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## **System Engineering: A Discipline for Unifying Engineering Education**

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**Abstract:** Engineering education is losing its focus as new engineering courses continue to be created. This is not to say systems engineering education is not considered. It does say each discipline's course tends to be taught in isolation. As a result our students are getting confused by so much diversity with no visible connection. This contributes to the creation of virtual borders between electrical, mechanical and computer engineers and induces artificial barriers for teamwork. My viewpoint is as a professor in a country where engineering fundamentals are based on higher abstract training, such as mathematics. While results have been satisfactory, improvement is needed. Such improvement can come by making the systems view central to the educational process.. This includes giving students experience in working in interdisciplinary teams. My proposal is that systems engineering core courses be made the nucleus around which all engineering disciplines are centered. Furthermore it is proposed curriculum be modified to include case studies in core disciplines that can taught in many departments: modeling and simulation, requirements engineering, and validation and verification. In this way all students would be introduced to the basic elements of the system engineering conceptual framework. Process methodology would also be addressed.

### **Introduction**

Mathematics is an essential tool for most scientific disciplines. It is also an excellent way to teach abstract reasoning to engineering students. French engineering education follows this paradigm. Entry to the best engineering schools (*Grandes Ecoles* : great school) is based on selection at the A-level of the best college students in mathematics. After two years of training in a mathematics oriented education, they are again selected to enter the engineering school of their choice.

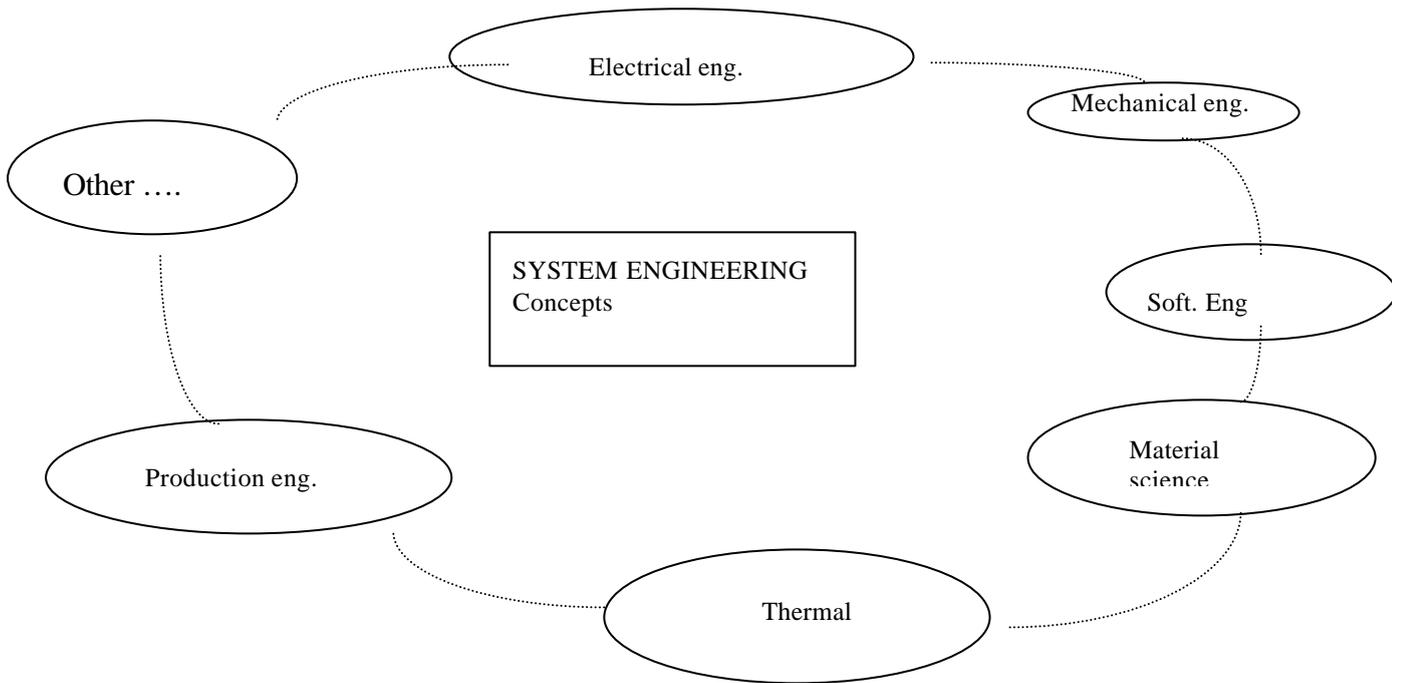
This system is currently criticized by many eminent French scientists, most notably messieurs Gilles de Genes and Georges Charpak --recent Nobel prize winners in physics/chemistry. While they acknowledge the importance of mathematics, they make the case it is not essential for technical disciplines which rely heavily on inductive reasoning, i.e., system engineering. Thus we have the situation that while system engineering is broadly espoused by French industry and government leaders, it has yet to be translated into the academic environment. This, in part, is due to a lack of universally accepted definitions and principals.

I believe creating a set of systems engineering core courses for inclusion in all engineering curricula would resolve many of the concerns raised by messieurs de Genes,

Charpak. and others.

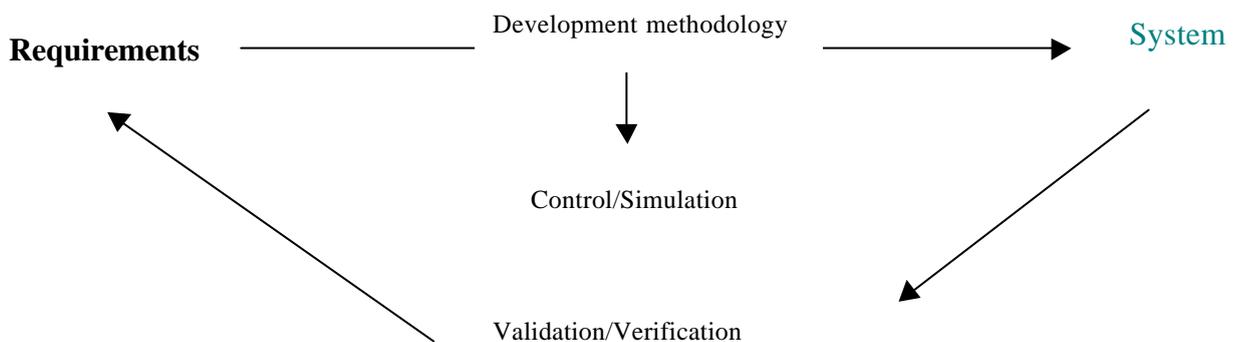
### Requirements for SE Education: Concept Unification

Based on my experience teaching in universities and industry, SE should be taught as both a discipline and a set of core courses to provide a means for unifying the other engineering disciplines.



We may ask what are the essential or core SE concepts? Are they only useful to systems engineers.? Experience suggests all engineers can improve their skill set by being taught system thinking.

As illustrated in the following figure, we have a development process that leads to the development of a system meeting a pre-determined set of requirements. Simulation is used to evaluate system behavior. Verification and Validation close the loop back to requirement to establish how well system performance meets customer objectives.



Concepts are mapped into core courses. These core courses should contain, in our view, most concepts basic to SE (for example, in methods teaching, one finds structuring and abstraction/refinement concepts and corresponding techniques).

From observation it is clear one course must be structured to teach students system engineering concepts. This course might be named: “A Basic introduction for engineering a System.

Such an approach will teach students how to:

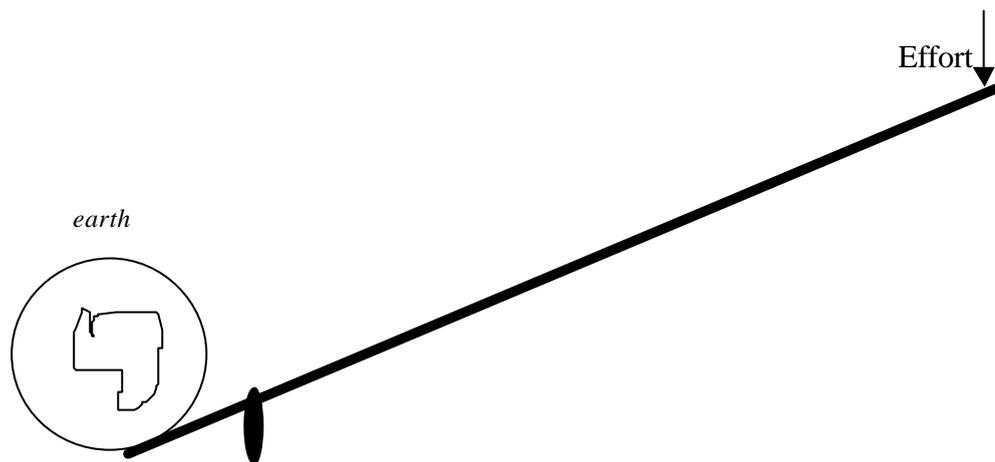
- Avoid redundancy and consistency problems and
- Convey common knowledge to students so they will, after graduation, know how to work together in engineering a system.

It is beyond the scope of this article to detail concepts contained within each core course. The objective is to define a systems engineering course of instruction using core modules as the unifying discipline for engineering education.

## **Experience in Teaching Systems Engineering Methodology issue**

The value of process methodology (a logical progression of activities) is often not recognized by many engineering educators. Currently both the systems and software engineering discipline recognize the importance of having a well understood design process. These manifested themselves as SD (structured Design Method) in the seventies and analysis methods as

SADT (Structural Analysis and Design Technique) in 1977. The value of a method is illustrated in Archimedes statement “*Give me a place to stand, and I will move the world.*”



The method corresponds to the application of the mechanical principle of the lever. The tool consists of the support and lever. The longer the lever, more powerful the method. However, the technique for pressing on the lever corresponds to the method used. With a

good teaching method concepts such as abstraction, hierarchy, and refined analysis were easily mastered by students. Similar teaching success have been achieved at an engineering school specializing in industrial engineering. A typical problem set was to design a gear box using an object paradigm. Passing software messages should have it a counterpart in the gear box. (the linear speed transmission between two gear wheels).

### **Requirements engineering: Why a requirements step is essential to all technical disciplines.**

While all computer science majors are taught the criticality of understanding requirements, many other majors, particularly those where the design process is prominent, do not impress upon students the need to get a good grasp of requirements before starting the design.

One technique used (repeatable) through sixteen short term projects per year at the technology institute IUT-B (Université de Toulouse le Mirail) proved successful in teaching students the value of requirements. First year students were assigned the task of acquire course requirements by contacting lecturers. Part of the assignment was to write these requirements in a specific format. When it came time for the requirements engineering lecture, the experience helped in raising student interest and attentiveness.

### **Validation and Verification (V&V) processes**

Most students consider V&V a waste of time. Getting students to understand why the V&V process needs to be embedded within their work has been a major undertaking. Equally daunting has been the task of convincing them the V&V process is needed for both hardware and software. Moreover, the same principles apply for verifying software in computer science or verifying mechanical structure in mechanical systems. Fault tolerance, system reliability, and associated concepts are basic elements in this core module.

To teach this to students, we have experimented with illustrating concepts with simple everyday life examples. For example, getting to a specific place from a requirement based on a map or why negotiation difficulties are often the result of either consistency problems or semantic problems related to bad syntax/terminology, etc ..

### **Modeling and simulation**

Defining Requirements is a modeling process. The requirement process is used to produce an abstract model of the system. Simulation is a means for partially verifying requirements and learning about system behavior. Simulation is also used in many requirement development schemas in order to have an executable specification to avoid having to build a prototype in the initial project phase.

Personal experiments, starting in 1988, with teaching modeling and simulation to all engineering students have shown that most students have little trouble with the concept of working across discipline to produce systems models. They learn a perspective

impossible to teach when modeling is taught in discipline specific modeling courses. Also clear was that their experience taught them the value of working across discipline to achieve a common objective.

The revival of modeling and simulation as an important tool for such things as the design of numerical systems underlines the importance of teaching students to have a systems view. There is not a problem with each engineering discipline teaching modeling separately. The problem lies with first teaching students system modeling. This teaches students why the electrical or mechanical systems they are modeling must be able in interfacing with the other systems elements. If students first course were one in systems modeling, much of the time spent by the various discipline teaching modeling fundamentals could be eliminated and this increase the time spent on teaching discipline specific modeling techniques. .

Lacking a core set of systems engineering courses, it is no wonder many of our students graduate with an incomplete understanding of how to engineer a system.

### **Conclusions**

Most European countries expect students to complete a five year course of study to earn a Bachelor of Engineering degree. The first two years are concentrated on taking foundation courses common to all of engineering. Specialized courses specific to their chosen field of study are taken in the years three through five.

Four core SE courses have been identified as being valuable to all engineers. Personal experience suggest that adding one course per year in the second through fifth year would be relatively easy and would produce much capable graduates.

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