EFFECTIVE TEACHING STRATEGIES FOR DIRECT AND INDIRECT INSTRUCTION IN TEACHING ENGINEERING IMPLEMENTED AT TALLINN UNIVERSITY OF TECHNOLOGY

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Abstract

In teaching engineering it is important to select the proper instructional strategy for a specific learning outcome. There are two broad types of learning outcomes: facts, rules and action sequences (on lower levels of complexity in the cognitive, affective and psychomotor domains), and concepts, patterns and abstractions (on higher level of complexity in the above named domains). Facts, rules and action sequences are taught using instructional strategies emphasizing knowledge acquisition (direct instruction). Concepts, patterns and abstractions are taught using strategies emphasizing inquiry or problem solving (indirect instruction). Knowledge acquisition and inquiry are different types of learning outcomes and they must be taught using specific strategies producing the desired outcome. Both types of learning may be combined, providing a menu of teaching strategies that help students solve problems, think critically and work cooperatively. This article presents teaching strategies suitable for direct and indirect instruction used in teaching engineering at Estonian Centre for Engineering Pedagogy at Tallinn University of Technology.
Key words: *teaching engineering, direct instruction, indirect instruction*.

Introduction

Teaching has only one purpose, and that is to facilitate learning. Learning can occur without teaching at any loss to anyone, but teaching can, and unfortunately often does occur without learning. In the latter case, the students obviously lose time, money, potential gains in knowledge and cognitive development, and perhaps confidence in themselves and in the educational system. But less obviously, teachers lose faith in their students and in them. For our own sake as well as our students', we should make teaching and learning synonymous sides of the same coin.

Have you ever wondered why some teachers are more liked than others? Students cannot wait to attend the classes of some teachers, but dread attending the classes of others.

Knowledge of a variety of instructional strategies and flexibility to change them within and among lessons are two of greatest assets a teacher can have. Just as the carpenter or electrician must select a proper tool for a specific task, a teacher must be able to select a proper instructional strategy for a specific learning outcome.

Even before instruction takes place, teachers should think about and make decisions concerning prerequisite knowledge of students, teaching content, instructional strategies, the use of instructional materials and teaching technology, teaching techniques, classroom management and discipline, and assessment of student learning, and a host of other related issues. During instruction, teachers must implement these decisions in a dynamic way. Decision making involves giving consideration to a matter, identifying the desired end result, determining the options to get to the end result and selecting the most suitable option to achieve the desired purpose. Teacher decisions will ultimately influence student learning.

Background to the Problem

According to Felder & Brent (2005) students learn in many ways – by seeing and hearing; reflecting and acting; reasoning logically and intuitively; memorising and visualising; drawing analogies and building mathematical models. Teaching methods also vary. Some educators lecture, others demonstrate and discuss; some focus on principles and others on applications; some emphasise memory and other understanding. How much a student learns in a class is governed by student's ability and prior preparation, but also by compatibility of student's learning style and the instructor's teaching style.

Students learn in various ways, and teachers should vary their use of instructional strategies in order to relate students' learning styles and needs. One of the most important factors in how interesting teachers are to their students is their use of a key behaviour: instructional variety. Knowledge of a variety of instructional strategies and the flexibility to change them both within and among lessons are two of the greatest assets a teacher can have. Just as the carpenter must select the proper tool for a specific task, a teacher must select the proper instructional strategy for a specific learning outcome.

There are two board classifications of learning outcomes:

1) Facts, rules and action sequences – usually represent behaviours at lower levels of complexity in the cognitive, affective and psychomotor domains.

2) Concepts, patterns and abstractions – represent behaviours of at the higher levels of complexity in these domains.

One way to vary instruction is to use deductive and inductive models. Instructional strategies of deductive model are direct and straightforward and lend themselves to direct instructional approaches, whereas instructional strategies of inductive model are intended to tap into the interests and thinking abilities of the students, being more indirect.

Teachers should select the proper instructional strategy for a specific learning outcome (Borich 2011):

1) Outcomes for teaching facts, rules and action sequences often represent behaviours at lower levels of complexity in the cognitive, affective and psychomotor domains. These include the knowledge, comprehension and application levels of the cognitive domain; the awareness, responding and valuing levels of the affective domain; and the imitation, manipulation and precision levels of the psychomotor domain;
2) Outcomes for teaching concepts, patterns and abstractions represent behaviours at the higher levels of complexity in these domains. They include outcomes at the analysis, synthesis and evaluation levels of the cognitive domain; the organization and characterization levels of the affective domain; and the articulation and naturalization levels of the psychomotor domain.

Facts, rules and action sequences are most commonly taught using instructional strategies of deductive model that emphasize knowledge acquisition (direct instruction), in a presentation-recitation format, involving large amount of teacher talk, questions and answers, review and practice, and the immediate correction of student errors (Eggen & Kauchak, 2006).

Concepts, patterns and abstractions are most commonly taught using instructional strategies of inductive model that emphasize inquiry or problem solving (indirect instruction). Knowledge acquisition and inquiry are different types of learning outcomes, and each must be linked with specific strategies to reach the desired outcome (Borich, 2011). Both types of learning could be combined to provide a menu of teaching strategies that help students solve problems, think critically and work cooperatively.

Instructional Strategies of Deductive Model

Instructional strategies of deductive model are instructional approaches that start with a known principle and then attention moves to the unknown. The strengths of the deductive model are the directness and specific focus of the teaching strategy, and the tight linkage between the teacher's examples and the task required of students. The lesson begins with known principles and then leads to examples of the new principle. It is a fairly direct straightforward way of addressing the lesson objective (Burden, 2010).

Direct instructional approaches are academically focused with the teacher clearly stating the goals for the lesson. The teacher monitors student understanding and provides feedback to students on their performance.

Direct instruction has four key components:

1) Clear determination and articulation of goals;
2) Teacher-directed instruction;
3) Careful monitoring of students´ outcomes;
4) Consistent use of effective classroom organization and management methods.

Direct instruction is effective because it is based on behaviouralistic learning principles (obtaining students´ attention, reinforcing correct responses, providing corrective feedback, and practicing correct responses), increasing the academic learning time during which students are attending to the task at a high success rate. Students learn basic skills more rapidly when they receive a greater portion of their instruction directly from the teacher, thus gaining systematic knowledge (Melezinek, 1999).

Most students cannot stay focused throughout a lecture. After about 10-15 minutes their attention begins to drift, first for brief moments and then for longer intervals, and by the end of the lecture they are receiving very little and retaining less. A classroom research study has showed that immediately after a lecture students recalled 70% of the information presented in the first ten minutes and only 20% of that from the last ten minutes (Borich, 2011). Students' attention can be maintained throughout a class session by giving them periodically something to do (Felder & Brent, 2005).

There is no sense to stop a lecture and wait for students' questions. More effective in teaching engineering is to involve students actively, thus finding out what the students have not understood and only then the teacher answers arisen questions. The wide array of effective active methods in lecture should wipe off the notion that good teachers are born and not made (Rüütmann & Kipper, 2010).

Once a teacher incorporates students' active breaks into the lecture, an interactive lecture is given, during which students are in some way interacting with the material for brief, *controlled period of time*. A teacher must carefully time-control the student-active breaks, thus keeping students focused on the task (Felder, 2006 A).

At Estonian Centre for Engineering Pedagogy several tested interactive methods, suitable for teaching engineering are taught to the future technical teachers. The students practice holding interactive lectures in seminars and workshops. The following most frequently used interactive teaching methods are taught during the study program:

1) *Pair and compare* – students pair off with their neighbours and compare lecture notes filling in what they have missed, thus reviewing and processing reflectively the lecture content. Time: 2-3 minutes;
2) *Pair, compare and ask* – additionally to the previous teaching method, students jot down questions on the lecture content, thus the material is reviewed and analyzed.

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Teacher answers the questions that students cannot answer themselves. Time: 3 minutes, plus time to answer students' questions;

3) *Periodic free-recall, with pare and compare option* – students put away their lecture notes and write down the most important points of the lecture and questions they have, thus reviewing and processing reflectively the lecture content. Students may work individually or in pairs and answer each other's questions. Time 2-3 minutes, plus time for teacher to answer students' questions;
4) *Listen, recall and ask, then pair, compare and answer* – students only listen to mini-lecture with no note-writing, then open notebooks and write down all major points they can recall and questions they have. They pair off and compare lecture notes and answer each-other's questions. This activity makes students to review and mentally process your lecture content. Time 3-4 minutes for note-writing, 2-4 minutes for pair fill-ins and question answering, plus time for teacher to answer remaining questions;
5) *Solve a problem* – students solve a problem based on the lecture content it makes students to apply the lecture content, informing the teacher how they have understood. Time: 3 minutes for solving, 1-3 minutes to answer questions;
6) *Pair and discuss* – students pair off and discuss an open ended question, in order to apply, analyze or evaluate the lecture material and synthesize it with the course material. Time: 3-10 minutes, plus 5 -10 minutes for discussion;
7) *Think-pair-share* – teacher gives students an open question or a problem and asks them to think quietly, then to discuss with their neighbour and finally to share with the class;
8) *Students' teams achievement divisions* – after a lecture students' teams receive a worksheet to discuss, complete and give oral presentation on results to others;
9) *Send a problem* – each group of students write a question or a problem on a flashcard and write a right answer or a solution on the back. The card is passed to other groups which formulate their own answers and check them against that written on the back side, and write their alternative answers if necessary. At the end the original senders discuss alternative answers;
10) *The one-minute paper* – students summarize the most important or useful points they learned from the lecture and questions that remained. It helps students think, absorb, digest, extrapolate and internalize new material moving it to long-term memory;
11) *The muddiest point* – students give a quick response to a question: "What was not clear or confusing point in the lecture or topic?" They must identify and formulate what they did not understand. This method requires some higher-order thinking skills, ability to concentrate and pay attention;
12) *One-sentence summary* – students summarize concisely, completely and creatively a large amount of information of the lecture or topic, thus developing abilities to synthesize, summarize and integrate ideas and information;
13) *Directed paraphrasing* – develop students' ability to translate highly specialized information into everyday language paraphrasing a lesson compactly in their own words;
14) *Application cards* – after students have heard or read about an important principle, theory etc index cards are handed out to write down at least one possible real-world application for what has been learned. The method develops ability to think creatively, to apply principles to a new problem and situation, to draw interferences from observation.

A well-known direct instructional approach, explicit teaching calls for the teacher to gain student attention, reinforce correct responses, provide feedback to students on their progress, and increase the amount of time that students spend actively engaged in learning course content. Its objective is to teach skills and help students to master a body of knowledge. Ten general principles apply when developing and explicit teaching lesson (Borich, 2011):

1) Begin a lesson with a short statement of goals;
2) Begin a lesson with a short review of previous prerequisite learning;
3) Present new material in small steps, with student practice after each step;
4) Give clear and detailed instructions and explanations;
5) Provide a high level of active practice for all students;
6) Ask many questions, check for student understanding, and obtain responses from all students;
7) Guide students during initial practice;
8) Provide systematic feedback and corrections;
9) Provide explicit instruction and practice for seatwork exercises, and when necessary, monitor students during seatwork;
10) Continue practice until students are independent and confident.

Based on studies of explicit teaching, six teaching functions have been identified (Burden 2010):

1) Daily review – to determine if students have obtained the necessary prerequisite knowledge or skills for the lesson;
2) Presenting and structuring – effective teachers spend more time presenting new material and guiding practice than do less effective teachers, they also explain learning objectives to be covered, teach one point at a time and provide specific examples;
3) Conducting guided practice – the purpose of which is to supervise initial practice of a skill and to provide reinforcement necessary to progress new learning from short-term into long-term memory;
4) Providing feedback and correctives – providing students with an additional explanations and correct answers if necessary;
5) Conducting independent practice – providing the additional review and reinforcement;
6) Weekly and monthly review.

The following main strategies of direct instruction may be used in teaching engineering (Eggen & Kauchak, 2006):

1) Presentations – should be used when objectives other than knowledge are sought; the information is detailed, abstract or complex; learner involvement is important; higher cognitive learning is sought, or students are below average ability; presentations are more effective when using interactive breaks;
2) Demonstrations – involves a visual presentation to examine processes, information and ideas allowing students to observe real things and how they work;
3) Questioning – is a critical instructional strategy (Rüütmann & Kipper, 2010);
4) Recitations – determine if students remember or understand previously covered content with the teacher clearly in control of directing the learning;
5) Practice and drills – going over the material just learned to consolidate, clarify and emphasize what has already been learned and repeating information on the topic until it is firmly established in students´ minds;
6) Guided practice and homework – teacher-directed strategy for the use of techniques

through which students use and practice the knowledge and skills being addressed in the class, including seatwork, teacher-led practice, student cooperative practice and homework;

7) Review – an opportunity to look at the topic another time, not requiring drill techniques, being intended to reinforce the material learned.

When preparing a lesson plan, it is not enough to write a discussion plan. Teacher should select at least three discussion questions ahead that will advance student understanding. These key questions should guide meaningful discussion in the class, the questions should include words how, why, what if. Also teachers could ask students to explain their views by citing material from what has been covered in the class (Rüütmann & Kipper, 2010).

The direct instructional approaches are characterized by full-class instruction by the organization of learning based questions, provision of detailed and redundant practice, by presentation of material. Direct instruction is most appropriate when the content in textbooks does not appear in appropriately sized piece, and when it is necessary to arouse student interest.

While using direct instruction, the teacher is clearly in control of the content or skill to be learned and the pace and rhythm of the lesson, introducing new skills or concepts in a relatively short period of time.

Direct instruction is limited to learning units of the content taught so they can be remembered and composing parts of the content learned into a whole, so that a rapid and automatic answer can occur. The task for the learner is simply to produce a response that mirrors the form and content of the stimulus. Learning at lower levels of the cognitive, affective and psychomotor domains relays heavily on remembering and composing, a great deal of teaching involves these simple processes.

Instructional Strategies of Inductive Model

Instructional strategies of inductive model are instructional approaches that start with and unknown principle and then attention moves to a known one. A teacher using an inductive approach may start a lesson with asking questions and using examples and thus helping students to recognize the principle being learned. This inductive approach is indirect, but very effective because students interact with the content to make meaning. Inductive approach often begins with exploratory activities and lead to students discovering a concept or generalization.

Real-world activities, however often involve analysis, synthesis and decision-making behaviours in the cognitive domain, organization and characterization behaviours in the affective domain, and articulation and naturalization behaviours in the psychomotor domain. These behaviours are not learned by memorizing and rapidly and automatically reassembling them into a whole. Instead they must be constructed by learners' own attempts to use personal experiences and past learning to bring meaning to and make sense out of the content provided. Teaching for higher-order outcomes requires instructional strategies that represent the indirect instruction (Felder, 2006 A).

Indirect instruction is an approach to teaching and learning in which concepts, patterns and abstractions are taught in the context of strategies that emphasize concept learning, inquiry learning and problem-centred learning.

There are various ways to use indirect strategies: some have a higher degree of teacher-directed activities and others have students more actively involved in planning and designing instructional activities. In teaching engineering more commonly used indirect instructional strategies are inductive and social strategies.

More commonly used instructional strategies of inductive model in teaching engineering are:

1) Concept attainment strategies – concepts serve as the building blocks for student higher-level thinking, being the main ideas used to help to categorize and differentiate information: comparisons, classifications, metaphors and analogies, using questions, drawing examples and non-examples in order to define the essential and nonessential attributes needed for making accurate generalizations;
2) Inquiry lessons – inquiry, discovery and problem-solving approaches, being open-ended and creative way of seeking knowledge, consisting of following steps identify and clarity the problem, for hypotheses, collect data, brainstorm solutions, formulate questions, investigate, analyze and interpret the data to test hypotheses, discuss, reflect, draw conclusions, present results;
3) Projects, reports, problems – project-based lessons flow in problem-solving environment where students work independently or cooperatively solving problems.

More common indirect social strategies used in teaching engineering are:

1) Discussions – students learn when they participate, thinking out loud about concepts. The use of full-group discussions and small-group discussions improves student interactions. The best strategy in small-group discussions is to use think-pair-share method (teacher poses a question; students think individually; each students discusses his/her answer with a fellow student; students share their answers with the whole class) – students learn from one another;
2) Students self-evaluation – engaging students in critical evaluation of their own responses and thereby taking responsibility for their own learning;
3) Cooperative learning – involving students work together addressing specific instructional tasks, aiding and supporting each other;
4) Simulations – student-directed activity placing students in situations that model a real-life environment requiring, assuming roles, making decisions, facing consequences.

The learner acquires information by transforming stimulus material into a response that requires students to rearrange and elaborate on the stimulus material. The process of generalization helps students classify different-appearing stimuli into the same categories on the basis of essential attributes.

The main strategies of the inductive approach in teaching engineering are: use of advance organizers (gives students a conceptual preview of what is to come and helps them store, label, package the content for retention and later use), conceptual movement (inductive-deductive), use of examples and non-examples (helping to define the essential and nonessential attributes needed for making accurate generalizations), use of questions (to guide students into discovering new dimensions of problem or new ways of resolving a dilemma), use of student ideas (to heighten student interest, tailor feedback, organize subject content around student problems, encourage positive attitudes toward the subject), student self-evaluation (to reason out their answers, comment and consider the accuracy of the responses), use of group discussion (involves student exchanges with successive interactions among a large number of students, helps to review, summarize and evaluate).

Generalization in indirect strategy is a process by which the learner responds in a similar manner to different stimuli, thereby increasing the range of instances to which particular facts, rules and sequences apply. By discrimination learner selectively restricts the acceptable range of instances by eliminating things that may look like the concept but differ from it on critical dimensions. The processes of generalization and discrimination together help students classify different-appearing stimuli into the same categories on the basis of essential attributes acting as magnets, drawing together all instances of a concept without the learner having to see or memorize all instances of it.

In indirect instruction the role of questions is to guide students into discovering new dimensions of a problem or new ways of resolving a dilemma. The use of questions during indirect instruction includes the following (Orlich, 2007):

1) Refocusing;
2) Presenting contradictions to be resolved;
3) Probing for deeper more thorough responses;
4) Extending the discussion to new areas;
5) Passing responsibility to the class.

The inductive model, which is often described as guided discovery, is a straightforward but powerful model designed to help students acquire deep and thorough understanding of well-defined topics. Instead of beginning with general principles and eventually getting applications, the instruction begins with specifics – a set of observations or experimental data to interpret, a case study to analyse, or a complex real-world problem to solve. As the students attempt to analyse the data or scenario or solve a problem, they generate a need for facts, rules, procedures, and guiding principles, at which point they are either presented with the needed information or helped to discover it for themselves.

Grounded in the view that learners construct their own understanding of the world rather than record it in an already-organised form, the model requires teachers to be skilled in questioning and guiding students thinking and making on-the-spot decisions. This is sophisticated and demanding instruction. The inductive model is effective for promoting students involvement and motivation within a safe and supportive learning environment.

Lessons using the inductive approach begin with and are built around examples. The examples become the experiences that learners use to construct their understanding of the topics they are studying. Social interaction is used to analyse the examples. The teacher guides students towards a more mature understanding and real learning involves personal invention or construction. Clear objectives are as essential when using the inductive instruction as they are with any other instructional format.

According to Prince & Felder (2006) the inductive model is an umbrella term that encompasses a range of indirect instructional methods, including inquiry learning, problem-based learning, project-based learning, case-based teaching, discovery learning, and just-in-time teaching. These methods have many features in common, besides the fact that they all qualify as inductive. They are all learner-centred they impose more responsibility on students for their own learning than the traditional lecture-based deductive approach does. They are all supported by research findings that students learn by fitting new information into existing cognitive structures. These methods almost always involve students discussing questions and solving problems in class with lot of collaborative or cooperative learning.

The inductive model is designed to help students reach two types of learning objectives:

1) For students to acquire s deep and thorough understanding of specific and well-defined topics;
2) To develop students' critical thinking abilities. Students try to find patterns in the new information and with the teacher's guidance they construct a thorough understanding of the topics and learn to make and assess conclusions based on evidence.

Understanding the differences between principles and generalisations contributes to critical thinking. The validity of conclusions based on generalisations depends on the validity of the generalisations themselves. The abilities to make and assess these conclusions are important critical-thinking skills.

The planning process for lessons using the inductive model involves three essential steps:

1) *Identifying topics* – topics may come from textbooks, curriculum guides, or other sources. When the topics are concepts, principles, generalisations, the inductive instruction can be used effectively;
2) *Specifying learning objectives* – clear learning objectives are essential and they provide a framework for planning and implementing lessons;
3) *Identifying examples* – to present all information needed, relationship between concepts, concrete materials, pictures, models, short case studies, simulations.
4) *Creating examples.*

According to Eggen & Kauchak (2006), implementing a lesson using the inductive model combines following five interrelated phases, together with an emphasis on thinking and strategies for increasing student motivation:

1) *Lesson introduction* – attract students' attention and provide conceptual framework for the lesson, by using a statement, posing a problem, review of the previous day's work, etc;
2) *The open-ended phase* – promoting student involvement and motivation and ensure their success with an example, emphasise comparing, find patterns and generalise, provide evidence for conclusions;
3) *Convergent phase* – students' responses converge on a specific learning objective, knowledge construction and schema development primarily takes place;
4) *Closure* – occurs when students embed their understanding in a complex schema, encode it into long-term memory, and achieve a sense of equilibrium. This phase provides opportunities to help students develop their abilities to recognise irrelevant information, being an important thinking skill;
5) *Application* – typically includes a seatwork or homework assignment, to make the topic meaningful and ensure transfer students must be able to apply it in a real-world context.

Effective assessments are consistent with teacher's objectives. Both paper-and-pencil and performance assessment can be used to measure student understanding. Assessments that capitalise on applications in real-world contexts and include detailed feedback are among the most powerful tools fir increasing learning.

Inductive teaching methods suitable for teaching engineering (project-based, problem-based learning, and "just-in-time" teaching) are taught in the teaching process of the master program for technical teachers at Estonian Centre for Engineering Pedagogy.

In *problem-based learning* students are confronted with an open-ended, real-world problem and work in teams to identify learning needs and develop a viable solution, with instructors acting as facilitators rather than primary sources of information. A well-designed problem guides students to use course content and methods, illustrates fundamental principles, concepts, and induces the students to infer those things for themselves instead of getting them directly from the instructor; thus engaging the students in the types of reflection and activities that lead to higher-order learning. Problem-based learning is not an easy teaching method to implement. It requires considerable subject expertise and flexibility on the part of instructors, who may be forced out of their areas of expertise (Felder, 2006 A).

Project-based learning begins with an assignment to carry out one or more tasks that lead to the production of the final product – a design, a model, a device or a computer simulation and is very suitable for engineering education. The culmination of the project is normally a written report summarizing the procedure used to produce the product and presenting the outcome.

According to DeGraaff & Kolmos (2003) there are three types of projects in engineering education that differ in the degree of student autonomy:

1) *Task project:* student teams work on projects that have been defined by the instructor, using largely instructor-prescribed methods. This type of project provides minimal student motivation and skill development, and is part of traditional instruction in most engineering curricula;
2) *Discipline project:* the instructor defines the subject area of the projects and specifies in general terms the approaches to be used (which normally involve methods common in the discipline of the subject area), but the students identify the specific project and design the particular approach they will take to complete it;
3) *Problem project:* the students have nearly complete autonomy to choose their project and their approach to it.

A common difficulty faced by engineering students in a project-based environment is transferring methods and skills acquired in one project to another project in a different subject or discipline. Teachers educators should include such transference in their course objectives and should guide students to see connections between their current project and what they have learned previously, gradually withdrawing this support as the students become more adept at seeing the connections themselves. Teachers should also prepare students to fill in gaps in content knowledge when a need arises, taking into account the fact that such gaps may more likely arise in project-based learning than in conventional lecture-based instruction.

Just-in-time teaching (Felder, 2006 A) combines Web-based technology with active learning methods in the classroom. Students individually complete Web-based assignments before class in which they answer questions, the instructor reads through their answers before class and adjusts the lessons accordingly (“just in time”). The use of questions to drive learning makes the method inductive. It can be combined with almost any in-class active learning approach. The preliminary Web-based exercises normally require the student to preview the textbook material. The exercises are conceptual in nature and are designed to help students confront misconceptions they may have about the course material. They serve the functions of encouraging students to prepare for class regularly, helping teachers to identify students’ difficulties in time to adjust their lesson plans, and setting the stage for active engagement in the classroom. Just-in-time teaching classes are a combination of *interactive lectures*, in which the instructor does a fair amount of mini-lecturing between activities and laboratories. In the lectures, the instructor might begin by summarizing student responses to the preparatory exercises and then discussing common errors. The collaborative recitations are likely to begin with a review of the homework, and then teams of students work on new problems (Felder, 2006 A). Just-in-time teaching is used in teaching technical teachers at Estonian Centre for Engineering Pedagogy.

Applying Induction and Deduction

Both induction and deduction are important tools for concept learning, inquiry learning and problem-centred learning. But neither model need be used to the exclusion of the other. The teaching of concepts with the indirect instructional strategies uses inductive and deductive thinking to develop initially crude and overly restrictive concepts into more expansive and accurate understandings (Felder, 2006 B). In Table 1 some examples of direct and indirect instruction have been presented.

Table 1. Examples of Direct and Indirect Instruction.

Direct Instruction	Indirect Instruction
Objective: To teach facts, rules and action sequences	Objective: To teach concepts, patterns and abstractions
The teacher begins the lesson with a review of the previous day work	The teacher begins the lesson with advance organizers that provide an overall picture and allow for concept expansion.
The teacher presents new content in small steps, providing explanations and examples	The teacher focuses student responses using induction and/or deduction to refine and focus generalizations
The teacher provides an opportunity for guided practice on a small number of sample problems and then prompts and models when necessary to attain 60-80% accuracy	The teacher presents examples and non-examples of the generalizations, identifying critical and non-critical attributes
The teacher provides feedback and correctives according to whether the answer was correct, quick and firm; correct but hesitant; incorrect due to carelessness; or incorrect due to the lack of knowledge	The teacher draws additional examples from students' own experiences, interests and problems
The teacher provides an opportunity for independent practice with seatwork and strives for automatic responses that are at least 95% correct	The teacher uses questions to guide discovery and articulation of the generalization
The teacher provides weekly and monthly reviews and re-teaches unlearned content	The teacher involves students in evaluating their own responses
	The teacher promotes and moderates discussion to firm up and extend generalizations when necessary

Under direct instruction the objective is rapid attainment of facts, rules and action sequences. Content is divided into small, easily learned steps through the presentation, involving brief explanations, examples, practice and feedback. Both guided and independent practice help ensure that students are actively engaged in the learning process at a high rate of success. Weekly and monthly reviews reinforce learned content and indicate what may need to be re-taught. Table 2 illustrates the different steps involved in inductive versus deductive teaching.

Under indirect instruction, the objective is to teach concepts, patterns and abstractions with a problem, inquiry or concept-centred lesson. The teacher prepares for teaching high-order outcomes by providing an overall framework or content organization into which the lesson is placed, allowing for problem solutions, inquiry and concepts to be developed. Initially crude and inaccurate responses are gradually refined through induction and deduction, focusing on generalization of what is learned to some larger context. To accomplish this, both examples and non-examples – some drawn from student interests and experiences – are used to distinguish essential from non-essential attributes.

Throughout the teacher uses questions to guide students to inquire about and discover concepts and problem solutions and to evaluate their own responses. When the content is relatively unstructured, discussion groups may replace a more teacher-controlled format, and the teacher becomes a moderator:

1) Orienting students to the objective of the discussion;
2) Providing new or more accurate information where needed;
3) Reviewing, summarizing or putting together opinions and facts into a meaningful relationship;
4) Adjusting the flow of information and ideas to be most productive for the goals of the lesson;
5) Combining ideas and promoting compromise to arrive at an appropriate consensus.

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Table 2. Comparison of Inductive and Deductive Teaching.

Teaching Inductively	Teaching Deductively
The teacher presents specific data from which a generalization is to be drawn	The teacher introduces the generalization to be learned
Students are allowed uninterrupted time to observe or study the data illustrating generalization	The teacher reviews the task-relevant prior facts, rules, and action sequences needed to form the generalization
Students are shown additional examples and non-examples supporting generalization	Students raise a question, pose an hypothesis or make prediction thought to be supported by generalization
Student attention is guided first to the critical (relevant) aspects of the data supporting the generalization and then to the non-critical (irrelevant) aspects	Data, events, materials and objects are gathered and observed to test the prediction
A generalization is made that distinguishes the examples from the non-examples	The results of the test are analyzed and a conclusion is drawn as to whether the prediction is supported by the data, events, materials or subjects that were observed
	The starting generalization is refined or revised in accordance with the observations.

Questioning is a primary tool in teaching engineering for leading students into higher order thinking while using either inductive or deductive model. Students should be asked more *how, why*, or *what do you suppose* questions, not only *what* questions. Knowledge requires memory only, repeating information exactly memorised - the *what*. Comprehension, however, calls for rephrasing, rewording and comparing information. Application requires the learner to apply knowledge and understanding to determine an appropriate, correct answer. Analysis asks students to identify motives or causes, draw conclusions, determine evidence. Synthesis leads students to make predictions, produce original communications, or solve problems. Evaluation causes students to make judgements, offer and support opinions (Rüütmann & Kipper, 2010).

Through a cleverly planned questioning strategy, an engineering teacher can creatively lead students through the cognitive taxonomy of thinking. Cognition is the act in which learners think about information and then process the material into action. Benjamin Bloom (1956) has outlined progressive levels of cognitive activity proceeding from information through knowledge, comprehension or understanding, application, analysis, and synthesis to evaluation. Thus, when taught on *knowledge* level, the learner remembers specific facts, terms, ideas. Expectations focus on recall and data retrieval. At *comprehension* level, the learner is lead to understand whatever is presented by means of simple, repeated explanations. Moving up the scale to *application* requires that learners remember, understand and make use of ideas, rules, facts or other data, first in a known situation and then perhaps in unfamiliar situations. The first high-level objective is *analysis* - when taught on analysis level, learners disassemble and examine the components of a concept, a set of facts, a collection of information and classify the elements in some organised way for future communication. At the next level, *synthesis*, objectives ask learners to take information that has been analysed and reassemble it, perhaps in some original or unique way, to solv a problem, overcome a challenge, or resolve an issue. The highest level of Bloom's cognitive taxonomy, *evaluation*, asks learners to judge an idea, abstraction, problem solution, or other learning according to given or personally developed criteria. Characteristics of application, analysis and synthesis are present in evaluation. Effective teaching calls on learners to work their way all the way upward on presented taxonomic scale.

According to most theorists and practicioners, the vast majority of current teaching activity aims at the knowledge and comprehension levels (Elliott, 2005). Teachers seem to want to spend more time giving learners information and then helping them understand its meaning, but they spend little time helping them to know what to do with this information. According

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to Borich (2011) 70% of all questions require the simple recall of facts, but only 30% require clarifying, expanding, generalising and making inferences – one of every five questions require higher-level thinking.

Carefully devised questions facilitate the observation, communication, comparison, ordering, categorisation, relating, inferring from, and application of information. Beginning with *what* or the simple recall questions (e.g. what is the definition of a triangle?), in teaching engineering a teacher should lead from the knowledge base into understanding (e.g. what steps are required to draw a triangle?), and from undesrtanding into practical application (e.g. draw a triangle), from application into a more careful analysis (e.g. in which of the following pictures you see a triangle?), and after analysis into a synthesis or a reassembling of the notion in a new and different way (e.g. explain what are some of the ways you could make a triangle without using a ruler?). This entire process can then be assessed and judged as having marit, quality, or worth, teaching students to evaluate all ideas on a consistent set of criteria (e.g. given the following fragments of geometric shapes, decide which can be used to construct a triangle). Unfortunately, evaluation questions are reserved for the end of a unit and are considered more suitable for the middle and high school levels. Both misconceptions have reduced the impact of evaluation on learners. Evaluation questions have the distinct quality of confronting the learner with authentic problems much as they appear in the real world – making decisions and judgements is a primary task in adult life.

Questioning is one of the missing pieces in teacher education. One of the most effective ways of creating variety during instruction is to ask questions. Teachers often ask close-ended questions that don't allow the students to demonstrate their level of knowledge or lack of knowledge. The quality of response is always affected by the quality of the question. Questions are critical elements for teachers to use to stimulate student thinking especially in teaching engineering.

Direct and indirect instruction are often used together even within the same lesson. Teachers should not adopt one to the exclusion of the other. Each contains a set of strategies that can compose an efficient and effective method for the teaching of facts, rules and sequences and to solve problems, inquire and learn concepts in engineering.

Discussion

Engineering educators should gain greater confidence through the use of extended range of contemporary teaching tools by obtaining specifics of the art of teaching. Effective strategies and models for teaching thinking skills and capitalizing deep understanding are used at Estonian Centre for Engineering Pedagogy in teaching engineering educators.

As the results of the research (Rüütmann, 2009) 64% of students were sensors, while traditional engineering instruction is usually oriented toward intuitive learning, emphasizing theory and mathematical modelling. 87% of the students were visual learners, but most of engineering instruction is overwhelmingly verbal, emphasizing written explanations and mathematical formulations of physical phenomena. 61% of the students were active, while most engineering courses other than laboratories rely on lectures as the principal method for transmitting information. There is a great mismatch between students' learning styles and instructors' teaching methods. Thus it is of high importance for engineering educators to make instruction more effective to abolish these mismatches, and taking account of them.

Engineering is traditionally taught deductively. The instructor introduces a topic by lecturing on general principles, then uses the principles to derive mathematical models, shows illustrative applications of the models, gives students practice in similar derivations and applications in homework, and finally tests their ability to do the same sorts of things on exams.

A preferable alternative to deductive model is to use in some lessons *inductive model,* as used at Estonian Centre for Engineering Pedagogy – not adopting induction to the exclusion of deduction. Instead of beginning all lectures with general principles and eventually getting to applications, engineering educator begins sometimes with specifics – a set of observations or experimental data to interpret, or a complex real-world problem to solve. As the students attempt to analyze the data or scenario or solve the problem, they generate a need for facts, rules, procedures, and guiding principles, at which point they are either presented with the needed information or helped to discover it for themselves.

Before teaching a topic or series of lessons using any inductive method, engineering educators should write *learning objectives* that define what the student should be able to do (explain, calculate, derive, design, model, critique) when the instruction has been concluded. If instructional objectives are at a low cognitive level, requiring almost exclusively rote memorization of facts or mechanical substitution into formulas, there is no reason to use an inductive method. The objectives should guide the choice of focus problems, learning activities, and assessment methods (Rüütmann 2009).

McKeachie (2006), Bligh (2000) and Nilson (2003) cite numerous studies indicating that the lecture is as effective as any other method in conveying factual knowledge. But on other criteria: attitude change, development of thinking and problem solving skills, transfer of knowledge to new situations, student satisfaction with the course, motivation for further learning and post-course retention of knowledge – the classical lecture falls short of more student active methods such as discussion. Actually the interactive lecture can be highly motivational, but its success depends on the lecturer in engineering education. Interactive lectures are used for presenting general background information – the main ideas, thus providing systematic basic knowledge, followed by the constructivist approach focusing on particular applications and problems being centred in the study programme for engineering educators (Rüütmann, 2009).

Accordingly to Prince and Felder (2006) inductive teaching and learning is an umbrella term that encompasses a range of instructional methods, including problem-based learning, project-based learning and just-in-time teaching. They are all *learner centred* meaning that they impose more responsibility on students for their own learning than the traditional lecture-based deductive approach does. They can all be characterized as *constructivist* methods, building on the widely accepted principle that students construct their own versions of reality rather than simply absorbing versions presented by their teachers. Students are active and construct knowledge linking new information to previous knowledge.

Through inductive teaching at Estonian Centre for Engineering Pedagogy the procedures and processes of thinking are taught and how to recognise, define and solve open-ended problems which can be learned by practicing. Thus students assume more responsibility and are better motivated, becoming successful lifelong learners and better practitioners in their future teaching profession. Inductive teaching encourages students to analyse, critique, judge, compare, contrast, evaluate, assess, create, predict, apply, use, implement and gain professional perfection.

Teaching is more than mere methodology. Theory and philosophy about teaching and learning must empower reflective teachers to make thoughtful decisions about teaching methods and the support of student learning outcomes.

Conclusions

When used with the appropriate content and purpose, direct and indirect instruction can significantly improve teaching effectiveness. Although both models of instruction are significant contributions to teaching and learning, neither should exclusively dominate the instructional style in teaching engineering. It would be unfortunate if teaching exemplified only the direct model or the indirect model as the original purpose of introducing these models is to increase the instructional strategies in teaching engineering.

Models of direct and indirect instruction and their strategies provide a variety of instructional tools that could be used in many combinations to match teacher's particular objectives and students. Just as different entrees have prominent and equal places on a menu, so should the direct and indirect models have prominent and equal places in teaching engineering. Teachers should alternately employ both, the direct and indirect instruction to create tantalizing combinations of educational flavours for the students.

Professional-level teaching is both an art and a science. Like an artist, a good technical teacher makes decision from both a technical and a creative perspective. Professional technical teachers develop their science by using carefully-planned, fine-tuned lessons that reflect an understanding of many different teaching techniques. They develop artistry by being aware of what they are doing, and how it affects their learners. They are constantly aware that the choices they make affect the intellectual, attitudinal and psychomotor skills of their students. The nature of teaching requires continuous growth in order to engage and challenge increasingly diverse students in a rapidly changing world.

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