Using ICT for transfer of knowledge with application in solving technical science problems

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***Abstract*— Educating students in technical science requires teaching critical thinking and making students capable of compiling knowledge from several courses. Students are usually educated on how to solve most simple problems and often fail when confronted with complex ones. We describe a concept for teaching students how to solve problems from domain of technical science that are both theoretical and real-life, composed of multiple knowledge vectors. Presented concept is a combination of problem-based learning, programmed learning and knowledge space theory thus enabling individual approach. Example implementation is an e-learning supplement to the university course *Network and transmission line theory*.**

I. Introduction

At a number of universities attempts are being made to break away from the traditional knowledge transfer model which can be described as "sage on the stage" [1] and move towards more individualistic approach that can be labeled as "guide on the side" [1]. This transition is usually associated with the design of interactive and multimedia materials for classroom use.

We find technical science and especially engineering courses important in this transformation. Enrolled students are taught about technology by using technology. This forms a recursive process where a non-systematic approach can create a problem even for the students eager to learn. Educator's lack of knowledge in individualistic design of teaching materials can result in frustration for the majority of students if they cannot learn using their full intellectual potential. "Merely providing students with information is not sufficient for learning" [2].

In a great majority of classes students are still seen as a more or less homogenous group. Little thought is given to the fact that students are diverse by the way they think and process information. University students come from different schools or even educational systems (foreign exchange students) and every student has a unique initial set of skills defined by knowledge acquired through previous education. When some students fall outside of preset knowledge standards during their education students themselves are considered to be the problem, and not the knowledge transfer system [3].

It does not come as a surprise that these are facts also known by students, and they, in need to pass numerous tough exams, find various ways to work around the system—either by learning only smaller parts of the course material, or by not learning at all. It is not a problem that small numbers of students get excellent grades. But we find unacceptable that the blame for this is solely on the students. Bloom's taxonomy [4], [5] is the proof that any person can master any subject if considerable effort is spent in analyzing the best way to approach the knowledge receiver's individuality. It has been previously established that "Most teachers lack knowledge on adaptive instruction, and almost all textbooks fail to help teachers make individualized instructional plans" [6].

Many universities are still in the developing phase of adapting their knowledge transfer process towards a more individualized approach. Changes cost resources; but we feel that a well designed knowledge transfer system implemented using information and communication technologies (ICT) must be optimal way towards improvement.

II. Background for development

We chose the widely accepted division of learning theories on behaviorism, cognitivism and constructivism. It is outside of this article's scope to analyze each of them in detail, but we will briefly summarize them by looking at them from the student's side.

- Behaviorism forces students to learn by doing, experiencing, and by trial and error, ignoring the thought processes occurring in the student's mind.
- Cognitivism is focused on the mind structures and processes, with respect to how learners organize and synthesize information when gathering new knowledge.
- Finally, constructivism guides learners to build a personal interpretation of the world based on experiences and interactions, dynamic of learning is learner-controlled, and the teacher's role is focused on guiding rather than teaching. Knowledge is transferred so it can be applied to complex problems which students have not previously been confronted with.

It has been concluded that for use of ICT, constructivism is the most adequate approach [7].

Although today behaviorism in knowledge transfer is not a popular theory, programmed instruction is a concept which stems from behaviorism. Programmed instruction is a teaching method developed in the United States during 1960s with one of the intentions being to reduce linearity of a printed book. This is achieved by giving students both guidance through acquiring knowledge and then immediately a way to apply it. But we must consider the fact that constructing programmed instruction courses was quite an effort for course designers, and students still had to go through the entire book in order to learn the subject, without the possibility of painlessly skipping parts they were already familiar with. Today, with the ever increasing trend of using ICT in knowledge transfer processes, the philosophy of small steps, active answers and self-paced learning—which are some of the basics of programmed instruction—can be reapplied.

Designing these small steps programmed courses are constructed from is also an important issue, since the end result must be a systematic dissemination of the course subject. The theory of both analyzing and synthesizing course user's (student's) knowledge set is comprised in the theory of knowledge spaces and/or vectors. We find that using the abstract of this theory is helpful in determining the scope of questions the student is to be asked when confronted with a problem.

The basic knowledge space is the universe, and is infinite. From the universe we select a logically connected set of information—a finite knowledge subspace which includes all information on one subject. This subspace is a very small part of the original knowledge space but can still be too large to be used as basis for creating a course. Another part of the subject knowledge space can be chosen, which contains all the knowledge that is to be put in the knowledge transfer process within a single course. This knowledge space can then be decomposed in any way the course designer sees fit. The resulting decomposition can be used to construct the contents of steps in a programmed course. Considerations on decomposition are outside the scope of this article.

Learning technical science requires theoretical problems, but engineers must also be able to solve problems in real life. A way for managing this need exists in the form of the problem-based learning concept (PBL). It consists of using a real-life situation and managing students' efforts on acquiring just the right knowledge to solve the problem [7]. It follows the constructivism principle. Although, for a teacher who is not knowledgeable in problem-giving methodologies, the task of finding the right problem(s) which encompasses the knowledge one whishes to transfer to the students, can be traumatic, without applying some other way of designing problems.

We must also take into account another categorization of student's ways of learning—the media used to present course material. With regard to preferred ways of learning, students can be divided on:

- visual (students who prefer images and text),
- auditory (preferred hearing or listening) and
- kinesthetic ("hands-on" learning).

Although a combination of all three is best, Cantoni et. al. suggests that course design should be oriented towards visual students [8].

Whether or not is it necessary to apply ICT in the knowledge transfer process? A number of comparative studies done in the previous years of traditional versus ICT enhanced teaching show that ICT enhanced courses are as effective as traditional courses [9], [10], [1]. The question for the purpose of spending on ICT is frequently raised, since results show no immediate difference. The answer and the justification for spending effort when implementing ICT in the knowledge transfer process is in the facts that ICT courses are, if properly constructed, less expensive to deliver, self-paced, provided content is consistent, and are generally a faster way to learn—students can study at their own pace and skip the material they feel familiar enough with.

III. Proposed concept

In order to satisfy most of the needs regarding the diversity of students, we developed a concept that will be adaptable to the student knowledge, both previously and newly acquired. For educators, this concept creates a roadmap to use when constructing classroom material for any technical science course. For students though, the concept can be made highly adaptive with regards to their level of knowledge.

For reference purposes, we name this concept *Variable Depth Learning* (VaDeL). The basic premise of the concept is that it approaches each student as a variable—a unique and distinguishable input. VaDeL enables each student to learn problem solving in technical science to the depth necessary to satisfy the level of knowledge teacher sets while constructing the problem.

Regardless of the way information is relayed, the basic goal of teaching students how to solve problems using their own critical thinking still remains. We divide the general problem solving technique into 4 phases, as shown in fig. 1.

VaDeL is divided in two components - one vertical component (*main vertical*) and multiple horizontal components (*horizontal*). While the basic steps in the main vertical are fixed, the number of steps in a horizontal depends on the skill the problem constructor possesses.

The main vertical can be seen as a backbone of the problem solving process. Ideally, the student who has enough knowledge to solve a problem without making errors will only make progress through the main vertical, without going deeper through horizontals. Also, the "guide on the side" principle is best used on the main vertical. The system of horizontals is used to pinpoint the knowledge the student needs to upgrade or modify in order to return on the main vertical and continue the problem solving process. Horizontals should usually be left to the student to explore on his own, reducing the time teacher has to spend on tutoring each student.

A. Main vertical

Every problem must begin with a clear problem definition, which is the starting point in the main vertical. Problem definition should be written in such a way to enable analytical thinking and to call for the student's research skills. This means problem is given in a way that will motivate the student to think creatively, instead of trying to find similarities with problems he solved earlier. This can be achieved by making the problems as based in real-life engineering problems as possible. Problems should also be multidisciplinary, but proper care should be taken so the student is aware that he will have to gain knowledge usually not taught in class he enrolled. For example, to analyze a behavior of an electrical network, one may have to use knowledge of forming and solving differential equations. The problem definitions should be written using a very general description, avoiding numerical data. It can be left to the student to find appropriate data based on

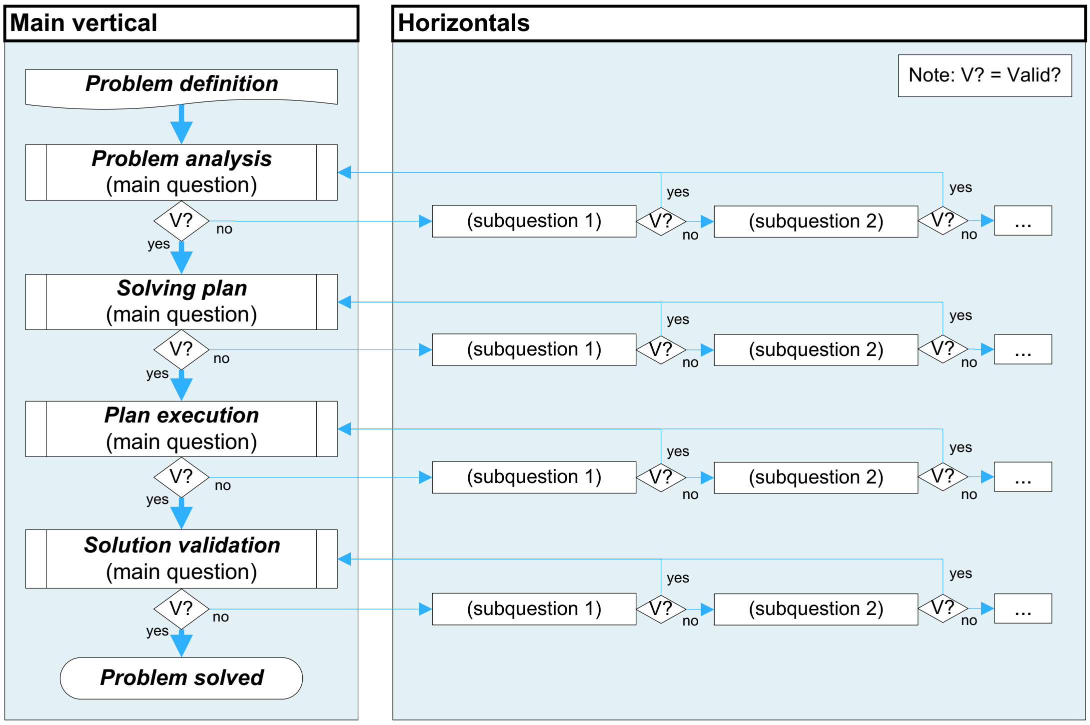

Fig. 1. VaDeL concept for solving technical science problems

real-life circumstances with which the problem is to be solved—thus creating a challenge for the student's researching skills. Finally, we suggest including as few variables as possible. Problems that develop critical thinking are best written if they are least burdened with numbers and variables.

Along the main vertical four phases can be identified: (1) problem analysis, (2) solving plan, (3) plan execution, and (4) solution validation (see fig. 1).

The first phase of the problem solving process is problem analysis. For any given technical science problem definition, an elaborate problem analysis must be performed in order to identify the behavior of the observed system. Depending on the way problem definition is written, one of the students tasks in this phase is to determine all the variables. He must find out what is given (fixed) in the problem, and what he yet has to discover in the problem solving process. Cause-effect and other analysis of correlation can then be performed on each variable or group of variables. Variables can also have a time frame in which they exist—for example, transient responses of a network to a pulse. Conditions and assumptions in the problem must also be observed. The student should try to guess the basic form of the solution. Finally, the student should find possible ways of getting to a final soulution—and have all alternatives in mind for the next phase of the problem solving process.

Harskamp and Shure show that more skilled problem solvers spend the majority of given time for solving particular problem on problem analysis, necessary tools and knowledge for getting to the solution [6]. An average student, having been trained (behaviorism) instead of taught to think, tends to start applying knowledge gained from solving similar (or same) problems earlier in the knowledge transfer process. The latter have much difficulty determining their first steps on the way to the solution.

During the second phase a plan is formed, usually in the mind of the problem solver, on how to approach the process of getting from problem analysis to the final solution. First step is deciding on which path, developed in the problem analysis stage, is most effective for a given problem. After making a decision, basic aims of the solving process must be determined.

In the third phase the formed plan is executed using the information gathered during problem analysis—if the plan is viable and the student's knowledge is sufficient for execution, a possible solution is produced. The student does not enter the system of horizontals.

The final phase of the process deals with validating the solution. Solution produced in the previous phase is compared to initial estimation made in analysis and to the question posed in the problem. If the solution is satisfying as an answer, the problem is considered solved. The process can end here, but a more critical thinking oriented process should also encourage further discussion. After successfully solving the problem, students should see if the consequences of the solution are of importance to the state of the original problem. It should be analyzed if all the assumptions were correct and if the conditions could have been given in a different way. Also, it should be analyzed what would happen if one or more conditions would have been changed and/or left out of the original problem.

Course designers are not obliged to develop only one question per phase, as one question alone usually can not be sufficient to determine if one posesses required knowledge. If multiple main questions within a phase are asked, each one must have its own set of horizontal subquestions.

This concept of problem solving ensures that the diversity of students is taken into account, together with the learning theories discussed earlier in this article. The problem analysis phase serves as support for the basic principle of constructivism theory—each student can develop his own way of acquiring a solution.

B. Horizontals

The student needs to become familiar with the degree by which his knowledge is or is not sufficient for solving the problem. If it is determined that the knowledge is not sufficient, proper instructions for gaining the knowledge must be given to the student. For dealing with this problem, we developed a concept of *horizontals* for each phase in the main vertical. Thorough horizontals which the student can both gain and measure his own knowledge.

In our opinion basic paradigm of an ICT system developed to teach students critical thinking is that incorrect answers are not really wrong and should not immediately be discarded. We suggest that instead of just determining that student made an error, the focus should be on making the student understand, on his own, why the error occurred, thus helping the student discover the point in his own knowledge where the error was first formed. It is vital that such an ICT system is highly interactive and provides adequate feedback to the student about his progress thus maintaining student's high motivation.

On the other hand, if student possesses advanced knowledge on the matter presented, it must be possible to quickly pass through the *main vertical* to either complete the problem or get to the point where he needs to upgrade his knowledge.

For illustration we shall discuss an example where the student is given a concisely formed problem definition, produced through accurate usage of problem giving techniques. The student is confronted with the main question (one that best captures what the students needs to understand) in which he has to analyze the problem. The scope of main question can be determined using the knowledge space theory [11], [12]. The student makes an entry in the system, and the system recognizes it as correct. In such situation, student passed the "Problem analysis" (see fig. 1) in the main vertical and is routed to another question concerning the development of a plan to obtain the solution. Now student again makes an entry in the system, but the entry is recognized as incorrect. Student is rerouted to a subquestion contained within a horizontal of the same level. Instead of plainly stating to the student that he entered a wrong answer, that he should try again or that he failed, the student is confronted with another question from the same domain, but this time with one with smaller scope. The process can be repeated in the horizontal as many times as necessary.

The final, rightmost part of a single horizontal can be defined in any way the course designer prefers—for example, text that describes the theory student needs to study more carefully to be able to answer the questions or a link to resources for research with guidelines for analyzing the material. We suggest avoiding messages stating that the student's knowledge is not yet sufficient for solving the problem.

There is no unique definition on how many subquestions the student is confronted within a single horizontal. Every next subquestion should be simpler than the one before as student needs less pre-acquired knowledge. By using the basic principles of knowledge space theory, the errors in student thinking can be predicted thus making the subquestions more suited for student's state of knowledge.

The technical form of questions given to the student and the student entry are limited only by the technical knowledge of the course designer and/or available course development software—questions can be given either in the form of blank entry, multiple choice, or even as a drawing whiteboard.

Designers should have in mind that students answers must be analyzed using comparison algorithms. Such algorithms must be developed if they do not exist and should be flexible enough to allow certain deviations from the fully correct answer, based on the problem at hand. This deviation can be defined as the percent in which the student's solution is different from the fully correct one entered in the problem solution database. It should be narrowest for the beginning phases of problem solving consequently becoming wider as the student comes closer to problem solution.

The question of gaining initial knowledge for solving the problems remains. We suggest a self-standing ICT solution, without any initial knowledge given to the student in the course the problems are presented in. This goes to support the constructivist theory and problem based learning. Students are confronted with the problem first. The knowledge necessary to solve the problems is gained through the concept of vertical and horizontals. Furthermore, this concept can serve to illustrate to the student the extent to which his initial knowledge is or is not sufficient for a given problem without the need to go through the initial classroom lectures. This amplifies the individual approach the system is able to give if appropriately implemented with use of ICT.

An example implementation of this concept can be seen online, where an e-learning system we have developed as a supplement to a course of Network and Transmission Line Theory is availabe [13].

C. Adjusting to student's knowledge

While constructing course curriculums and class materials, educators often lose sight of the fact that the end users are students. In most cases, students process information in a considerably different way than the educator, since the educator is already familiar with the course matter. Educators spend a lot of time familiarizing themselves with the subject while students needs to learn the material in the time allocated for the course, which is usually not more then one semester. We find it a necessity for the educator to be aware of the process of constructing the knowledge in the student's mind.

The most effective way is to observe this through knowledge space theory. Although the first intention of the theory is a more precise evaluation of the student's knowledge, it has been established [11], [12] that the same theory can be used to individualize the course material presentation. The essential concept is that after student's state of knowledge is determined, he only has to be served with the course material that will teach him knowledge he does not possess.

We used this theory in the VaDeL concept, as illustrated in fig. 2, which explains our basic paradigm on knowledge construction in the student's mind. We assume that knowledge decomposition has been performed for the course. We will use the term *knowledge leaf* for the smallest (lowest) part of the decomposition. Several leaves can be merged to form a *knowledge branch*. Multiple knowledge branches form the knowledge space of one course.

In fig. 2, a part of the process where the student enters an answer in the system is shown. Entry validation algorithm compares the student's answer with the one in that is considered to be fully correct by the system. Differences are analyzed, and a conclusion is formed on the correctness of the entered answer. The answer can be considered satisfactory or unsatisfactory.

If the answer is not satisfactory, it is necessary to determine the cause of the student's inability to produce a satisfying answer. We find 2 possible reasons for this, as shown in in fig. 2:

- The student does not possess any knowledge (represented as **1.1.1**, **1.1.2**, etc.) required to successfully solve the problem. The student is immediately rerouted to the problem analysis horizontal. This eventually leads to course material through which the student can acquire knowledge associated with these knowledge leaves. Student must be guided to merge the knowledge to form a full knowledge branch (represented as **1.1**) in order to successfully complete the problem.
- The student possesses parts of knowledge required for getting to a solution of the problem. In this example, the student possesses knowledge parts **1.2.1**. through **1.2.5**. Student enters a horizontal when knowledge from leaf **1.2.6** has been introduced in the question. Students knowledge is not sufficient in this area, so course materials associated with knowledge leaves **1.2.6**, **1.2.7**, etc. need to be presented to the student. Care must be taken that the newly acquired knowledge is properly merged in the student's mind, and constructs a full knowledge branch, represented as leaf **1.2**).

If the system finds the answer fully correct or within preset deviation parameters, a conclusion can be produced.

- The student possesses all the knowledge required for solving the problem (knowledge leaves **1.3.1**, **1.3.2**, etc.) and is able to successfully merge it (knowledge branch **1.3**) to gain a satisfying solution. Even though students are expected to stay on the main vertical, [14] suggests that proper care should be taken to eliminate carelessness in the students dynamic of problem solving.

The student's state of knowledge can then be determined as the system observes the input student provides in the main vertical questions. If the student, in any of the four phases of problem solving, is rerouted from the main vertical to a corresponding horizontal, his knowledge is considered insufficient with regard to the question presented for the phase.

When planning the ICT system to use VaDeL principles, we suggest implementing automatic outputs to a database which will provide feedback on the route the students pass from problem definition to the state of having the problem solved.

Furthermore, if a problem is in the category of leaf **1.1**, it can be considered as too complex or otherwise inadequate. We suggest either lowering the complexity of problems of this kind or making it available to students only after they solve other, easier problems.

If the problem is in category of leaf **1.3**, it can be considered as too simple. If the problem is used to remove carelessness, it can be considered appropriate.

D. ICT system development considerations

Each problem should form a self-contained concept that would traditionally be explained in one lecture. A course is a collection of such problems which are unified as an information theme. Technical science and mathematical principles that can be applied to more than one problem are favored over those that have more limited application.

At the points in problems where the student is given the course material (lectures, textbooks, etc.), care should be taken of the fact that reading from a computer screen is slower than from a traditional book, and that parts of the material should be printable. If technical infrastructure in the educational institution performing the course is a problem for using the system, it can be made distributable via CD-ROMs, or shared by a local network instead of Internet.

Routinely converting conventional classroom sessions to slide shows can be avoided by incorporating enough interactivity while in the process of course (and supporting ICT system) design.

To support the "guide on the side" principle, proper care must be taken to enable simple communication between students on the course and between of each student and the teacher, including individual tutoring, group discussions, and peer-based collaborations on problem-solving. Care must be taken to monitor students' on-line activities so problems in student thinking can later be statistically analyzed. Results of analysis should be used for improvements in system usability.

Individual students should be able to choose or be directed to different problems depending upon interest, need, or competency level, thus enabling an individual approach. Students can have points of choice in the process where multiple problems can be presented. Students can then choose problems which interest them the most. Regardless of such choices, all students must pass through all the problems. Students learn at different rates, and individual learners may process information differently. Therefore, efficiency of learning can be increased if the instruction can be tailored to the individual requirements of the learner [15].

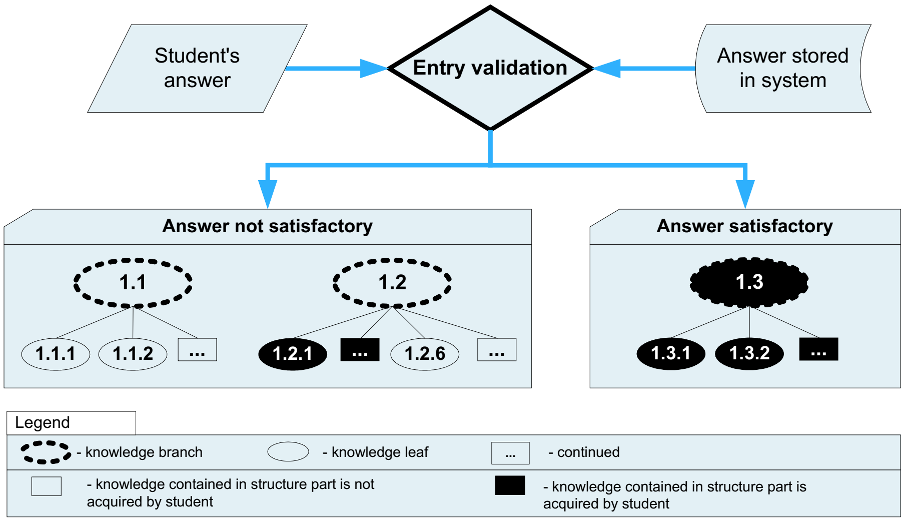

Fig. 2. Determining student's knowledge structure

IV. Conclusion

The central proposition of this paper is a concept of virtual verticals and horizontals which can, through the use of ICT for implementation, teach students how to solve complex problems by allowing them to use any previously acquired knowledge immediately. If the student's knowledge is found to be insufficient for solving any part of the problem appropriate help should be offered to the student. A systematic approach to pinpoint the exact knowledge the student must learn in order to be able to move on to the next step of solving the problem is presented.

The benefits of an accordingly designed system are that it is usually less expensive to deliver knowledge: learning is self-paced, faster (learners can skip material they already know), provides consistent content (in traditional learning different teachers may teach different material about the same subject), is available any place and any time (e-learners can take training sessions when they want), is updatable easily and quickly. We suggest such a system can lead to an increased retention and a stronger grasp on the subject and be easily managed for large groups of students. Students taking an online course may have the opportunity to participate in a free environment in which they can make errors without directly exposing themselves, and eventually receive feedback on the consequences of their actions.

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