Global J. of Engng. Educ., Vol.4, No.3
Published in Australia

Will the Application of Constructivism Bring a Solution to Today's Problems of Engineering Education?*

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This article discusses the authors' own experiences as teachers and teacher educators in tackling some of the difficulties encountered by students in learning engineering and science subjects. Misconceptions or unsuitable preconceptions cause many difficulties. The students often also lack the ability to deal with and simplify scientific phenomena. The teachers' awareness and capability to cope with the misconceptions and preconceptions is of crucial importance. The authors' point of view is that the students' curiosity should be aroused; they should be encouraged to ask questions and take an active role in finding out answers. Many questions have simple answers if the phenomena is correctly analysed and understood. The students should be encouraged to trust their capabilities to use their former knowledge and to process it further. If a situation or problem can be presented that causes a contradiction in the learner's mind, then this can arouse interest and motivation. These approaches can lead to meaningful learning. The paper includes a description and analysis of a classroom situation where the teacher discusses combustion with his/her students. While combustion is a familiar phenomenon to everybody, a brief discussion with students will bring forward many misconceptions of which only some are logical and predictable. The constructivist approach will give a basis for the successful learning of difficult phenomena and concepts.

INTRODUCTION

The rapid increase of information over very short periods of time is a major problem in engineering education that seems worldwide. Limited time resources do not enable educators to teach everything, however important or relevant. In order to cope with this, a curriculum or course must be planned to include mainly such topics and means which are relevant in view of deeper understanding and which have a sufficient transfer, ie applying the contents of a subject to a variety of contexts also in other disciplines.

The information society sets demands on skills to collect data and information, process and use it and critically evaluate it. Demands are also set on skills of identifying and defining problems and solving them in an imaginative way. Communication skills must be trained, including the ability to understand and be understood when high tech topics are dealt with, both with experts and novices.

It is important that the students are trained to be flexible, adaptable and prepared to take responsibility for their own learning and their own continuous personal and professional development. This goal sets the requirements for education to include the means by which the students become autonomous learners. To ensure that students have those versatile skills mentioned in addition to cognitive skills and knowledge of substance matters, the teaching methods chosen should include such methodologies that activate the students and encourage them to work and learn both independently and in teams.

This should all be taken into consideration, for example, when planning how to present a problem or give an assignment to students. An educated student

*A revised and expanded version of an opening address presented at the 2nd *Global Congress on Engineering Education*, held at Hochschule Wismar, Wismar, Germany, from 2 to 7 July 2000. This paper was awarded the UICEE gold award (third grade) by popular vote of Congress participants for the most significant contribution to the field of engineering education.

mastering those qualifications mentioned will be properly equipped to prosper in the society of today where change is a norm.

Educators of engineering students have often seen that students seem to be able to provide correct answers or numerical solutions to a variety of problems. In reality, they are not able to make true observations on the basis of which to draw conclusions. Their ability to transfer the knowledge they hold to new situations is not always sufficient and should be improved. Although students often seem to be able to provide acceptable answers, teachers cannot always be assured of their deep understanding.

As teacher educators working in a teacher-training programme, the authors have also noticed that many teachers emphasise quantitative or mathematical calculations in problem solving. The focus on the phenomena itself is left in the background. The mathematical solutions are of course significant in science and engineering teaching, but it should be recognised that it is only one tool and not sufficient on its own. The way of teaching should set demands on the student in a versatile, rational and appropriate way. This way, an education for engineering students can be achieved that meets the wide requirements of industrial life [1].

CONSTRUCTIVISM

During the latest decades, hundreds of articles and reviews have been written on constructivism and its applications. Some of the basic principles the authors have found to be useful in engineering education are introduced here:

- Learning is a process.
  - Knowledge cannot be directly transmitted form the teacher to the learner, it will have to be constructed or reconstructed by the learner him/herself.
- New knowledge is adopted by using prior knowledge.
  - Preconceptions and misconceptions have an important effect on how the learner constructs new knowledge.
  - Beliefs and attitudes of the learner should be considered.
- Emphasising understanding will promote a meaningful construction of knowledge.
- Learning is always connected to context.
- Learning is the result of the learner's own activity.
  - The learner's autonomy and initiative should be encouraged.
- Same concepts can be interpreted or understood in many ways.
- Social interaction plays a crucial role in learning.
  - F. ex. cooperative learning should be supported.
  - Learners should be encouraged to communicate with each other and the teacher.
- Goal-directed learning is a skill that can be learned.
- Curricula should be flexible and take into consideration the skills of the learners and the relativity and variability of knowledge.

The constructivist theories of learning are based on many different sources and there are many different schools of thought within these theories. Thus, constructivism takes on a variety of forms. A mutual aspect of the various trends of constructivism is that students must have a responsible attitude towards learning and get actively involved. Real learning can only occur when the students are motivated and demonstrate commitment and enthusiasm for their subject. Nobody can learn for somebody else; everybody has to do it on his/her own.

Helping students promote their learning skills is an activity that is of long-term value and also a benefit to society. Ideas about constructivism and its influence on the daily work of an individual teacher and on teacher education have been taken from references [2-4].

Misconceptions and Preconceptions

The answers to the question, *why are students so often unable to learn science and engineering subjects?* can be found in the difficult concepts and phenomena included in these subjects. One of the important theses of constructivism states that new knowledge is based on earlier beliefs and assumptions. Prior knowledge, beliefs and assumptions, and sometimes even misconceptions, are included in the preconceptions everybody holds. The students often construct new knowledge and more advanced or complex concepts without having suitable and sufficient fundamentals or preconceptions. Their prior knowledge comes from their earlier studies, texts and lectures but very much also from everyday information, news, commercials, parents and friends.

The models which students have built up on these bases are not always very accurate or correct. Nevertheless the students form sensible and coherent understandings or cognitive structures of phenomena in their own world from their own points of view.

It is obvious that the students' conceptions when attending lectures are not always what the teacher would expect. It is therefore important that the teacher is aware of the students' preconceptions and misconceptions. The teacher should be able to take into consideration the insufficient or unsuitable preconceptions and be able to deal with the misconceptions inhibiting learning.

DEMONSTRATION OF APPLYING CONSTRUCTIVISM

Applying constructivism with help of the well-known phenomena of combustion will now be presented and will include a description of the interaction between the teacher and class. With the help of the presented problem, a survey has been undertaken seeking to identify how a student is able to pick up the essentials of an experiment and further how the student can analyse the situation and predict what will happen in the experiment. With these methods it is also possible to find out to some extent the students' preconceptions and also misconceptions of the phenomena.

In science and engineering it is not exceptional that students have deep-seated ideas about the natural world that differ from empirical evidence and explanations accepted in science. Some examples would be that heavy objects always sink in water, heavy objects fall at a greater speed than light ones, bubbles in boiling water are hydrogen and oxygen gases, vigorously boiling water is at a higher temperature than gently boiling water, mass changes when matter melts or boils and that burning causes a decrease in mass. It is therefore of great value in planning a successful course that the teacher is aware of and has the means to reveal the beliefs or presumptions of the students [5][6].

It is not unusual that students become aware of and accept some of the facts taught, but after some period of time fall back to using their former beliefs and build answers to questions and solve problems using false intuition. Lately, much research has been made in science teaching on ways to find out what the students are thinking. Tests have been planned on the basis of which comparisons between different methods of teaching can be made. Examples of teaching methods that have been compared include traditional, tutorial and workshop teaching [7-11].

Combustion

The application of these ideas can be demonstrated by analysing a classroom situation where the common phenomena of combustion is dealt with. Combustion and burning seems to be an easy topic because of the students' everyday experiences. The phenomenon is of course familiar to all students - or so it is assumed. It can therefore be difficult to start the lesson or lecture on a topic about which the students believe they know everything - or at least enough.

The students' interest must be aroused and the class must get focused on the topic and phenomenon that will be dealt with. This can be done, for example, by using one or more leading questions, examining some relevant picture or dealing with some task they have been given. The prior knowledge of the students can also be surveyed, including the students' preconceptions. At this stage, it is very important for the teacher to take into account what he/she already knows about the students' preconceptions and misconceptions. This can be done by an open discussion, small quizzes or tests, questionnaires, teamwork, leading assignments, or working on the Internet in pairs or small groups.

Here are some examples of small but revealing questions:

- What similarities and differences are there when a gas, liquid or solid substance burns?
- What kinds of substances burn?
- Why do some substances burn and why are some incombustible?
- How does a substance burn?
- How can it be predicted if a substance burns or not?
- What makes a substance combustible?
- When is a substance incombustible?
- What are the requirements for combustion?
- When does a substance burn?
- What happens when a substance does not burn?

It is useful for the teacher to keep the answers well in mind and to try to find out the reasons for the answers given. Some very common misconceptions that are revealed include:

- Metals do not burn.
- Gases are always evolved when something burns.
- Carbon dioxide is always released.

Experiment with Iron Wool

For some reason, misconceptions can be very difficult to get rid of. Just telling how things really are is seldom sufficient. Small demonstrations can prove very useful, both when surveying the students' prior knowledge and correcting their misconceptions. A good and easy demonstration, which can be used when combustion is dealt with, is the burning of iron wool.

A small piece of iron wool is placed in one cup of a balance. Balance is stabilised with weights in the other cup. The class is then asked: *What will happen when the iron wool is ignited?*

The alternatives given are:

1. The iron side will go up (it will become lighter).
2. The iron side will go down (it will become heavier).
3. Nothing will happen to the balance.

Probably all alternatives will get some support. It might be quite a surprise which alternative will get the most support.

The next step of the demonstration is to give the students a few minutes time to think about how they will justify their choice. This can be made in groups or pairs. The justifications should be presented to the class. For this to be possible, it is important that the teacher has created an open-minded, genial, trustful and polite atmosphere in the classroom between the students and the teacher and students.

The justifications will give the most valuable information for the teacher. It also helps the students to become conscious of their learning styles and abilities to predict new phenomena on the basis of prior knowledge. The students have the possibility to take charge of their own learning; they will learn how to justify their opinions and how to argue with students representing some other opinion.

One very common misconception that leads to the support of alternative 3 is justified by comments like:

Nothing will happen because iron won't burn.
Even if the iron will burn, nothing else will happen because nothing will leave the iron; the atoms only change places.

There are many justifications for alternative 1 (it will become lighter):

When something burns, there will be some smoke vanishing and there will only be some ashes left. The ashes will be lighter because everything else is gone.
The iron reacts with air and the product will rise as a gas, at least to some extent.
The other components of the steel wool will oxidise and evolve and there will be only iron left.
The evolving of iron oxide makes it lighter.

Alternative 2 (it will become heavier) will give justifications like:

It will become heavier because carbon dioxide will be included in the iron wool.
The iron wool is charred.
The other components of the steel wool will oxidise and become heavier.
There will be iron oxide, which is heavier than iron.
When iron wool is burnt it will become more solid and stable.

Before igniting the iron wool, the teacher should ask the students to be very attentive and make observations. They should use all their senses. One way of making the demonstration more interesting and to get still one more topic for later discussion is to use a nine-volt battery when igniting the iron wool.

After the iron has been burnt and the students have seen what happened, they should be given a few minutes time to discuss in groups or pairs their observations, check their reasoning and try to find some explanations. Many of the students have reached a point of contradiction in their minds, which causes a motivation to find out how things really are. This is why the process should be given some time and it is important that the students find out the reasons for their false predictions. This will help them get rid of some misconceptions concerning combustion and also adopt new relevant knowledge about the phenomena.

It is important at this stage that there is an open interaction between the teacher and the students. The teacher should guide the discussion by suitable questions but avoid giving the correct answers straightaway.

When the students have given the correct explanations, the teacher should make certain that everybody can agree with these explanations. A few analysing words could also be said about the misconceptions but in a way that encourages the students and does not result in a bad atmosphere.

There are numerous topics, which can be chosen for the continuing discussion depending on the level and subject.

The reaction products of combustion should be discussed in any case, including:

- What gases evolve?
- What do the ashes contain?
- What is the oxidation state of the iron oxide produced?
- What will it take for the iron to get to the oxidation state +III?
- What influence do impurities or circumstances like moisture, temperature, pressure or draught have on the combustion reaction?

Some very interesting applications are found in the field of corrosion engineering, such as:

- What is rust?
- What is the difference between the products Fe^{2+} and Fe^{3+} ?
- Can rust be a threat to noble metals like f. ex. copper?

- Does the change in mass give any information about how corroded a piece of iron is?

Other interesting questions cover:

- What is smoke?
- What is the light seen and what causes it?
- What causes the colours people see?
- Why was no smoke seen?

From the field of thermodynamics and measuring techniques there are many topics and questions that can be discussed, including:

- Energy exchange.
- Exothermic and endothermic reactions.
- Open and closed systems; how is the boundary chosen?
- Spontaneity of reactions.
- Full or partial combustion.

Somewhat more chemical or electrochemical topics would be:

- The qualitative and quantitative analysis methods for the products, including the iron or steel wool.
- Reaction kinetics.
- Full or partial combustion.
- The use of the battery for igniting.

SUMMARY

The teacher-centred mode of instruction has the advantage of being able to cover large amounts of material, but does not always ensure that the students learn and are able to apply knowledge. Sometimes too little substantial learning occurs as a result of ordinary lectures. Alternative methods of instruction can be successfully implemented in science and engineering education that result in increased student understanding.

It must be remembered that even small demonstrations can be useful, but their full potential should be used. The integration of multiple teaching methods with ordinary lectures also enhances student participation. A useful method that gives the students a possibility to participate and take charge of their own learning is to integrate lectures with f. ex. cooperative learning, classroom discussions, workshops and seminars.

Learning by doing is an efficient method in science and engineering education, which should include an experimental or empirical approach. Laboratory works should be given a reasonable share of time. In all forms of science and engineering education the value of giving the students time and opportunities to make predictions and observations and draw conclusions should be realised.

Many arguments encourage constructivist teaching practices, but ever-diminishing time resources calls for the question: *where can one get the time?* There are also many other complications in constructivist teaching that make it important to deploy the techniques wisely in the right place for the right purpose.

When knowledge is not particularly troublesome, teaching by telling can turn out to be the best and most efficient method [12]. When a process of higher level of reasoning is required, collaborative or cooperative learning strategies and the use of concept maps have proven successful. Making the students rely extensively on explaining concepts to each other can be very fruitful.

There are many alternative teaching methods. The choice is the teacher's. Open-minded experimentation of different teaching methods will help to find the methods suitable for the students and the subject and which the teacher finds convenient.

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BIOGRAPHIES

Samuli Kolari is currently a Principal Lecturer and head of the Physics Institute at Tam-pere Polytechnic in Tampere, Finland. He received his MSc degree in physics at the University of Turku in 1975 and his post-graduate degree of LicSc in 1979 at the University of Turku. Before his career as an engineering educator, he worked as a researcher in the field of solid state physics at Wihuri Physical Laboratory for seven years. He still works as a part-time consultant for the industry. He has been working as an engineering educator for the last 20 years with special interest in pedagogical matters of science and engineering education.

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