Emphasizing the Role of Model in Engineering Education.

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Abstract

Practicing engineers, scientists and researchers use models naturally. Students, on the other hand, are presented with models and applications, as if the concept of models and their relationship with objects and applications were obvious and innate. The apparent disconnection between classes and "real world" is a source of frustration and might be very often related to the lack of knowledge of how and why models are important for us. This importance goes beyond the models found in textbooks. This work presents some ideas that might be used in classes to illustrate and talk about these roles. The experience we have had with students to whom these ideas have been presented shows that understanding these roles helps them.

Introduction

Modelling is inherent to our daily life and without doubt to our professional activities. All our actions, beliefs, decisions, are determined by the models we have of our surroundings, other people, objects we work with and so on. Of course, we do not think at all on models in our daily life and there is no need to do so. Furthermore, in our profession we become so accustomed to some models that many of us loose sight of them in the process. Yet, when it comes to science and engineering, being aware of models and the role they play in the process of creation and advancement is an important asset. And it is our hypothesis that making students aware of them early in their education might boost their understanding of many courses and relations among many applications seemingly different.

We have found that despite the use of models in different courses, the concept of model is not so obvious to most students. For many, having different models for one device seems to be confusing. For an even larger set of students, and many engineers as well, different types of models for a same process and device are completely unrelated. It is natural then to find students disconnecting models and applications. A common expression embodies this perception: "theory does not apply to real world."

On the other end of spectrum, researchers and engineers who explore new frontiers often see the modelling process in their work so natural that their reports do not show any reference to them. A possible exception to this remark is when the objective of the work is to derive the model or to show the advantage of a new model for particular purposes.

Engineering students are not subject to the concept of modelling and are seldom confronted to the need of different models. Specific models are introduced as necessary for their courses. Models are presented, developed and used naturally, because without them it is impossible to work. They are effectively manipulated, expanded to more complex or simpler models, included in simulators, and so on. Yet, nowhere, few exceptions aside, there is an explicit reference to the importance of different kind of models, both in levels and in complexity. A notable exception is the Treatise of Electricity, in French, published in Switzerland as a series of textbooks, where we find a description of modelling levels [Neirynck, 1974].
Despite its importance, there is little general theory about scientific modelling, and this is in turn reflected in a lack of consistent exposure of students to modelling and the role of models. The hypothesis of this presentation is that understanding the basics of models, their levels, the need for different types and different complexity, and how models relate different fields of human activity, can be useful for students, and might increment their productivity as well as their work in learning and applying different concepts of engineering.

Students are very surprised when they hear us saying that engineers work with models first, and with real things later, especially when laboratory work is involved. There might be no substitute to hands on experience, and we agree with that principle. Yet hands on experience is deprived of usefulness if the student does not have a previous model of what to expect, or if the experience does not provide us with a model to be used .In fact, experimental work in teaching labs usually provide the student with some sort of models that will allow him to repeat the experience once and another time, or to mentally "repeat" it without using instruments, with the confidence that his/her mental picture is correct. However, the model again is presented just like that, as a magical sort of result. It may have been derived correctly, but the impact in learning and the importance that it may have as a tool is not mentioned.

Our discussion in this paper concerns different aspects of how we use models and how this knowledge may help our students. Our experience has shown that this is in fact the case, although this assertion is based on empirical appreciations only. For the moment, we have considered worth sharing our points of view on this issue. The science of modelling, the mathematical and other methods used in creating models and so on are left out of this work.

Basic notions

This section is taken mostly from [Wikipedia, 2009], where the reader can find more references and a more expanded discussion on topics presented here.

A model is a representation of a process, an object, phenomena or whatever we deal with, that we make to simplify our views according to particular purposes. Although in science it is usually expected to be a physical, mathematical, or logical representation, sometimes a verbal, an incomplete or a fuzzy description is enough for our work.

Reality is too complex for a model to cover all its aspects. Since we want to facilitate our calculations and descriptions we try to work with models as simple as possible, at the expense of exactness. To achieve simplicity, we start extract particular characteristics of the object or process we model, arriving at an abstract representation. Furthermore, it is found the more abstract the model is, the less it works with minor details, allowing us to increase productivity.

Inserting the model in the process

Fig. 1 shows the conceptual use of models in an analysis procedure [Hasler and Neirynck, 1985]. There is a physical situation for which we want to predict results. We first deduce a model for our physical setting to obtain something to work with. Using different procedures, very often mathematical and perhaps involving the introduction of other models, we arrive at a solution, which in fact is again a model of something we expect. Most times, it may reduce to a simple equality. This solution "tells" us what we will get. The important step is now to compare this solution to the experimental outcome. If the error in our prediction is within tolerable limits, we assume our process to be correct; otherwise, we start checking, first the manipulation to verify that no incorrectness was introduced there, and then our interpretations. If necessary, we change our model and start again.

Although this scheme is simplified, it illustrates actual processes. A design process follows a similar path, as exemplified by Fig. 2. Here, the "interpretation" action after the solution model is very often an analysis procedure done following the steps exemplified in Fig. 1 before building the physical realization.

Figure 1 Analysis procedure

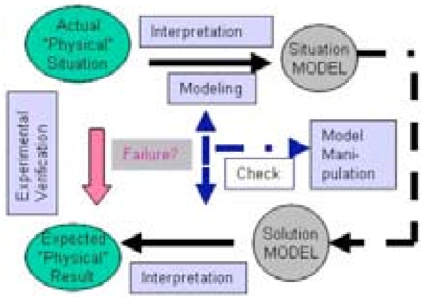
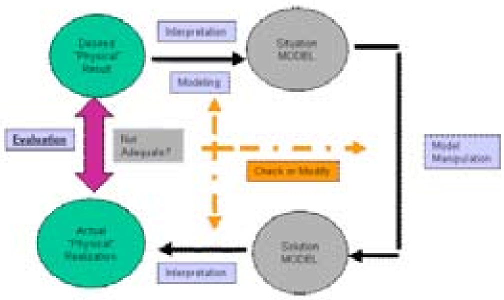


Fig. 2 Design Process



It is worth noticing that very often the evaluation and experimentation phases are themselves simulations realized with more complex models that have been derived and tested by groups of researchers and engineers. This is particularly true in environments where experimental set ups are too costly or impractical to do just to check up. After all, it is not easy to launch a satellite just to see if the equations in the first iterations are correct!

Since most times our students are presented with models and experiments that have been tested hundreds or thousands of times, it is easy for them to miss the role of models in the analysis and design process and the need of developing more complex models. They assume that simulator's results are in always real solutions because we limit our classes to those cases. This is not completely wrong, but the model role should not be left out. Presenting an experimental example where the use of one model fails but a more complex one provides a solution, is a good experience to illustrate the process of Fig. 1.

Furthermore, students should be aware that simulators themselves are built upon more complex models and that only after simulator results have been verified once and again, sometimes hundreds of times, we can trust them. Quite often, students do not know this and to our surprise we have discovered practicing engineers who ignore it too. Our hypothesis here is that making students aware early of this process can help them not only in the appreciation of the models, but also in asking questions about their validity and checking alternatives.

Modelling Levels and depth of models

There are several levels of modelling with which we work. Without going into discussion of a wealth of model types (see [Wikipedia, 2009] and discussions there), some levels are of interest for our students to recognize because they are used throughout engineering studies. The set of levels here is based on [Neirynck, 1974]. Although the terminology might be close to electrical engineering, the concept is general. Starting with the most abstract level we consider:

Linguistic level: The description is more in the realm of verbal type, albeit special syntax rules sometimes.

In this level we find programming, verbal descriptions, mathematical developments, and so on. This is the most abstract level and usually the one with allowing us to achieve more productivity, since construction details are very often ignored.

Systems level: This is also of high abstraction. However, the description begins to bring out a sketch of physical realization without entering into too many technical details. Relationship between "input" and "output" data and transfer is important. At this level, constraints that apply to physical realizations are very often derived.

Subsystems and blocks level: Even if the difference between this and the previous levels is more a matter of size than of quality, one important aspect of subsystems is that we think of them as necessary steps and blocks to build systems. In analogy with programming, we could equate subsystems to public subroutines and functions that may be reused in different situations. With blocks we build subsystems and systems. In a certain way, blocks are at the border between abstraction and concrete.

The circuit, mechanism or structural level: This is a level in which connections to physical realizations are more tangible, at the same time that a certain abstraction is developed.

The materials and physical level: Strongly connected to "real world" and also a source for abstraction. In short, this is the level upon which all the others are built and the one which makes possible the physical realization of the systems and devices developed in those levels. As one student said once, "without this realm", all the other levels work with paper only.

Theoretically speaking, all engineering applications may be explained with the last level modelling. Yet, complexity would be such that even the most simple physical systems would require years of work. Thus the need for simplifying descriptions and develop abstractions.

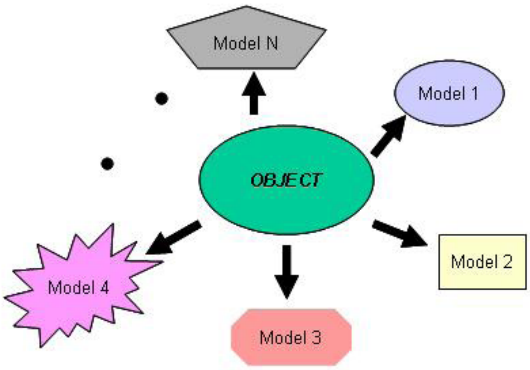
Sometimes the borders between levels is fuzzy. Moreover, since abstraction boosts productivity while concretizations allow realizability, engineers have developed tools for automation, or CAD, in which different levels of models for the same operation bring the product from an upper level to a lower level equivalence.

Besides considering level, diversity in depth or complexity should be mentioned early to students. First bringing up convenience of simple models versus complex ones, and then introducing the need for complex models to get better agreements with measurements under circumstances where simpler ones are no more useful, provides good opportunities to appreciate both the convenience and need of models.

Relating models and elements: a two way road

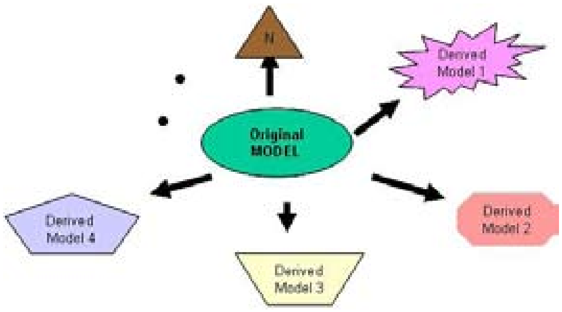
Students learn in early courses that elements may have different models (Fig. 3). Many do not grasp easily the necessity of such a variety of models, unless they are aware of the processes illustrated by figures 1 and 2.

Figure 3. Different Models for one object



Many times models are developed from a first one, as illustrated in Fig. 4.. This is very common in many courses, when to a mathematical model we begin to add elements based on physical considerations or effects. Or by mathematical operations we proceed to obtain simpler models that function well under limited conditions. There are many reasons to do this. One, for example, is that it is easier and more intuitive to build up a whole picture dealing with small parts at a time, than trying to build it at once and at the expense of loss of understanding.

Fig. 4 Different models may be related by derivation

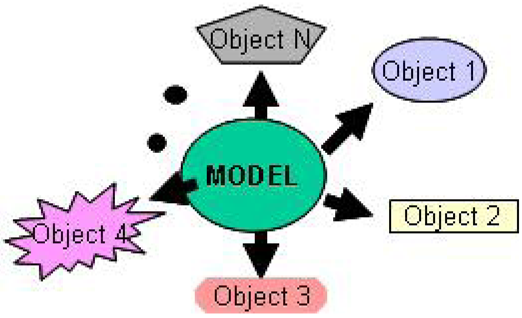


What brings additional interest to relations between models and objects, and the impact that this has in productivity for engineers is something that has been known to mathematicians for a long time, a fact that underlies the reasons of having our students study Mathematics:

“Although it is usual to classify mathematics into separate areas, such as arithmetic, algebra, geometry and so on, this classification owes more to human convenience than the subject’s true structure. In mathematics, there are no hard and fast boundaries between apparently distinct areas, and problems that seem to belong to one area may be solved using methods from another. In fact, the greatest breakthroughs often hinge upon making some unexpected connection between previously distinct topics.” (Stewart, 2008)

In modelling terms, we can say that just as a device can have different models, one same model can explain different devices or phenomena (Fig. 5). Since two different devices or phenomena in two apparently unrelated fields A and B, have a common model as a link, it may be possible to work in one field A and solve problems of the other field B, or to use properties from the device in B to replicate them in A. This fact has been the source of many discoveries and inventions. It can also explain why, for example, electronics has acquired such prominence in applications nowadays, how prostheses are designed, and so on. Most engineers and researchers exploit this link, again, without giving to it any type of educational consideration. Students to whom the link is explained and illustrated by practical examples usually tend to become productive faster, and they also connect different courses easier

Figure 5: Different objects for one model



Discussion

Bringing to the student's attention the importance of modelling, how models shape our work, in how many ways we solve problems thanks to a proper use of models and so on, will help them in understanding earlier and faster many courses, relationship among courses and applications. This can also help in motivation.

The minimum for them to be aware of is the role of models in analysis and design processes, since this helps connect both worlds, the experimental and the modelling. Also, different levels of modelling and the need of different complexity connect classes and engineering activities as well. Students will have a better picture of why and how different courses talk about the same things sometimes in a "different way."

The different interaction between objects and models, and between different models, can illustrate source of applications, levels of complexity and connect again courses to applications.

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