Global J. of Engng. Educ., Vol.7, No.2
Published in Australia

Promoting the Conceptual Understanding of Engineering Students through Visualisation*

Carina Savander-Ranne
Helsinki Polytechnic, Bulevardi 31, FIN-01800 Helsinki, Finland
Samuli Kolari
Tampere Polytechnic, PO Box 21, Teiskontie, FIN-33521 Tampere, Finland

An important goal of engineering education is the acquisition of problem-solving skills. The profound mastery of relevant concepts and phenomena provides an essential foundation for the attainment of knowledge and understanding in engineering subjects, as well as a prerequisite for good problem-solving skills. New knowledge and conceptual understanding are both built on existing knowledge. Learners build connections between their existing knowledge and new experiences. Therefore, it is important that lecturers be able to acquire knowledge of their students' conceptions. Approaches to teaching that may promote conceptual understanding are suggested in this article. The use of a PDEODE worksheet (Predict – Discuss – Explain – Observe – Discuss – Explain) is introduced. This can be applied when dealing with phenomena, demonstrations, hands-on experiments and other problems, amongst others. This intensifies and clarifies the learning process. Using visualisation aids in elucidating abstractions helps students to form mental visual images and make visual interpretations of what concepts mean. Combining visualisation with peer interaction and cooperative learning yields good synergy.

CONCEPTUAL UNDERSTANDING AND PROBLEM-SOLVING SKILLS

An important target for engineering education is the gaining of problem-solving skills. Intense mastery of relevant concepts and phenomena generates a necessary base for the acquisition of knowledge and understanding in engineering subjects; it also provides the requisite skills for good problem solving. The physical sciences provide a foundation to build upon and a premise for the better understanding and utilisation of the concepts and phenomena needed within various domains of engineering. When discussing problem-solving skills, these should not be understood in the limited sense of solving numerical problems with the help of algorithms.

In the field of engineering, problem solving is ultimately applied to the design of new products, to planning or trouble shooting industrial processes and so on. It is argued that good problem-solving skills can be achieved through a good mastering of concepts and understanding of phenomena [1][2]. It is also claimed that a common cause of failure in problem solving in the physical sciences and engineering subjects is the lack of conceptual understanding and deeper insight into the consequences of phenomena [3][4].

Several studies report that students who are able to solve numerical problems are not necessarily able to solve conceptual problems. Students have been found to rely more on algorithmic techniques rather than reasoning skills. For example, students may be able to solve numerical problems dealing with gas laws, but unable to solve conceptual problems on the same topic when problems are presented in the form of a diagram. Students who are able to solve stoichiometric problems may have serious difficulties in understanding a diagram-based performance on the combination of atoms and molecules, yet be unable to solve problems

*A revised and expanded version of two papers presented at the 6th *UICEE Annual Conference on Engineering Education*, held in Cairns, Australia, from 10 to 14 February 2003, and combined here. The papers were awarded the UICEE gold award (C. Savander-Ranne) and bronze award (S. Kolari) by popular vote of Congress participants for the most significant contribution to the field of engineering education.

presented in this form. Such results have been replicated in studies with both homogeneous and heterogeneous student populations. [5-10]

It has been noted that student performance is responsive to what textbooks and educators emphasise. The authors have experienced, and studies suggest, that a majority of problems set for students in the physical sciences are numerical rather than conceptual [11]. Much time and effort have been, and continue to be, devoted to teaching problem solving in the algorithmic sense. In some cases, this means that students merely explore in their minds the algorithms they hold and then manipulate, sometimes randomly, the most suitable ones. Conceptual understanding cannot be assumed to follow when the focus is on such narrowly defined problem solving. Conceptual understanding and a more qualitative approach need to be incorporated in setting educational goals and the instruction should be designed accordingly [5][9-12].

Approaches to teaching that may promote conceptual understanding are suggested in this article. Utilising visualisation aids in elucidating abstractions can help students to form mental visual images and make visual interpretations of what concepts actually mean. Positive synergy is generated by combining visualisation with peer interaction and cooperative learning.

CONSTRUCTIVISM – PRIOR KNOWLEDGE

One basic constructivist principle of learning is that new knowledge is built on existing knowledge. Learners build connections between that what they already know or have experienced and the material they are learning [13]. Jean Piaget asserts that knowledge is constructed through an adaptive process that consists of two complementary parts: assimilation and accommodation [14]. Assimilation refers to the creation of new knowledge structures by reviewing and building on existing knowledge structures. Accommodation is necessary when new perceptions and experiences do not fit existing knowledge structures and knowledge structures must be reshaped in order to accommodate the new experiences. Thus, what is learnt is dictated by two influences: the schemas that people already have in their heads and the information contained in the external stimuli that people respond to [15][16].

Taking into consideration the impact prior knowledge has on learning, lecturers should have good knowledge of students' existing conceptions and a means to acquire greater insight into student knowledge. It is well known that students of engineering and the physical sciences possess so-called alternative or intuitive ideas and beliefs about phenomena. These might also be called everyday or naïve conceptions and are referred to as misconceptions in many studies. Of course, the fact that students have alternative frameworks holds true in other fields too; this may also be true for teachers and lecturers in some cases.

Conceptual change can be seen as learning new concepts or changing the meaning of concepts already held, preferably in a more scientific direction. By addressing students' alternative conceptions, lecturers can help learners to build meanings that are compatible with those accepted in science and technology.

The difficulties and importance of accomplishing conceptual change can well be understood on the basis of the information-processing model presented in Figure 1. The authors have modified the information-processing model [17][18]. This was based on Mayer, Johnstone and Kolb [19][20][21].

In the model described, the sense receptors accept new information, which is briefly held in the sensory memory. Relevant and irrelevant information is separated and the relevant moves on to the short-term memory, also called the working memory. The learner constructs new knowledge in the short-term memory by interpreting, organising and integrating selected information. This new organised knowledge interacts with the relevant old knowledge, which is retrieved from the long-term memory, and subsequently transforms it. Mental manipulations and arithmetic functions are carried out in the short-term memory. The long-term memory is the storage for knowledge structures.

In Figure 1, apprehension and comprehension mean two different and opposed processes of grasping or taking hold of experience. Apprehension means mainly taking hold of experience through reliance on tangible, felt qualities of immediate experience - understanding by a concrete experience [21]. For example, if one leaves his/her old-fashioned bicycle out in the rain, it will probably rust. Apprehension leads to one repainting and recoating it and being more careful of how one handles it. Comprehension means understanding through reliance on conceptual interpretation and symbolic representation – conceptualisation [21]. In this, case one has a deeper understanding of the concepts of rust and corrosion and one is able to design, for example, materials for a bicycle that are more corrosion resistant, but still fulfil the mechanical requirements.

According to constructivist approaches to learning, students must have a responsible attitude towards their own learning. Students have to be motivated and show commitment. A constructivist view on learning and knowledge is that knowledge is not directly

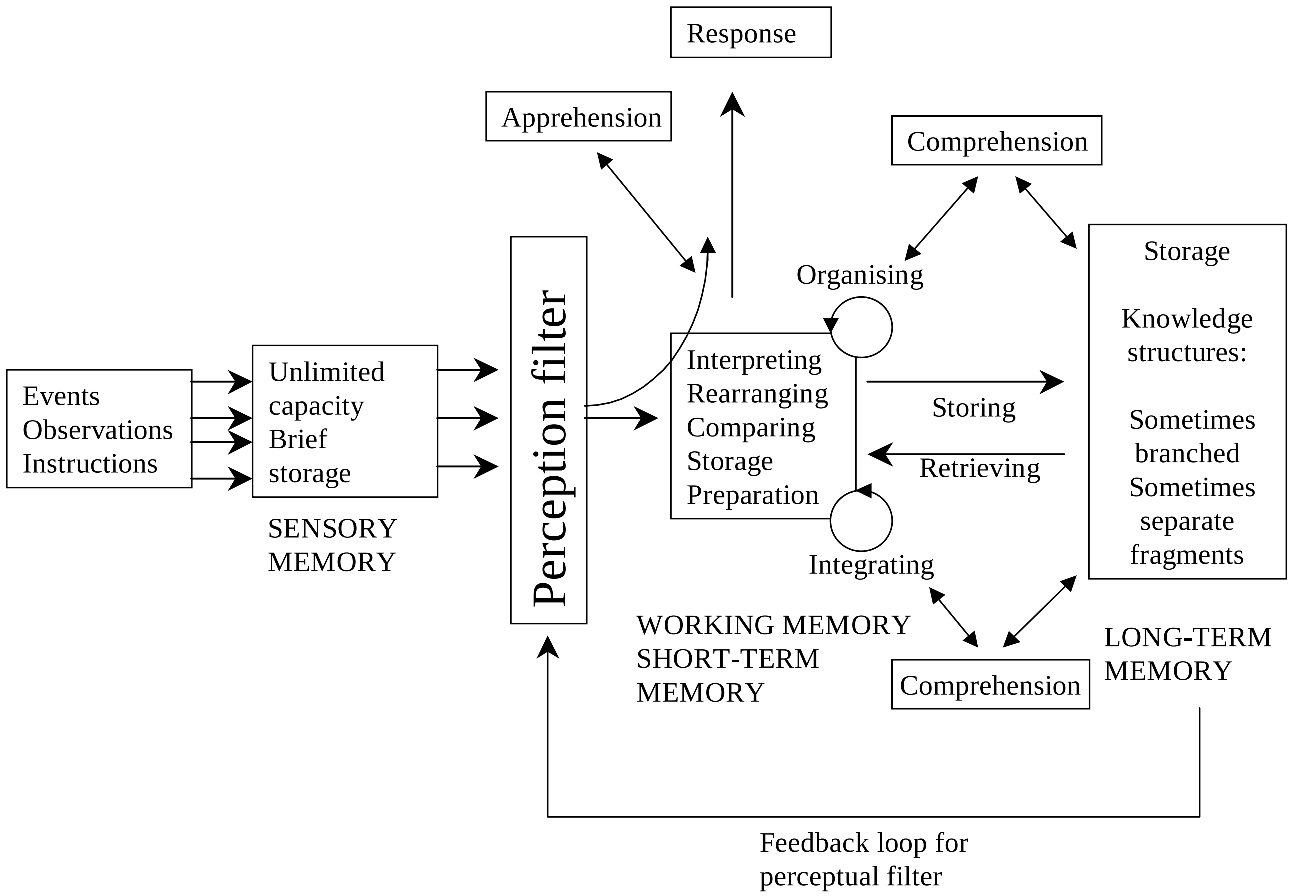

Figure 1: The information-processing model as modified by the authors [17][18].

transmittable from lecturers to learners. Learning and internalising knowledge demands an active engagement of learners whereby they build their own knowledge. The preconceptions, interests and motivations of students determine what they pay attention to. Their memory system interprets this selected information. The new information is integrated with the old and familiar information present in the long-term memory and the learner's prior knowledge base. Misconceptions are also a part of the learners' knowledge structures and interfere with subsequent learning so that the new information cannot be integrated appropriately; thus, weak understanding and misunderstanding of new concepts is inevitable [19][20][22-24].

Lecturers should be able to assist students in improving their conceptual understanding and problem solving skills. For this, lecturers need to have insight into students' prior knowledge. However, this is not sufficient in itself. It is important that students themselves are aware of their prior knowledge, preconceptions and possible misconceptions. Lecturers should therefore acquire tools that provide insight into students' conceptions and by which students are helped to become aware of their misconceptions [11][25][26]. An interactive learning environment can meet these requirements and, using a PDEODE worksheet (Predict – Discuss – Explain – Observe – Discuss – Explain), like the one shown in Figure 2, may be of assistance in achieving these goals.

ASSESSING CONCEPTUAL UNDERSTANDING

It is not easy to know if students are learning, and even more so difficult to know whether they have achieved true conceptual understanding. Assessing understanding requires careful observation and thorough analysis. A student's ability to recite definitions of concepts is of limited value as an indicator of conceptual understanding. Definitions should, at the very least, be accompanied by examples. Even then, students are very talented in sorting out examples that they are sure of and avoiding those examples that they find unclear or difficult. Hence, no significant information is obtained on the quality of understanding of a concept. Additional questions need to be asked by which a definition can be clarified and situations need to be designed where justifications must be presented. As noted above, the ability to solve numerical problems and handle algorithms is no proof of conceptual understanding and does not display the conceptual dif-

PDEODE-worksheet **Name** *NN*
Date *12.1.2000*
Topic: *Combustion* **Group** *1 B*

Prediction *b) The iron side will go up. It becomes lighter.* ____________________________

Explanation/Reasoning *When something burns, there will be some smoke vanishing and there will only be ashes left. The ashes will be lighter because everything else is gone.* _____
____

Mutual explanation/reasoning (Group members *NN and MM*_______________________)
The ashes contain carbon and carbon is lighter than iron. Usually oxides will evolve. Thus, the evolving of iron oxide makes it lighter. ____
____

Observations *Iron wool really burned. It sparkled. We saw some light, felt some warmth, no smoke, no odour but heard some slight sputter.*
____

The iron side went down. We were wrong! It became heavier! __________________________
____

(Space for drawings)

Explanations/Reasoning *Oxygen combined with the iron and produced iron oxide. Iron oxide is solid and stays in the cup. The mass in that cup increases.* ______________________
____
____
____

Comments/Questions 1. *Iron oxide does not evolve, it is solid, and it is not gaseous.* _____
2. *There is no carbon; it was a mistake.* ______________________
Why didn t we see any smoke? ____________________________

If we measure the increase of the mass, can we then conclude something about the oxidation state? ____

Figure 2: Worksheet for the PDEODE assignment modified by the authors on the basis of White and Gunstone [38].

ficulties of an issue and how a student is able to cope with these difficulties. Success in numerical problem solving may even be misleading.

The following are engagements that may give insight into student understanding. Ask students to:

- Define, describe and visualise a concept or phenomenon.
- Synthesise an answer by providing explanations and justifications, such as:
  - Why does something happen?
  - How does something happen?
  - What are the consequences of this?
- Analyse an example or information that is new to them.
- Transfer knowledge to new, yet related, situations.
- Identify relevant or related concepts and combine concepts.

Some Applications

Students can be asked to utilise macroscopic, microscopic and symbolic levels in their descriptions and include justifications. Examples of this include:

- Define and describe in your own words what is rusting and what is corrosion.
- Describe what happens when iron rusts. Why does iron rust?
- Describe the processes involved when the following metals are exposed to a humid sea

climate: iron; aluminium; zinc; copper; silver; gold.
- Describe what happens in the following reaction:
  $A + B \leftrightarrows C \qquad \Delta H = -nn\ kJ$
  If B is oxygen, compare the reactions where A is hydrogen, where A is iron and where A is gold. Can you conclude anything by finding the value for nn in each case?

In the end, all means to test conceptual understanding have their limitations. The lecturer's pedagogical content knowledge and constant reflection on the formulation of questions and on student answers are needed for a successful outcome.

A successful approach to courses and lectures is very much due to the lecturers' constant reflection on questions such as:

- What concepts must be understood when dealing with this topic?
- Do my students master these necessary concepts? How can I guide my students to a better understanding and mastery of relevant concepts?
- What makes these concepts difficult?
- How can I visualise or elucidate these concepts?
- What misconceptions do my students hold?
- Why do they hold these misconceptions? What is the origin of these misconceptions?

In case studies on a textile engineering and a materials engineering course carried out by Kolari and Savander-Ranne, a concept test administered at the start of the course proved helpful in revealing what knowledge students possessed from previous courses [27][28]. The tests also revealed that few students possessed an active mastery of the essential concepts when commencing the courses.

These concept tests administered to textile and materials engineering students helped the lecturers to plan their lectures so that they were more congruent with students' existing knowledge [27][28]. They also helped students to decide how necessary it was to do some recalling of key concepts from prerequisite courses.

DEALING WITH MISCONCEPTIONS

There are many studies on students' misconceptions and the measures needed to correct these. It has also been shown in several studies that achieving conceptual change is difficult. One essential tool is to reveal what misconceptions students hold and to find out why they believe what they believe. Unless the source of the misconception is understood, it will be difficult, if not impossible, to deal with. It will be similarly difficult to guide students to a view that is compatible with that of the scientific community.

Learning and understanding require both perceiving and processing information. Learning and understanding are influenced by the ability to perceive, interpret and process information, integrate it with old knowledge structures and organise it, place it in their memory and retrieve it. Thus, these are all elements of the learning process. Individuals perceive and process information in different ways; as such, students display a diversity of learning styles [29].

Brain-based research during the last two decades has been able to track differences in learning styles of male and female students. Male students tend to be deductive in their conceptualisations while females tend to favour inductive thinking. Asking students to give examples is often easier for female students than for male students [30]. The way that lecturers deliver their lectures has a considerable influence on students' learning processes and how students are enabled to perceive, interpret and process knowledge. These subsequently influence the knowledge structures of the long-term memory (see Figure 1).

Although students are taught the basic properties of gases and the gas laws, some continue to think that gases do not have any weight. Students' everyday experiences, and what and how they have been taught, influence their conceptions. Everyday experiences of balloons, or of CO_2 gas escaping from bottles, give an impression that gases are always light. The belief that burning substances become lighter and vanish in the air is an expected one; this is because many burning substances give this impression [31][32]. Such visual impressions are difficult to overcome; however, using visualisation eligibly is also an efficient tool in order to achieve conceptual change.

A classical misconception of students, and one that Kolari and Savander-Ranne have met and dealt with, is that students believe that the bubbles evolving from boiling water are hydrogen and oxygen gas [31][32]. The reason for students having such a conception may lie in the chemistry taught at lower education levels. Students do not have a holistic picture of all of the concepts involved in vaporisation, phase changes and the breaking of bonds. It is a basic chemical principle that reactions are reversible and that energy either flows out of the system or into the system, depending on what direction of the reaction is studied.

$$H_2(g) + \tfrac{1}{2}\, O_2(g) \leftrightarrows H_2O(g) \qquad \Delta H = -242\ kJ$$

From the written reaction above, it can be seen that, when one mole of hydrogen and half a mole of oxygen react, one mole of water is produced. The enthalpy change is 242 kJ and energy flows out of the system. For the water to decompose, 242 kJ of energy per mole of water will be needed. A conclusion that the bubbles evolving are hydrogen and oxygen is understandable and may be due to students' beliefs that boiling the water introduces sufficient energy for the water to decompose.

Most students master the phenomenon of vaporisation. Many students also understand that a certain amount of heat is needed for phase changes to occur, just to break down intermolecular forces. What they do not necessarily realise is that decomposing a water molecule into hydrogen and oxygen requires much more energy because the intramolecular bonds between the hydrogen atoms and the oxygen atom then have to be broken. In this case, the misconception regarding the nature of the bubbles must be dealt with through a conceptual understanding of energy levels.

MAKING USE OF PEER COOPERATION AND A PDEODE APPROACH

Many lecturers employ a single approach when explaining – an approach that is declarative, procedural and theoretical in its knowledge orientation. Such an approach does not necessarily lead to students internalising the knowledge and being able to integrate and apply it. Concepts gain meaning for students, and mental models and schemes are constructed, on the basis of prior knowledge and what is perceived and experienced. Giving experiences and aiding perception is therefore important. Even though time is scarce, it would be beneficial to teach some concepts in two different ways, to try out new approaches or, better still, apply a completely new teaching method.

Students learn by different means and the development of meaning for a concept varies from student to student [29]. Peer interaction and cooperation give the means for students to benefit from several different approaches and have been documented as tools to foster conceptual understanding and conceptual change [33]. Encouraging students to discuss and cooperate presents an opportunity for them to deal with concepts, processes and phenomena in multiple ways. Peer interaction gives students the possibility to communicate with their partners, to discuss opinions and conflicts, make predictions, interpretations and explanations and to construct and co-construct knowledge. Students are forced to reflect when required to justify and defend their own ideas and points of view. They have to make their intuitive and emerging ideas explicit and public, but in an environment where nobody stands alone. In this context, it is important that there is an atmosphere in class and within the groups that supports discussion and a diversity of views [33][34].

A PDEODE – worksheet (Predict – Discuss – Explain – Observe – Discuss – Explain) (see Figure 2) can be applied when dealing with phenomena, demonstrations, hands-on experiments and other problems. This intensifies and clarifies the learning process. It is constructed in such a manner so that it will sit well when peer interaction is pursued and thereby helps both lecturer and students to proceed systematically.

The questions and problems chosen for a teaching approach involving cooperative learning and peer interaction should arouse discussion on the part of the students, encourage them to raise questions, to see things from different perspectives, to disagree in a constructive way and to present divergent solutions that can be justified from several points of view. The problems should be sufficiently challenging and designed so that inadequate knowledge and misconceptions are revealed. In science and engineering subjects, an experiential context should not be forgotten. Presenting a problem in connection with a demonstration or a laboratory can be very fruitful. Typically, the problem would require students to predict, conclude and explain what will happen. In the course of the demonstration or laboratory, they then experience what really happens and seek out reasons for any divergent predictions. In this way, students become interested and genuinely engaged. The PDEODE-approach helps both students and lecturers in this process.

Theories of concept learning have thus far been mostly based on a cognitive constructivist perspective on learning. A well-planned problem can include a cognitive conflict, which will aid in developing disequilibration in the minds of students. For a pair or a group to reach joint resolution, each participant will have to reflect on his/her own opinions and on those of their peers. The situation may then lead to a socio-cognitive conflict described by Piaget, where both social and cognitive conflict are present [14]. As students become aware that there are points of view different from their own, they have to re-examine their own points of view and reassess their validity. They learn that they must justify their own opinions and communicate them well if they want others to accept them [35].

Peer cooperation also responds to Vygotsky's view that learning is the sharing of meaning in a social context [36]. His perspective on learning is situational and socio-cultural and he claims that higher mental functions are aided by social interaction, which precedes learners' internalisation of difficult scientific concepts. Tao and Gunstone have confirmed in a study of collaborative learning at the computer that the social construction of knowledge takes place within the context of peer cooperation and that it leads to students' conceptual change in the learning process [37].

VISUALISING THE OXIDATION REACTION OF IRON AND USING A PDEODE APPROACH

In order to illustrate visualising, elucidating and finding out student preconceptions, the authors combined the use of demonstration and the PDEODE-worksheet. This was achieved by utilising an experiment on burning iron wool [22][31][32]. A small piece of iron wool is placed in one cup of a set of scales. Balance is maintained with weights placed in the other cup. Students are then asked: *What will happen when the iron wool is ignited?* The alternatives given are:

a) The iron side will go down, it will become heavier.
b) The iron side will go up, it will become lighter.
c) The balance will remain stable.

Figure 2 shows the modified worksheet for the PDEODE assignment, while Figure 3 illustrates the demonstration procedure. Students are asked to make

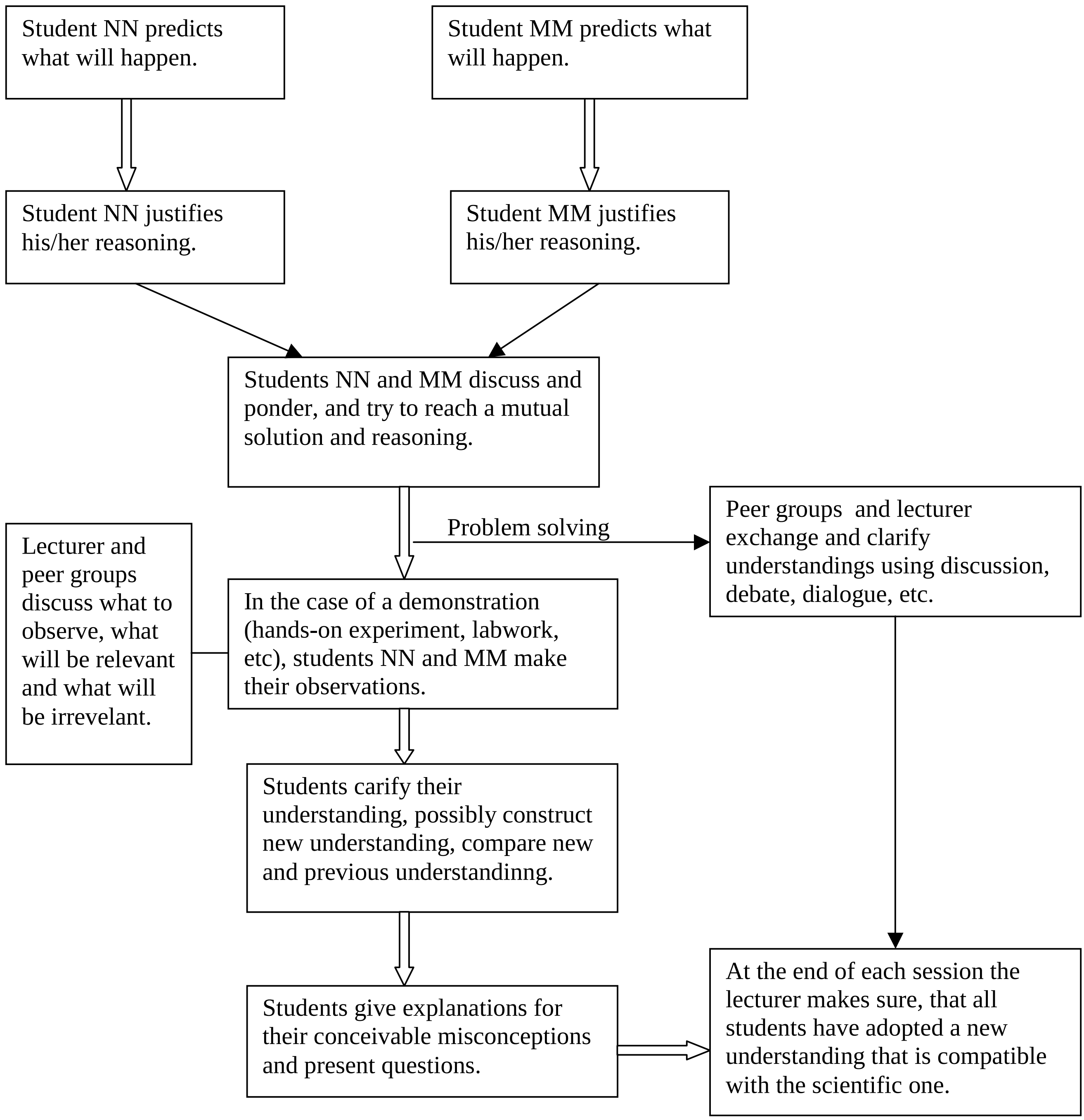

Figure 3: Pattern for the phases of processing a demonstration or problem by using the PDEODE-worksheet.

predictions individually about this reaction and give explanations in order to support their predictions. Students are then asked to work in pairs (or small groups). They try to achieve a mutual result by discussing and pondering together. After this stage, it is often beneficial for the lecturer to take part in the discussion. Also, before demonstrating, it is of crucial importance that students get a clear picture of what and how to make observations. The lecturer should guide students to make observations that are relevant. This does not mean that students should be told what they are about to see, what will happen and why it happens. They should be left with the joy of exploration and making deductions.

After having recorded their observations during a demonstration, students are asked to reconcile their predictions with their actual observations. They can be able to replace their possible ineffective conceptions with new ones. In this method, it is important that students analyse, compare, contrast and criticise the different views when discussing in groups or pairs. At the end, all discrepancies between observation and prediction should be confronted [19]. This approach helps in creating a learning environment that supports the information-processing model.

DISCUSSION

As many writers have already stressed, the mastering of concepts and a conceptual understanding of phenomena and processes are the essential foundation for problem-solving skills [1-4]. The mastery of concepts should be so thorough that students are not only capable of solving problems in the physical sciences and specific engineering subjects, but that they are also able to transfer knowledge and skills to other subjects and disciplines and, later, to the demanding tasks of their future engineering profession.

The case studies on textile and materials engineering mentioned above revealed that having concerns and aiding students to acquire and update the necessary prior knowledge was worthwhile and resulted in better learning results [27]. Because subjects in the physical sciences and engineering are of a cumulative nature, lecturers need to make careful analysis of the subject matter and reflect on the key concepts that students need to master in order to follow the current lecture course. Curricula should be planned so as to be spiral in structure so that the special features of science and engineering subjects can be taken into account.

It is important that a clearly qualitative approach is included in teaching physical sciences and engineering subjects. Entry-level courses, in particular, are those where attention should be paid to a qualitative approach and conceptual understanding. It is natural for students to have difficulties in understanding concepts when abstract topics are taught and therefore important that lecturers present and discuss concepts and phenomena qualitatively before presenting the quantitative approach. Both instruction and assessment should ultimately be based on conceptual understanding if conceptual problems are to acquire the status they deserve. Conceptual problems may seem trivial and give the impression that the content of a course is ramped down, but a closer look reveals their difficulty and their importance. Student knowledge is often assessed in terms of three categories of questions: recall, algorithmic and higher order [39]. Conceptual questions fall in the category of higher order.

One way to apply a qualitative approach to teaching physical sciences and engineering subjects is to use visualisation, for example, with the help of demonstrations and PDEODE-worksheets. Their integrated use should be carefully planned so that both cognitive internalisation and cognitive externalisation are included [22][40-42]. Here, cognitive internalisation is the process of formation of cognitive structures through human perception, representation and conception, and cognitive externalisation, which is the process of the human utilisation of cognitive structures in order to solve problems [42]. Equally important are laboratories: a seamless integration of laboratories and lectures will aid in achieving cognitive internalisation and externalisation. The PDEODE-worksheet can also be combined with laboratories.

Many subjects included in engineering education, such as chemistry, physics and material sciences, involve abstract concepts. The presentation of these subjects requires representations at the macroscopic, microscopic and symbolic levels. [23] Understanding is difficult because students do not necessarily see the connections between these representations. Observations are made at a macroscopic level, explanations and theories are presented at an atomic or molecular level, and written presentations include the symbolic level using symbols, formulae and equations. All these levels should be included, for example, when working with demonstrations and laboratories. They should be processed and integrated thoroughly. The PDEODE-worksheet has turned out to be an efficient assistant in this regard. Peer working and cooperative strategies should be adopted in order to help students see the connections between these three levels and to discuss meaning. This will improve their conceptual understanding and problem solving skills [43].

If too much material is presented over a short period of time, the short-term memory may become overloaded and learning and understanding may be inhibited. When ideas are presented that do not match existing mental structures, students should be able to deal with them or else they burden their short-term memory without being able to process it into the long-term memory. It should be noted that the presented material can set off complementary chains of thought in the learner that they are thereafter unable to process sufficiently for new models to be constructed in the long-term memory [22][44]. It is important that the teaching methods and arrangements are such that they support the learning process so that students are able to carry out the transfer from the short-term memory to the long-term memory. The authors claim that visualisation in the form of, for example, demonstrations or hands-on experiments compiled with a PDEODE approach, peer working and cooperation, will enhance the learning process.

Learning is improved by revealing students' prior knowledge and helping them to be as up-to-date as possible when attending lectures [27][28]. Concept tests, pre-lecture and lecture tasks and encouraging students to actively participate in dialogue and discussion help students to have an active grip on the subject matter throughout the course. Discovering students' misconceptions and addressing them are essential if conceptual change and true understanding are to be achieved. There are several different strategies by which conceptual change can be attempted. The lecturer makes the choice.

Studies in engineering and science teaching have shown that peer interaction and cooperative learning can lead to statistically significant improvement in academic achievements [1][27][28]. Active learning activities have been successfully incorporated in many programmes in order to maintain a high level of commitment and excellence and to increase the number of students who persist with the sciences, mathematics and engineering programmes [43][45]. Indeed, the authors' studies on textile and materials engineering programmes have shown that female students have found peer interaction and cooperative learning suitable for their learning styles but also that male students have found these applied approaches to be beneficial [27][28].

Studies into the differences between male and female learning styles have shown that both benefit from learning teams and group work. Cooperative learning is often easier for females to master in the early stages of its use; they learn while attending to a code of social interaction better than males. Stressful situations can be avoided through good cooperation. A good learning environment and atmosphere is important for both female and male students; however, stressful situations have been shown to influence male students more strongly and towards an unsatisfactory direction [30].

The pattern for the phases of processing a demonstration or problem is well in agreement with Krajcik's model of social constructivism, which summarises the constructing and restructuring of knowledge and understanding by students [3][46]. This process starts with students considering their current understanding. Knowledge of students' preconceptions and possible misconceptions helps the lecturer to find questions and problems by which students are able to create dissatisfaction with their current views, thereby allowing the introduction of ideas that lead to conflicting situations. This leads to a modification of students' current views and, finally, to conceptual change and conceptual understanding. This process is in accordance with that described by Posner et al [47]. After a level of dissatisfaction, students should have at hand a new conception that is intelligible, plausible and potentially fruitful.

We all know that changes in education happen slowly, but reading Confucius' thoughts from 2,500 years ago, we just wonder…

Tell me and I will forget.
Show me and I will remember.
Involve me and I will understand.

ACKNOWLEDGEMENTS

The authors are grateful to their employers, Helsinki Polytechnic and Tampere Polytechnic, as well as to the Academy of Finland and the EQUAL/Mirror project of the European Union (EU). Their support has given the authors the possibility to conduct their research.

REFERENCES

1. Mazur, E., *Peer Instruction: a User's Manual*. Englewood Cliffs: Prentice Hall (1997).
2. Pfundt, H. and Duit, R., *Bibliography: Students' Alternative Frameworks and Science Education* (4th edn). Kiel: IPN at the University of Kiel (1994).
3. Gabel, D.L. and Bunce, D.M., *Research on Problem Solving: Chemistry.* In: Gabel, D.L. (Ed.), Handbook of Research on Science, Teaching and Learning. New York: Macmillan, 301-326 (1994).
4. Herron, J.D., *The Chemistry Classroom*. Washington DC: American Chemical Society (1996).

5. Sawrey, B.A., Concept learning versus problem solving: revised. *J. of Chemical Educ.*, 67, **3**, 253-254 (1990).
6. Lin, H-S., The effectiveness of teaching chemistry through the history of science. *J. of Chemical Educ.*, 75, **10**, 1326-1330 (1998).
7. Gabel, D.L, Sherwood, R.D. and Enochs, L.J., Problem-solving skills of high school chemistry students. *J. of Research in Science Teaching*, 21, **2**, 221-233 (1984).
8. Nurrenbern, S.C. and Pickering, M., Concept learning versus problem solving: is there a difference? *J. of Chemical Educ.*, 64, 508-510 (1987).
9. Pickering, M., Further studies on concept learning versus problem solving. *J. of Chemical Educ.*, 67, **3**, 254-255 (1990).
10. Lythcott, J., Problem solving and requisite knowledge of chemistry. *J. of Chemical Educ.*, 67, **3**, 248-252 (1990).
11. Hobden, P., *The Role of Routine Problem Tasks in Science Teaching*. In: Fraser, B.J. and Tobin, K.G. (Eds), International Handbook of Science Education. London: Kluwer Academic Publishers, 219-231 (1998).
12. Pushkin, D.B., Introductory students, conceptual understanding, and algorithmic success. *J. of Chemical Educ.*, 75, **7**, 809-810 (1998).
13. Ausubel, D.P., *Educational Psychology: a Cognitive View*. New York: Holt, Rinehart and Winston (1968).
14. Nurrenbern, S.C., Piaget's theory of intellectuel developments revisited. *J. of Chemical Educ.*, 78, **8**, 1107-1110 (2001).
15. Fosnot, C.T., *Constructivism: a Psychological Theory of Learning*. In: Fosnot, C.T. (Ed.), Constructivism: Theory, Perspectives and Practice. New York: Teachers College Press, 8-33 (1996).
16. Roadruck, M.D., Chemical demonstrations; learning theories suggest caution. *J. of Chemical Educ.*, 70, **12**, 1025-1028 (1993).
17. Kolari, S., An Active Role for Students in the Learning Process in Engineering Education: Interactive Teaching Methods in Promoting Understanding. Doctoral dissertation, Tampere University of Technology, Publication 407 (2003).
18. Savander-Ranne, C., An Active Role for Students in the Learning Process in Engineering Education: A Means to Develop Conceptual Understanding. Doctoral dissertation, Tampere University of Technology, Publication 408 (2003).
19. Mayer, R.E., *The Promise of Educational Psychology. Learning in the Content Area*. Englewood Cliffs: Prentice-Hall, 5-20 (1999).
20. Johnstone, A.H., Chemistry teaching – science or alchemy? *J. of Chemical Educ.*, 74, **3**, 262-268 (1997).
21. Kolb, D.A., *Experiential Learning*. Englewood Cliffs: Prentice-Hall, 40-78 (1984).
22. Kolari, S. and Savander-Ranne, C., Are your students learning or are they just watching? *Proc. 5th UICEE Annual Conf. on Engng. Educ.*, Chennai, India, 107-110 (2002).
23. Gabel, D., *The Complexity of Chemistry and Implications for Teaching*. In: Fraser, B.J. and Tobin, K.G. (Eds), International Handbook of Science Education. London: Kluwer Academic Publishers, 233-248 (1998).
24. Nakleh, M.B., Why some students don't learn chemistry? *J. of Chemical Educ.*, 69, **3**, 191-196 (1992).
25. Duit, R. and Treagust, D.F., *Learning in Science – from Behaviourism towards Social Constructivism and Beyond*. In: Fraser, B.J. and Tobin, K.G. (Eds), International Handbook of Science Education. London: Kluwer Academic Publishers, 3-25 (1998).
26. De Jong, O., Korthagen, F. and Wubbels, T., *Research on Science Teacher Education in Europe: Teacher Thinking and Conceptual Change*. In: Fraser, B.J. and Tobin, K.G. (Eds), International Handbook of Science Education. London: Kluwer Academic Publishers, 745-758 (1998).
27. Kolari, S. and Savander-Ranne, C., Total integration and active participation in the learning process in textile engineering education. *World Trans. on Engng. and Technology Educ.*, 1, **2**, 261-274 (2002).
28. Kolari, S. and Savander-Ranne, C., A materials engineering lecture course with a more active and responsible role for the students. *World Trans. on Engng. and Technology Educ.*, 2, **1**, 157-171 (2003).
29. Felder, R.M. and Silverman, L.K., Learning and teaching styles. *Engng. Educ.*, 78, **7**, 674-681 (1988).
30. Gurian, M. and Henley, P., *Boys and Girls Learn Differently*. San Fransisco: Jossey-Bass, 44-49 (2001).
31. Kolari, S. and Savander-Ranne, C., Why do our students not learn as we wish them to? *Proc. 2nd Global Congress on Engng. Educ.*, Wismar, Germany, 153-155 (2000).
32. Kolari, S. and Savander-Ranne, C., Will the application of constructivism bring a solution to today's problems of engineering education? *Global J. of Engng. Educ.*, 4, **3**, 275-280 (2000).

33. Brown, A.L. and Palincsar, A.S., *Guided Co-operative Learning and Individual Knowledge Acquisition*. In: Resnick, L.B (Ed.), Knowing, Learning and Instruction. Essays in Honor of Robert Glaser. Hillsdale: Lawrence Erlbaum, 395-451 (1989).
34. Johnson, D. and Johnson R., *Co-operative Learning and Achievement*. In: Sharan, S. (Ed.), Co-operative Learning: Theory and Research. New York: Praeger, 23-37 (1990).
35. Damon, W., *Peer Relations and Learning*. In: Husén, T. and Postlethwaite, T.N. (Eds), The International Encyclopedia of Education. Oxford: Pergamon, 4368-4372 (1994).
36. Vygotsky, L.S., *Mind in Society: The Development of Higher Psychological Processes*. Cambridge: Harvard University Press (1978).
37. Tao, P-K. and Gunstone, R.F., Conceptual change in science through collaborative learning at the computer. *Inter. J. of Science Educ.*, 21, **1**, 39-57 (1999).
38. White, R.T. and Gunstone, R., *Probing Understanding*. London: Falmer Press (1993).
39. http://jchemed.chem.wisc.edu/JCEWWW/Features/CQandChP/CQs/WhatAreCQs.html
40. Kolari, S., Visualisation as a tool for teaching and learning. *Proc.* 6th *UICEE Annual Conf. on Engng. Educ.*, Cairns, Australia, 91-94 (2003).
41. Kolari, S. and Savander-Ranne, C., You know it, but do you actually understand it? *Proc. 5th Baltic Region Seminar on Engng. Educ.*, Gdynia, Poland, 69-72 (2001).
42. Gang, S., Decisive factors in teaching and learning. *The Physics Teacher,* 38, 408-410 (2000).
43. Bowen, C.W. and Phelps, A.J., Demonstration-based cooperative testing in general chemistry: a broader assessment-of-learning technique. *J. of Chemical Educ.*, 74, **6**, 715-719 (1997).
44. Rowe, M.B., Getting chemistry off the killer course list. *J. of Chemical Educ.*, 60, **11**, 954-956 (1983).
45. Zumdahl, S.A., Mission impossible? Improving retention of science majors among minorities and women. *J. of Chemical Educ.*, 73, **11**, A266-A267 (1996).
46. Krajcik, J.S., *Developing Students' Understanding of Chemical Concepts*. In: Glynn, S.M., Yeany, R.H. and Britton, B.K. (Eds), The Psychology of Learning Science. Hillsdale: Lawrence Erlbaum, 117-147 (1991).
47. Posner, G.J., Strike, K.A., Hewson, P.W. and Gertzog, W.A., Accommodation of a scientific conception: toward a theory of conceptual change. *Science Educ.*, 66, 211-227 (1982).

BIOGRAPHIES

Carina Savander-Ranne is a senior lecturer at the Helsinki Polytechnic in Helsinki, Finland, where she has been teaching chemistry and material sciences since 1982. She is presently doing research in the field of engineering education and engineering pedagogy at Tampere Polytechnic. She received her MSc in chemical engineering at the Helsinki University of Technology, Helsinki, Finland. Her postgraduate studies have been in the field of corrosion engineering, material sciences and pedagogy. She finished her doctoral thesis in 2003 in the field of materials engineering at Tampere University of Technology.

She was employed by industry before her career as a lecturer. She worked with civil engineering, specialising in water plants. She is also currently working as a teacher educator, her special field being teacher-training programmes for engineering educators.

Samuli Kolari is a principal lecturer at Tampere Polytechnic, Tampere, Finland. He is presently undertaking research in the field of engineering education and engineering pedagogy. He received his MSc degree in physics at the University of Turku in 1975 and his postgraduate degree of LicSc in 1979, also from the University of Turku. He graduated with his Doctor of Technology at Tampere University of Technology in 2003 in the field of materials engineering.

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 industry. He has been working as an engineering educator for the last 25 years with special interest in pedagogical matters of science and engineering education.

3rd Global Congress on Engineering Education: Congress Proceedings

edited by Zenon J. Pudlowski

This volume of Congress Proceedings is comprised of papers submitted for the *3rd Global Congress on Engineering Education*, which was held at Glasgow Caledonian University (GCU), Glasgow, Scotland, UK, between 30 June and 5 July 2002. The prime objective of this Congress was to bring together educators, professional organisations and industry leaders from around the world to continue discussions covering important issues, problems and challenges in engineering and technology education for this new millennium.

The papers in these Proceedings present global research and development activities with three opening addresses, 18 keynote addresses, 16 lead papers and almost 70 regular papers that have been contributed by authors from 30 countries across the globe. The papers present readers with a significant source of information on a wide spectrum of issues and topics in engineering and technology education. They detail findings describing current issues and trends, effective methods in the training of engineers and technologists, curriculum design and evaluation and the relevance of liberal education, the management of academic institutions and engineering faculties, social and philosophical aspects of engineering and its impact on modern societies, international case studies, the application of new technologies, academia/industry interaction programmes, sustainable development and international collaborative programmes and systems.

The 3rd Global Congress could be characterised as an academically fruitful event with most papers in these Proceedings being of a very high academic standard. Furthermore, all papers have gone through a strict refereeing process to ensure their relevance for years to come.