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Towards Dynamic Modeling of a Teaching/ Learning System: 1. The Unified Theory*

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This work implements a unique effort combining education metrics and engineering simulation modeling. The aim is to determine how to usefully model a teaching/learning system for a specific course taught to a junior engineering student, and use this model to help predict consequences of changes to the process. The methodology used by this study is known as 'system dynamics'. It generally includes two phases: qualitative and quantitative. The qualitative phase is based on mapping the resource flows and interrelations of the system and converting the map to a simulation model. This phase results in a unified theory for the model of interest. The quantitative phase is a quantitative computer simulation modeling using a purpose-built software. It is based on investigating the dynamic behavior of the system to obtain a better understanding of how a teaching/learning system works, and applying some proposed changes to the model to maintain sustainable improvement in performance of the system. This article mainly covers the first part of the work and addresses the qualitative phase of the study.

INTRODUCTION

THIS study attempts to apply industrial engineering simulation modeling techniques to the analysis of a teaching/learning system for an engineering course taught to a junior engineering student. The intent is to give some information about cause and effect relationships that would allow educators and education administrators to make necessary changes to the system, with greater knowledge of the ramifications than is presently available. This is essentially an uncharted area, and will use information that is not as reliable as that usually available to engineers. In fact, the direction in this area seems to be unique, in that no reference has been found in research journals or through discussions with education researchers. However, it seems that research into simulation modeling of teaching/learning systems is a worthwhile direction because:

- Simulation modeling is increasingly used by industries to help guide their process changes.
- Simulation modeling will likely be useful in helping define the direction of change for teaching/learning systems that are about to go through a massive change, driven by the continuing decrease of funds and the continuing improvement of technology.

The methodology

This work uses system dynamics as a suitable methodology to analyze the process of student learning. System dynamics is a specific system analysis approach that is being increasingly used in research in very diverse areas. The unique characteristic of this approach is its ability to represent the real world. It can accept the complexity, non-linearity, and feedback loop structures that are inherent in physical and non-physical systems [1].

The process of system dynamics for a teaching/learning system consists of five stages. The first stage, is the description or mapping of the system. It is the most important and the least straightforward of the stages in our analysis. It requires taking various bits of information about teaching/learning systems in the real world and turning them into a unified theory. The formulation and construction of a simulation model is performed in the second stage. The system description is translated and converted into the level and rate equations of a system dynamics model by providing the requisite parameters. Creating the simulation model requires that the rather general and incomplete description of the first stage be made explicit. Then in the third stage, simulation of the model, will start after the equations of the previous stage pass the logical criteria of an operable model, such as all variables being defined, and consistent units of measures. The first simulations at this stage will raise questions that cause repeated returns to both prior stages until the model becomes adequate for the purpose under consideration. Next, some policy alternatives are chosen for testing. Simulation tests determine which policies show the greatest promise. Finally, at the last stage, proposed policy changes will be tried to the model to maintain or obtain sustainable improvement in performance while considering the feasibility of implementing these changes in its real world. If the model is relevant and persuasive, then the process can be concluded for the necessary evaluations.

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The tool

The model of a teaching/learning system is constructed using the STELLA modeling language [2]. This computer program is a continuous simulation package with an appropriate multi-level, hierarchical environment for constructing and interacting with complex models. The language is built around a progression of structures that is particularly compatible with the nature of the teaching/learning system. According to its developers, STELLA is built on the systems approach, sometimes called Systems Thinking, to problem solving [3]. Using this program, the emphasis is placed on broad viewpoints, or the 'big picture view', so that interrelationships and interconnectivity are the focus rather than a collection of complex variables. However, several other simulation modeling languages are available but with regards to our survey and previous experience [4], STELLA seems one of the presently most promising for the purpose of our study.

The parameters

Many parameters and situations are considered in this study. Below are some examples.

1. **Types of learning**: Different types of learning are generally accepted and required in any educational process. They include: rote learning (memorizing), closed problem solving (understanding and comprehending), open problem solving (creative thinking), and skill development. Other types and sub-types have also been defined.
2. **Teaching system**: Different types of teaching systems are generally considered. They include: traditional teaching (professors, instructors, graduate students as TA's and RA's and lecturers, lectures, textbooks, lecture notes, overhead and slide projectors, labs, etc.), computer-driven overhead, interactive software, testing and marking software, interactive distance video, student computers, and internet facilities to reduce paper requirements.
3. **Subject matter**: Different types of subject matter can be generally considered. But learning materials extracted from an introductory course in Industrial Engineering taught to the second-year engineering students at University of Manitoba is chosen for the purpose of the study. The subject learning materials require a quantity of mathematical, physical, chemical, analytical, geometrical, and other abilities along with memory and dexterity.
4. **Student Type**: A student description requires at least three groups of parameters. They are: 'ability to learn' relative to subject type and learning type, 'prior knowledge' about the subject (and also general background knowledge), and 'desire to learn'. The ability to learn is not considered essentially fixed because certain learning skills may still be learned. The prior knowledge (and/or background knowledge) of the student can typically be adjusted by remedial programs if they have the basic ability to learn in the subject. Some types of desire (motivation) e.g. basic interest in subject, tend to be intrinsic while other types, e.g. seeing a relation between the subject and a future profession, can be adjusted to some extent by the structure and style of the teaching process.

The measures

The most significant problems will relate to measures of a student's abilities, learning level, and motivation. Although some measures, such as measures of the memory of data, are very good and easy to apply, measures in some areas are very subjective and in other areas do not exist at all. Moreover, many of the subjective measures are very time consuming to apply. For this reason it is required to define and show equivalencies between different teaching and learning techniques and students' traits and teaching system characteristics. For instance, one way is to use the wealth of information which exists in cognitive algebra (educated guesses). Measures of effectiveness of proposed teaching/learning systems relative to a reference system and relative to each other, include:

- the level of acquired knowledge of the student;
- the amount learned by the student;
- the time required by the student to go through the learning process;
- the learning rate of the student;
- the level of student motivation under the effect of external reinforcement factors.

THEORETICAL PREPARATION

The survey in education literature reveals that with respect to aspects related to teaching/learning systems there seems to be a consensus on the following general items [5, 6]:

- The process of learning includes cognitive, behavioral, and experimental dimensions or components.
- Teaching and learning are dual and complementary processes. But in any attempt to model an educational system, the heavier part should go to the 'learning side' rather than to the 'teaching side'.
- Learning is mainly a function of students interacting with the teaching method and subject matter variables.
- Some student learning results from instruction and some from other forms of organized experience.

Similarly, the main conditions under which the learning situation occur are recognized as follows:

- The individual differences of the students themselves; i.e., their academic ability, their

previous preparation at the secondary level, and the various motives or incentives that bring them to the university classroom.
- The nature of the learning materials, tasks, equipment, and facilities that will be involved in the academic course work including the structure and content of the academic programs themselves, the type of teaching aids, and the other educational facilities.
- The nature and quality of instruction the student receives, the conditions of practice, guidance, mode of presentation, feedback, and other teaching dimensions.
- Situational or environmental variables that may be either direct or indirect in their influence on learning outcomes, i.e., conditions and situations affecting teaching/learning process including those as simple as class size and those as complex as the various forms of reinforcement.

From the above items we can conclude that the main building blocks in a typical teaching/learning system seem to be the learning 'abilities' and 'desire' that a student possesses. These two building blocks have to be considered as the main cornerstones in a mechanism for any teaching/learning process. This, indeed, demands us to examine two relevant models. That is, the model of mind for identifying the levels of information processing in a student's memory and the model of motivation for realizing the student's intrinsic and extrinsic values and motives.

Levels of processing in the memory

How is knowledge acquired, maintained, and retrieved? How can we understand the representation of knowledge within the human mind? What is learning if it is not the acquisition of knowledge? Fortunately, the idea of different levels of processing is already well established in the psychological literature on human memory and in information processing [7, 8].

Models of human memory have described generally three distinct types of memory:

- a sensory register which holds incoming perceptions only briefly;
- a short-term memory (STM) which holds a limited amount of information for up to about 20 seconds;
- a long-term memory (LTM), which itself can be divided into episodic (storing episodes of experience) and semantic (storing and relating concepts).

Information can be held in store for longer periods by internal repetition (rehearsal) and if repeated or used sufficiently often it will become a permanent memory trace, presumably in episodic LTM. This process is what would normally be called rote memorization or surface level processing. But much incoming information is reassessed and categorized in STM before being passed to semantic LTM. This process is what is involved in deep level processing. Although we have a memory which is essentially unlimited in size and in which memories remain almost indefinitely, nevertheless, the ideas which go in may not come out. Retrieval from memory depends on the accuracy of a coding process which determines where the incoming information will be stored, and hence where it is expected subsequently to be found.

The long-term memory contains a database of concepts and records of events tied together within inter-connecting systems. Concepts are built up by repeated comparisons of incoming perceptions or information with pre-existing concepts in prior knowledge and by making linkages between images. If the coding system is to be effective and data recall easy, it is essential that the database should contain a large number of clearly defined and well differentiated concepts which also carry a large number of connecting links with other concepts, ideas or events (Fig. 1).

The ability to think divergently or creatively will presumably depend on the extent to which the memory has developed a multiplicity of unusual, but valid, interconnections. An orientation towards understanding (deep processing) depends on a deep level of processing and elaboration. Reproducing (surface approach) is more likely to involve overlearning by repetition at a shallow level of processing with little use of elaboration. In science and engineering courses, the deep approach involves considerable emphasis on detail and procedures, and may even require a preliminary stage of rote learning which is difficult to distinguish from a surface approach.

Models of student motivation

Motivation is defined in a general way by educators and psychologists as the processes that initiate and sustain behavior. Motivation is defined more specifically for learning in university courses as purposeful engagement in classroom tasks and study, to master concepts or skills. It seems that the most salient controversy in the field of motivation is whether behavior should be conceptualized as 'mechanistic' or 'cognitive' [9, 10]. In general, mechanistic analyses of behavior are characterized as stimulus-response (S-R) theories. They are categorized either as 'ego-psychology' or 'learning theory or drive' models. In the former, intervening hypothetical constructs are not employed in the analysis of actions, while in the latter constructs such as drive, habit, incentive are employed.

Cognitive theories of motivation, on the other hand, conceive of an action sequence as instigated not by stimulation, but by some source of information. External or internal events are encoded, categorized, and transformed into a belief. The direction and persistence of behavior as the organism pursues its goal is a function of the intervening thought processes. This approach may be broadly characterized as stimulus-cognition-response (S-C-R). That is; higher mental processes

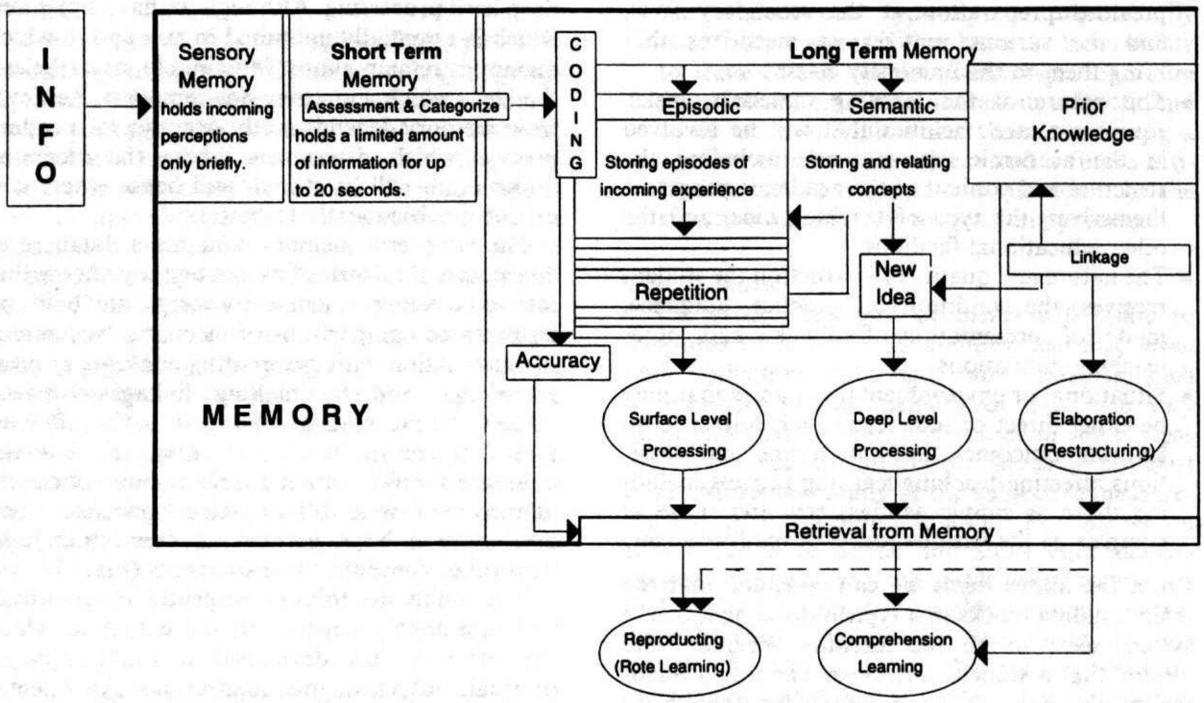

Fig. 1. The model of an information processing system.

intervene between inputs (stimuli) and behavioral outputs (responses). More specifically in a learning process, the structure of the learner's thought determines the action. If the main determinant of action is assumed to be an 'expectancy', then, the probability of success is expressed in terms of the difficulty of one's learning task (typical expectancy models). In more recent cognitive models, students' perception about themselves and their task difficulty are the most important factors. In these models many cognitive processes like information seeking, and various causal attributions determine students' learning actions.

Our chosen model for student motivation

Although there are many models of motivation that may be relevant to student learning, our approach is a kind of collective one. We look at motivation in a way that gives answer to a fundamental question: 'What do different theories of motivation offer to a teaching/learning system to enhance the process?' On this basis, we have developed a model to organize what are the most important influences of one's personal motivations on learning. The model is based on the premises that students' motivation is heavily influenced by their thinking about what they perceive as important and what they believe they can accomplish [11, 12]. According to this model, student's 'desire to learn' comprises of values that represents perception of the learning task value and the impact of external reinforcement on these values (Fig. 2).

The student's task values comprises of a wide range of values that each have their own weight on the student's attitude and willingness toward the learning task. Values like interest in the subject (matter), interest in (future) use, and in grades/marks are the most known values of this kind in the literature. We have tried to identify and classify other main values as well. For instance, the amount of 'pride in future profession' is another factor which student sees in the learning task. This value comes either from an existing role model in student's real life or from a social comparison that he or she made. Self-worth, security in future job, social obligation (toward parents, friends, and society), choice, bandwagon effect, and association of the learning task with something which the student likes are the other internal perceived values.

A similar effort has been made for identifying the external reinforcement factors that have their own impact on the student's learning task values. They have been classified in seven categories and each with their own corresponding sub-categories. These external factors vary from parameters like characteristics of the teaching system and the nature and quality of the subject matter to those like interpersonal relations. The impact of environmental factors such as satisfaction with the institution or the attitude of others toward the student have been considered as well. Therefore, the model first tries to recognize the primary values and, second, identifies the external factors that promote student learning behavior. The interaction between these two categories of parameters (and their subcategories) determine the amount of efforts that each student puts into his or her learning task at any given time. Note that the subsequent progression of the motivation, that is, the effort students are willing to put into the task, results in their 'expectancy'. In fact, this stage connects the input

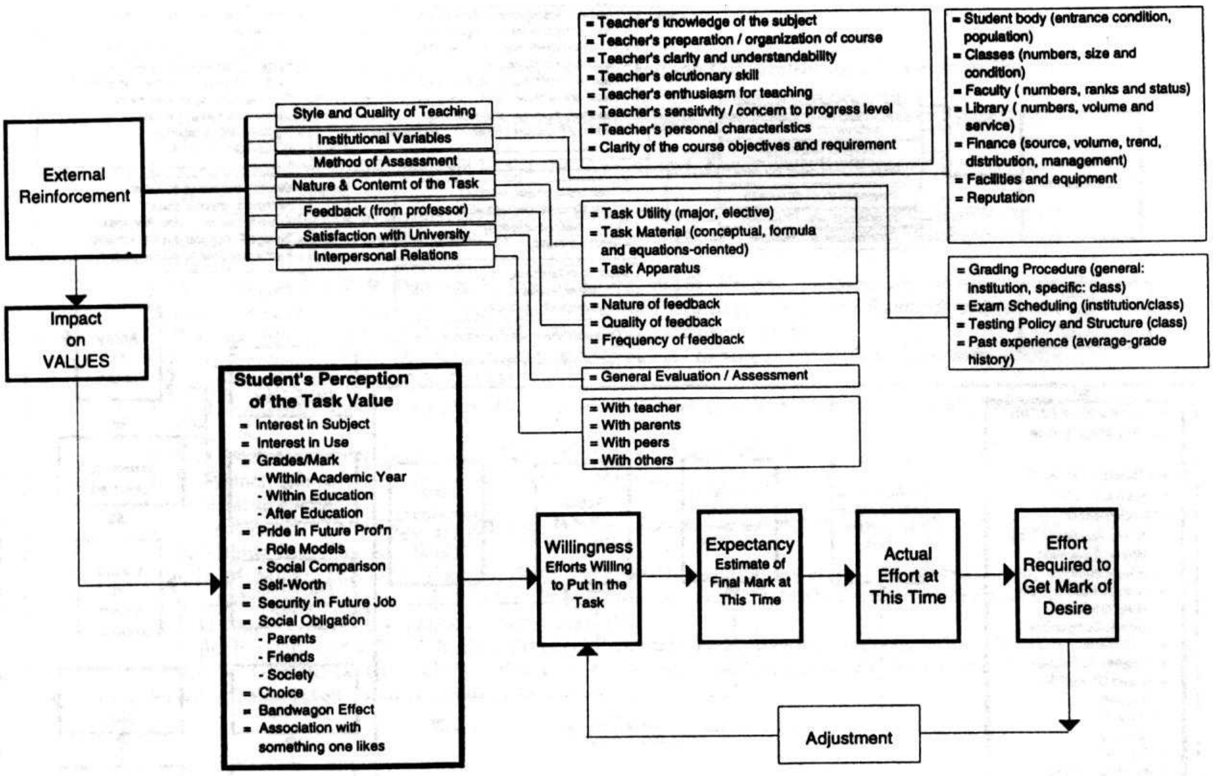

Fig 2. Model of the student's 'desire to learn'.

side of the process to its output side which is the students quantifiable outcomes (marks or grades of desire) at any one time. The adjustment feedback loop indicates that if students see little value in what they are learning or in the results of their effort, their motivation will be lessened, even if they believe that they are capable of success.

MECHANISM OF A TEACHING/LEARNING SYSTEM

The information resulted from Fig. 1 and Fig. 2, gives enough ground to claim that at this stage we are able to build our preliminary model for a teaching/learning process. By combining students' learning 'abilities' and 'motivation', we can conclude that if students believe that they are able to succeed with reasonable effort and if they see value in what they are learning, then a typical learning performance will take place.

Figure 3 demonstrates how these two major sets of components can be combined and simply interact with each other. The diagram consists of four main blocks. At the top-left is the block for external reinforcement factors. This block includes seven basic external reinforcers including different types of teaching systems, instructional materials and other parameters. The block for student's values is the next one. This block is directly under the influence of the previous block and includes ten studied main values as mentioned earlier. The block for the amount of effort that a student puts into the task is the subsequent block located in the center of the diagram. This block leads to the final block for the student's outcome (amount learned by the student). The last block is the product resulting from the combination of student's learning abilities and desire. The stock of 'Abilities to Learn,' at any time, is influenced by the level of 'Prior Knowledge' and amount of 'Learning Reinforcers.' Note too the adjustment feedback that returns from 'Amount Learned' at any time. Learning Reinforcers are different subsets of 'External Reinforcement' and their impacts are defined in accordance with the available statistical results from the studies in the literature. The stock of 'Abilities to Learn' simply represents that part of the system that deals with what happens in the mind of a typical student during an information processing operation. Different types of learners can be assumed but our focus will be mainly on three types of students: A total rote processor (surface processor), a total relater (deep processor), and a fifty-fifty rote-relater.

The diagram itself is an influence diagram. The impact of any external reinforcement factors on any of the student values has a subsequent effect on the amount of the effort that student puts into the learning task. This, consequently, influences the level of the desire to learn. In the mean time, the effect of learning reinforcers and level of prior knowledge build up the existing level of the student's abilities to learn. Finally, the levels of both student's learning abilities and desire determine the amount learned by the student. This is apparently

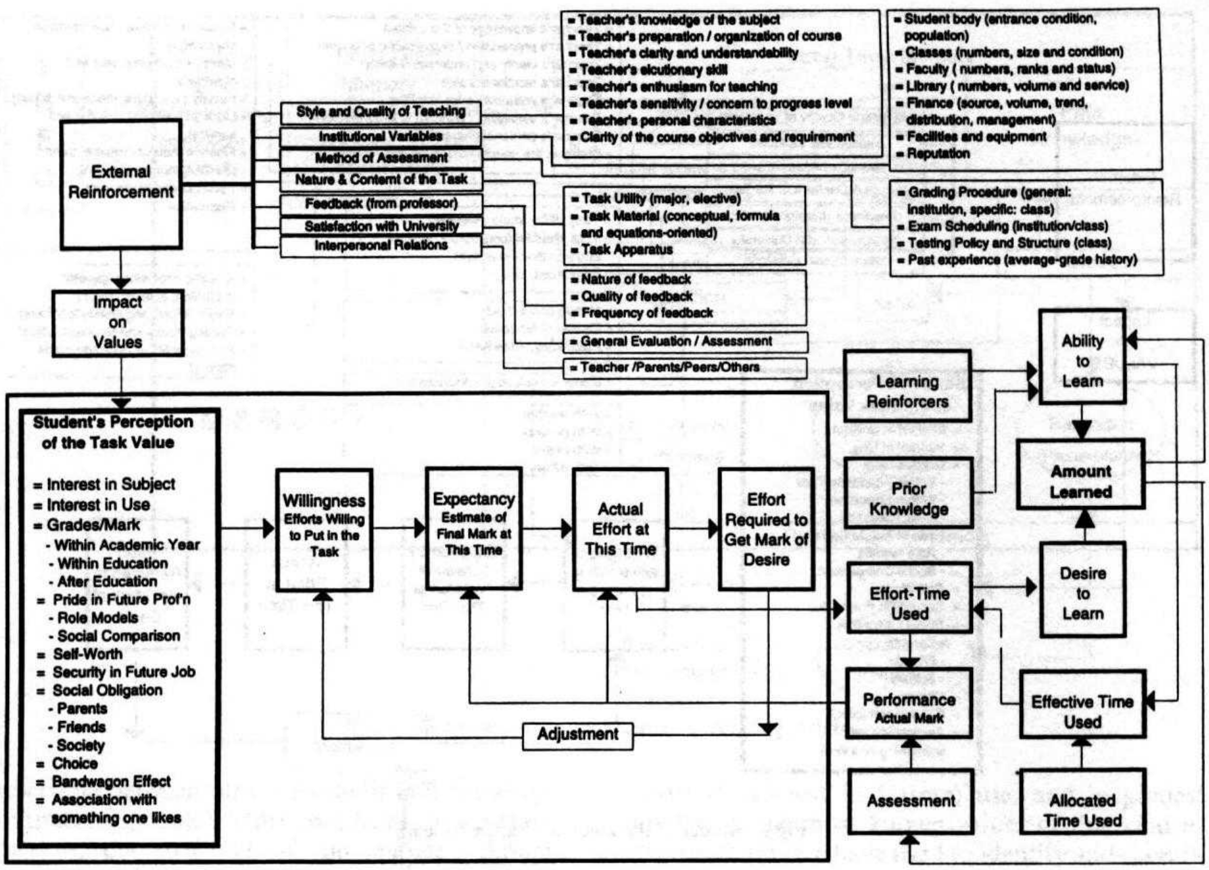

Fig. 3. Influence diagram for a teaching/learning process.

a cause and effect mechanism that drives the teaching/learning process. Many feedback loops exist in the system that have not been demonstrated in the diagram for the sake of the simplicity. Also, the impact of each external reinforcement factor on different student's values should have been studied in both their local and global senses. This issue can be better examined when we have the opportunity to show the details of the interconnecting flows between different components. Therefore, the next step will be to convert this diagram into a detailed STELLA stock level and flow diagram.

FUTURE WORK

Much of our initial task to model a teaching/learning system has been achieved successfully. The description and mapping of the teaching/learning system which is the most important and least straightforward of the stages in our system analysis approach was accomplished. We have identified the necessary elements that a typical teaching/learning system in the real world possesses and have turned them into a unified theory. The formulation and construction of the corresponding simulation model is the next task. Thus, the direction of our future work can be summarized as follows:

1. The completed mapping will be converted into a sound System Flow Diagram (stock level and flow diagram) by using the purpose-built software (STELLA).
2. A series of simulations to demonstrate the following items will be conducted:
   - The effect of the different teaching systems (many policy variables) on the learning rate and amount learned by a second year engineering student using real examples from part of a specific second-year engineering course (subject matter).
   - The effect of other external reinforcement factors (many policy variables) on the amount of the effort that a student puts into the learning task and subsequent effect on the learning rate and amount learned.
   - The effect of a combination of some selected external factors on the rate of learning and the amount learned.
   - The effect of some selected policies on the student achievement.
3. The resulting behaviors of the system will be interpreted and the best modeling structures will be determined.
4. The best modeling structures will be chosen for the purpose of validity/validation (whole-real experimentation stage).

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