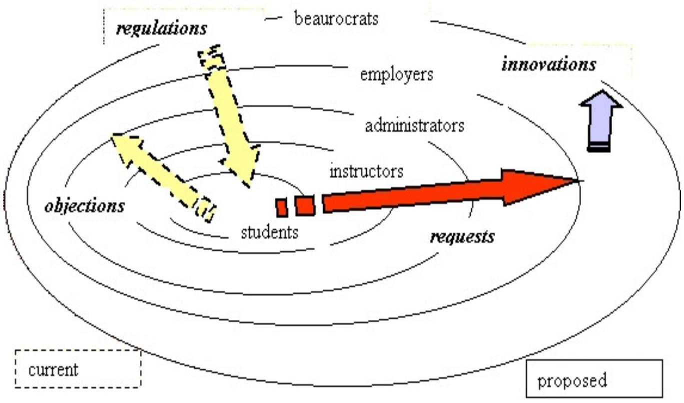

Figure 8: Proposal for improving the dialogue between educational partners.

Engineering learners must be exposed to the whole programme from the very beginning of the studies and made aware that education is a life-long-learning process. Developing the habit of searching for excellence will benefit them directly.

Furthermore, keeping a portfolio of all the work completed provides a good incentive to measure progress. It is expected that a sense of genuine pride will develop thus enhancing self-motivation. Students and instructors should work as co-learners.

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