Design of social systems: the case of a unique course

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***Abstract*—Almost every engineer deals with systems, but not all the systems are the same – there are several levels, of which the highest is the social system. The engineer who designs such a system has to take into account a variety of objectives, often contradictory, as constraints on the very ends that the design tries to accomplish. Social systems are the turf of industrial engineering, but its curriculum does not reflect this fact. The prevalent design knowledge is more about technological systems, so even the little design training that industrial engineers receive is not the one they need. This paper is about a course that aims at fixing both deficiencies by directly addressing the very weaknesses. The course, provided in the junior year, applies the PBL (problem/project based learning) style. Our lessons after eight semesters are that the industrial engineering curriculum must put much more emphasis on underdeveloped competencies such as system thinking, qualitative approach and research methods, open-ended problems solving and ambiguity tolerance. Unfortunately, most of these skills are suppressed in the current curriculum.**

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I. The need for the course

Almost every engineer deals with systems, but not all the systems are the same: there are several levels, with enormous differences among them. The number of levels may be as big as eight (Boulding, in: [14]), but the threefold division proposed by Ackoff [1] is good enough in order to make the point:

> A mechanical system is one that operates with a regularity dictated by its internal structure and the causal laws of nature, for example, a clock or an automobile. Because mechanical systems can display no choice, they can have no purposes of their own; nor can their parts.
>
> Organismic systems are ones that have at least one goal or purpose of their own – for example, survival, for which growth is often taken to be essential – but their parts have no goal or purpose.
>
> Social systems – of which organizations, institutions, and societies are examples – are open systems that (1) have purposes of their own, (2) at least some of whose essential parts have purposes of their own, and (3) are parts of larger (containing) systems that have purposes of their own (pp. 175-176).

Hence the distinct differentiator is the notion of a purpose, or an intention, and specifically whether the purpose is internal or external to the system. Among the various fields of engineering, only two deal with social systems as defined above, and these are industrial engineering (IE) and information systems engineering (which in some schools is a sub-specialization within IE). The uniqueness of a social system has a huge impact on its comprehension (for an elaborated analysis see e.g. [10]), and consequently on its design; yet the traditional IE curriculum does not reflect it, for reasons that are beyond the scope of this paper. For example, skills such as qualitative reasoning, soft system thinking or conceptual modeling have very little presence in the curriculum, while the design principles that are taught concern a product rather than a process. In addition, the stage of problem recognition and problem setting (where a causal explanation of a problem is provided) are underemphasized, compared to later stages such as alternatives design and alternatives evaluation. The course described here is aimed at bridging these gaps.

The course is titled "Workshop in problem solving" and is given in the junior year of IE at ORT Braude College of Engineering in Karmiel, Israel. As far as we know the course is one of a kind among the IE programs, at least in Israel, and due to the paucity of design literature in this discipline (except for the BPR genre) much knowledge has been learned by doing. The paper presents this preliminary knowledge in the following structure: section II introduces the course; section III presents the design model that is used, at a glance, to be elaborated by step-by-step in section IV; section V provides the students' feedback; finally we discuss our experience in section VI and summarize.

II. The course

The course is one-semester long and is required in the junior year. The students attend seven 2-hour class meetings in which they study the methodology, but most of their time in the course is dedicated to active learning outside the classroom. Each pair of students has to identify a real problem (to be confirmed by the teacher), to diagnose it, to design a solution and to outline its validation (due to the time limit, the solution is not implemented). The students meet their supervisor at least once a week to report their progress and to get feedback and directions. The students have five assignments along the course:

1. The problem (2 weeks after the outset)
2. Exercise in perusal of an academic paper (usually their first experience in such an assignment)
3. First draft (toward the middle of the course)
4. Second draft (a month prior to the course's end)

5. Final work

Each draft is elaborately commented by the supervisor but not marked, since scores are given only for the final work (95%) and the exercise (5%). However, the final score reflects by large the extent to which the students took the comments into account and applied them. Table 1 summarizes the topics of the bi-weekly lectures.

TABLE 1. THE TOPICS OF THE LECTURES

Week	Topic
1	Problem recognition and analysis
3	Problem setting
5	Modeling
7	Essentials of solution validation
9	The validation method
11	Operationalization
13	Reflection and closing

The course precede the capstone course that comes in the last semester, and could be considered as a preparation had the two courses been aligned.

III. THE DESIGN MODEL AT A GLANCE

Since the methodological literature in IE is sparse, we (the course team) have devised a framework for the design process. In order to cover all the three worlds we deal with, i.e. system thinking, problem solving and design (whether the last two are unified or separate is under debate), we have integrated three models into one (Figure 1). The first source is "A Systems View of Problem-Solving" [9]; the second is the Concept-Knowledge (C-K) theory [8], and the third is the problem-solving model [15].

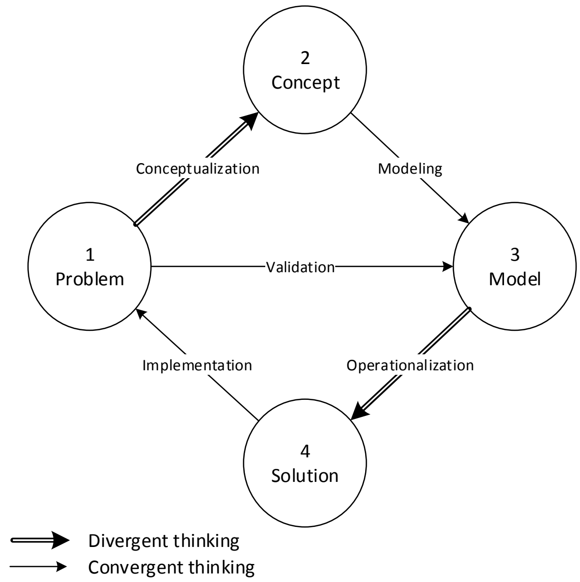

Fig. 1. Figure 1. The design model

Briefly stated (details in the next section): in stage 1 the problem is recognized and analyzed; in stage 2 the problem is conceptualized and contextualized, meaning stated by concepts that point toward a theoretical context and by that the problem becomes explainable. In stage 3 a behavioral model is structured, from which solutions can be derived, and indeed they are derived in stage 4; this stage is named "operationalization" since here an operational procedure substitutes a theoretical construct. Drawing upon [8], we define passes 1-2 and 3-4 as C-mode ("c" for concept) and the rest as K (knowledge) mode. Knowledge is defined as a statement that has a truth value; Dym et al [6] label it "convergent thinking", meaning a narrowing sequence of specific questions, followed by exact answers that pose further questions and so on. Contrary to knowledge, a "concept" (the outcome of divert thinking) is an idea that lacks a truth value, and implies thinking out of the box or reframing the problem; in other words, an alternative look at the facts that yields different concepts and explanations. Lastly, assuming that the problem has been solved, the pass 1-3 assures that the solution really works and for the "right" (i.e. the intended) reason. In the following sections we elaborate on each stage: how it was instructed and which lessons have been learned upon experience.

IV. THE DESIGN MODEL STAGE BY STAGE

A. *Problem recognition*

"Problem" means a gap [16], where the gap is between the present (a situation or event) and an expectation. Pounds [11] found four sources for expectations: a plan, previous knowledge, a benchmark or a problem imposed by a third party (the last source was excluded because we wanted the students to find problems by themselves). Being the expectation a part of the problem means that the problem cannot be a "given" – an old idea [4], but even today not a common sense. Hence in order to claim a problem one has to exhibit both facts and a gap; to that, in order to avoid daily problems, we have added the requirement of ambiguity, meaning that the cause of the problem is not clear on the spot (and therefor nor its solution). We further required that the scope of the problem would be associated with operational management. Here are some examples for acceptable problems:

1. Chronic delays in long projects (source: plan)
2. Repeating nonconformances in the annual quality audit (source: plan)
3. Constant increase in customers' complaints (source: benchmark)
4. Resistance to a technology change by – quite counterintuitively – the younger employees (source: previous knowledge)

We ask the students to provide a rich description of the situation, based on either their own experience or a genuine witness; by "rich" we mean various measures (time, amount, etc.) as well as distinction – those characteristics that tell apart the problematic from the nonproblematic items – at least at first sight. Next the students had to explicate the gap and its source, to specify the problem owner and to defend the nontriviality (ambiguity).

Lessons learned: students, perhaps because of the early years' indoctrination, tend to regard problems as "given" and undebatable, based exclusively on their personal standards. For example, a student argued that the older technicians in a team are underemployed – according to him, a waist; he could not conceive it as a purposeful decision of the team manager and did not try to expose the reason; in other words, there was no problem owner. A variant of this mistake is the omission of the gap, under a hidden assumption that a fact "must" be a problem by definition. Another failure we call "a normative problem", which is manifested by the expression "there is a need for… (e.g. linear programing)"; sure enough, the cart is put before the horses, since this need is the solution – but for which problem? A frequent response of the student after this stage reads: we thought we knew what a problem is, but now we understand that we have not.

B. Conceptualization

The purpose of this stage is to locate the problem in the relevant conceptual context; an example may clarify the point. Consider the second problem above (repeating nonconformances in the annual quality audit) – what can cause it? Apparently many causes: it could be a misbehavior, loose control, poor learning, a combination of the three or something else. The first thing that I asked the students to do was to categorize the twenty repeating nonconformances by alternative criteria, until one (or more) categorization makes sense. At first they found two categories: nonconformances of "momentary event" type, e.g. an equipment that had been left in a wrong place, and "lasting phenomenon" type, e.g. skipping a required periodical training for several periods; the former can be attributed to mere discipline fault while the latter may imply control or unlearning issues, and the distribution between these two types indicates the more dominant. Since it was the latter, the next step was to discriminate the context – recall, control or unlearning. The students hypothesized that the existence of formal procedures (in this case, of periodical training) would imply a control problem, while its missing is associated with organizational (bad) memory [18] – a ramification of organizational learning; so they searched the procedures.

Let us generalize the process we have just gone through: the idea is to single out keywords from the description of the situation and from them to construct a net of semantic relations that "makes sense". In this example we start with the keyword "nonconformance", whose relations are depicted in figure 2; one can see that one branch leads to learning while the other points to control. Sure enough, such a net may have many variants, since the procedure is vague; this is exactly what stand behind the phrase "divergent thinking".

This problem and its conceptualization demonstrate the traits of a social system: an explicit intention of the management is not met because other parties have different intentions, even if unstated. Further, we cannot grasp the source of these diverted intentions unless we investigate the meaning each party ascribes to the concepts [12].

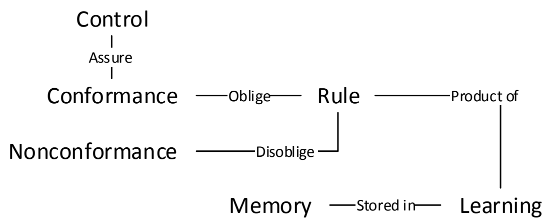

Fig. 2. Figure 2. Conceptual model

Lessons learned: the first pitfall that students face is intuitive (or better say "guessed") conceptualization; for instance, the team in the case in point has immediately jumped to the conclusion (actually the solution) that somebody has to be punished, meaning that their tacit context was of discipline. Other deficiencies are the underdeveloped qualitative and divergent thinking capabilities – the students are too used to both quantitative and convergent thinking. Further, the hypotheses that such a conceptual model raises call for qualitative research, which is another weakness. Last but not least, the alternation of conceptual frames requires broad knowledge, in line with the complexity of the social system; unfortunately, the students' social knowledge is all but that.

C. Modeling

Since the essence of engineering is to make changes and to solve problems, the model has to be solvable – meaning to connect manageable means to desired ends. Once the student has formulated the problem and constructed the conceptual model, he is aware of the dependent variable (which is the problematic situation) and of the context, and these two are his/her lead toward a behavioral model. We call this model "behavioral" since it describes how the system behaves upon the variables' change. The way is to start with the dependent variable and to ask: what can influence this variable? Than proceeding to the right-hand side (see figure 3) until a manageable variable is reached. Continuing with the previous example, assume that a control problem had been determined; hence the dependent variable, the one we wish to decrease, is "amount of repeating nonconformances", within the context of control. From the literature (which the students have to find and study by themselves) they figure out the other variables, from left (the ends) to right (the means). Note that the dependent variable instantly becomes the index of the target.

To generalize: the pivots in this stage are the dependent variable, i.e. the problematic situation, and the context – taken from the concept stage. The dependent variable determines the voyage in the literature in a certain direction, thus this stage embodies the style of convergent thinking.

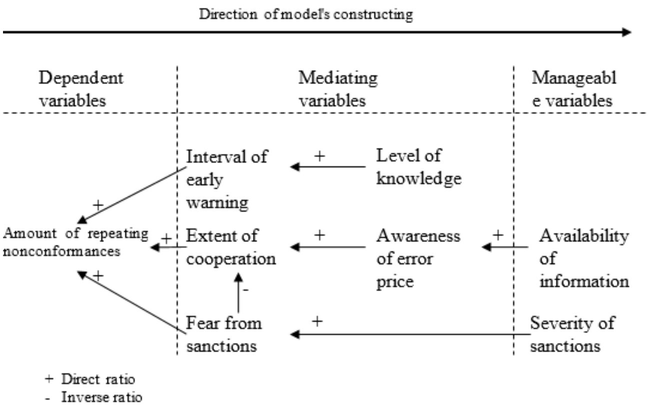

Fig. 3. Figure 3. Behavioral model

Lessons learned: the model is meaningless unless all the variables are degree variables [5; 17], which can increase or decrease; here lies the main difficulty for the students, who carelessly use either concepts (like "sanctions") or specific values (e.g. "severe sanctions"). We suspect that this tendency has been acquired through exercising the "fishbone diagram", which is more like a mind map than a scientific model, and therefore lacks the emphasis on variables.

D. Operationalization

In this stage the students have to design the solution, meaning to manipulate one or more of the manageable variables in the desired direction (that's why the "operationalization" title). For instance, if they decide to work through the "availability of information" (and with a good reason, because it has only positive consequences), they outline the data and the flow that will attain the outcome, and not the less important – contrive the implementation plan. Since many alternative solutions are possible, it is divergent thinking that exercised along this stage (more so as the stage begins). Note that the implementation itself is not a part of the course, because it may last much longer than the semester, and besides – we prefer to put emphasis on other facets of the design process.

Lessons learned: the main weakness is the students' undervaluation of the societal aspects of the system, among them: conflicting interests, resistance to change, time of assimilation, organizational coherence, personal issues, etc. Therefore their designs are too often simplistic and nonrealistic; they tend to adopt a mechanistic attitude and to assume that every managerial command is executed right away and without any attenuation. However, since there is no implementation, our comments cannot transcend the theoretical level.

E. Validation

This stage is also theoretical, and its expected outcomes is a sort of research design, aimed at validating the model through the solution. Since the aim is to make a change, the eligible research methods are usually a field experiment or action research, and a great emphasis is put on rigorousness. The challenge is usually to measure the mediating variables, in order to ensure that if the solution worked it was because of the intended cause (the dependent variable has already been indexed in the problem analysis). The students are required to self-study the specific research method and to find precedents of the appropriate measurement; they also have to consider the internal and external validity of the experiment. Both the operationalization and the validation stages address the ABET learning outcome of conducting experiments.

Lessons learned: the measurement of abstract variables, which are most often the case, is an Achilles heel; the students are novices (they have little introductory knowledge) and the result is a very poor instrument validity. We are troubled by the idea that the students do not reach a satisfactory level of this competence throughout their studies.

V. Feedback from the Students

At the end of each semester we conduct an After Action Review (AAR – [7]), in which the students reflect upon their experience. Over the years three main achievements of the course have been repeatedly mentioned:

- Enhancement of the information literacy, namely the skills of searching, evaluation and exploitation of scholarly sources. For the students it was the first time to determine their information needs and to read academic papers.
- Awareness of the relativity of the problem; I use this word intentionally because the engineering studies

tend toward positivism, and the students were enlightened by the notion of non-given, thus relative, problems.

- Discovering self-directed learning abilities that have been suppressed thus far, along with critical and divergent thinking. The ownership that students felt for their work was a strong source of motivation (at least for the better students).

VI. Discussion and summary

We see in the capstone projects, and more so after graduation, that industrial engineers do deal with social systems and employ qualitative thinking, but they lack knowledge and skills to do that. The reasons for that deficiency are beyond our scope, but the course described here is a rare effort to bridge this gap. Note that our curriculum includes a course in research methods as a prerequisite for the course in point, and this is another exception among the IE curricula (it is as unusual as to deserve a paper – see [3]). As a result of the imbalanced curriculum, the students exhibit significant deficiencies along the course (and to some extent afterward as well):

- Bias toward quantitative thinking, as strong as to believe that the unquantifiable does not exist. Further, they mistakenly confuse quantitativeness with objectivity, disdain qualitative faculties and are intolerant to the ambiguity associated with them. When they employ qualitative thinking (because the real world is not completely quantifiable) they do so tacitly and poorly.
- Undervaluation of social considerations because they are "soft" and "it is not engineering"; it resembles Schein's [13] observation that engineers "prefer 'people free' solutions" (p. 14); not the less important is the unawareness of "soft systems" [2].
- Students are not acquainted with systems models, let alone constructing them; actually their knowledge is limited to predefined mathematic models which they know only to solve (stated differently, their design skills are limited to activity 3 – model).
- Poor knowledge and experience in research methods (despite the course they undergo, which is a drop in the ocean), mainly in operationalization and validation. As a matter of fact, due to the limited duration of the capstone project, the students do not have the opportunity to validate their solutions against the real world.
- Tendency for convergent thinking, probably cultivated by the abundance of scientific courses during the early years in college, in which the answers are strictly true or false.
- Incompetence of self-directed learning, from information search through critical evaluation to the "enough" decision.
- Above all, the ability to apply theoretical knowledge; the students know a lot of things (from statistics to design) but are clueless upon practicing.

There is a bright side: by teaching the course (for several years now) we have developed methodological knowledge in engineering design within social systems. Such knowledge is surprisingly rare in IE, and much further research is required before we have a sound dedicated methodology.

VII. Acknowledgment

I am grateful to my partner, friend and colleague, Dr. Yair Ma'ayan, who has built the course with me and shared his insights.

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