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Visualisation Promotes Apprehension and Comprehension*

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In the fields of physical sciences and engineering, there are many difficult and abstract topics and phenomena. The student population entering engineering education programmes is becoming more and more heterogeneous. The incoming students often have little experience in technical applications and phenomena in physical sciences. They also have very diverse learning styles. In this day and age, when change is the norm, the demands on engineering educators are extensive. Students should be provided with various skills, such as communication, teamwork and learning skills, in addition to a good command of the subject matter. Visualisation aids the lecturer to meet the diversity of learning styles represented by engineering students and aids the students to attach meaning to concepts and phenomena. On the basis of retrospective reflection on their experiences as lecturers and educators in the field of engineering education and on the basis of two case studies, the authors present a concrete example of a method of utilising visualisation in the field of materials science dealing with metals. The authors also discuss the use of a PDEODE worksheet (Predict-Discuss-Explain-Observe-Discuss-Explain) in integrating lectures, demonstrations and lab work. The pedagogical background of the PDEODE worksheet is also dealt with.

INTRODUCTION

VISUALISATION, in a broad sense and in the way that the authors see it within the context of engineering education, means forming a picture, a model or a scheme of something in the mind. Visualisation is used to help the student form mental visual images, to make visual interpretations of what concepts or processes mean, or to elucidate abstractions. Visualisation is needed to explain the connections between the symbolic representations and the micro and the macro world. Many abstract concepts and phenomena are dealt with in engineering subjects. It is not always easy for students to adopt these and assimilate a correct understanding of them. Valid engineering skills cannot be achieved by mere rote learning. Learning should include true understanding.

Learning and understanding are influenced by the way students are able to perceive, interpret and process information, integrate it with old knowledge structures and organise it, place it in their memory and retrieve it. The way that lecturers deliver their lectures has a considerable influence on how students are enabled to perceive, interpret and process knowledge. This subsequently influences the knowledge structures of the long-term memory (see Fig. 1) [1–4].

Learning may be achieved through the cognitive translation between representations at different levels of abstraction. Visualisation in the technical sense can be seen as providing the relevant representations to assist the learner in carrying out this cognitive process. Thus visualisation assists in a translation of a more abstract representation to a less abstract one and from a more complete representation to a less complete one [5]. A good lecturer visualises and helps the students to form relevant mental models of the relevant issues.

It has been shown in numerous studies that using dynamic teaching methods and encouraging students to be actively engaged in their own learning processes is a means of supporting effective learning. Lecturers face many challenges when guiding students to acquire the diversity of skills needed in the profession of an engineer. Naturally, lecturers need a good command of their own field of engineering. However, this is not sufficient; they must also be interested in developing their skills as lecturers in a broader sense. This means that they have to reflect on the many aspects of teaching and learning. They have to attain pedagogical knowledge and, together with their subject matter knowledge, develop it into pedagogical content knowledge [6–10]. The ability to visualise is an important tool and a part of a lecturer's pedagogical content knowledge. Visualisation helps when clarifying, explaining, verifying, motivating and arousing curiosity. It also helps in recollecting and building analogies [11–13].

In this article, the authors deal with the importance of meeting the diversity of students' learning styles and suggest ways of making use of White's elements of memory. The authors suggest how to

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elucidate abstractions and help students form mental visual images and visual interpretations of what the various concepts mean. An example is dealt with where students actively process knowledge and are guided through apprehension and comprehension, thus achieving a deeper understanding. Students' active processing can be aided by the use of a PDEODE worksheet (Predict-Discuss-Explain-Observe-Discuss-Explain) and a PDEODE method that has been developed by the authors on the basis of White and Gunstone [14]. The example used is a problem of materials sciences in which students can have misconceptions when dealing with plastic and elastic deformation. The example also helps in visualising the connection between the macro, micro and symbolic representations [4, 11, 14, 15].

THEORETICAL FRAMEWORK FOR PDEODE PROCESSING

Learning requires both perceiving and processing information: mere perception is not enough; something has to be done. Individuals perceive and process information in different ways, thus students display a diversity of learning styles [16]. What and how much students learn depends on many factors, such as how teaching strategies are compatible with students' learning styles, how lecturers are able to assist students in utilising their memory, along with student motivation, activity and commitment.

An important factor is also that the students themselves should be aware of their own learning styles and be able to consciously work accordingly.

Learning styles

There are many learning style models, Kolb's [3] model being one of the best known. However, the authors have chosen to use the Felder–Soloman Index of Learning Styles (ILS) [17–20]. The ILS has been developed to determine the learning preferences of engineering students. Felder–Soloman describes four dimensions of learning styles: active–reflective, sensing–intuitive, visual–verbal and sequential–global. 'Active' and 'reflective' describe the ways learners process the information, 'sensing' and 'intuitive' describe the ways they perceive information. 'Visual' and 'verbal' deal with the ways learners receive information, whereas 'sequential' and 'global' deal with the ways they understand information.

Active processors make sense of an experience by immediately using new information, applying ideas, testing them, doing and manipulating. Reflective processors make sense of an experience by reflecting on and thinking about it. They transform knowledge by structuring, ordering and intellectualising it.

According to Kolb, concrete perceivers absorb information through direct experience, by doing, acting, sensing and feeling. Abstract perceivers take in information through conceptualisation, analysis, observation and thinking. In the ILS model of Felder–Soloman [17], concrete perceivers are classified as sensing learners who prefer concrete, practical information and are oriented towards facts and procedures. Abstract perceivers are classified as intuitive learners. They prefer concepts, tend to be more innovative and are oriented towards theories and meanings. They tend to prefer ideas they themselves develop. Sensing learners prefer external information, while intuitive learners prefer internal.

The visual–verbal dimension of learning styles categorises input modality. The sensory channels by which external information is perceived can be visual, auditory or kinesthetic. Visual information includes pictures, diagrams, charts, plots, animations, etc. Auditory information includes spoken words and other sounds. Written words, however, are not equivalent to real visual information. Our brains generally convert written words into spoken words. Felder and Soloman categorise written and spoken words as verbal information. Kinesthetic learning includes both information perception such as touching, smelling and tasting, and information processing such as moving and interacting. Felder and Soloman include the processing aspect of kinesthetic learning in the active–reflective dimension of their learning styles [16–17].

The sequential–global dimension describes how learners proceed towards understanding. Sequential learners prefer linear, orderly steps, logically following each other. Global learners benefit from knowing the whole picture. They are holistic and learn in layers or large steps. Sequential learners may be strong in convergent thinking and analysis, while global learners may be better in divergent thinking and synthesis [16–17].

When combining the ways of perceiving and processing, we get several alternatives. For example, learners can be intuitive in their way of perceiving information but active in the way they process it. This means that they like to develop ideas and theories through reflection but then process them actively, make experiments and try out how they work.

Some research programmes on learning styles show that many engineering students are active, sensing, visual and sequential learners. However, our studies of polytechnic and university engineering students in Finland have shown that the students studied are fairly well balanced in the sequential–global dimension [20]. The authors have noticed in their studies on engineering education and their work as teacher educators in the field of engineering education that lecturers in higher education frequently tend to apply teaching methods that are more likely to meet intuitive, sequential and verbal learners [18, 19, 21–23].

It is not wise to select students for engineering programmes with one specific learning style profile. We need engineers with diverse skills (i.e. both those who prefer developing through innovative reflection and those who get results through active processing). Thus the teaching methods and approaches used should be such that they accommodate a diversity of learning styles and help students use their strengths and develop their weaknesses.

Elements of memory

White [11] defines a model for understanding in terms of seven elements of memory and their pattern of association. These elements are: strings, propositions, images, episodes, intellectual skills, motor skills and cognitive strategies. Understanding takes on different meanings, depending on the scale and nature of what is to be understood. The word 'understanding' is complex, involving the amount of knowledge, its type and its degree of interlinking in a person's mind, its availability and its applicability. Merely measuring the amount of knowledge is insufficient when seeking to estimate understanding. In understanding, the nature of knowledge and the pattern of associations between its elements is important. The pattern of association refers to the extent of links between elements. Knowledge of a topic can be atomistic and consist of many sparsely connected elements or it can be holistic, where the same elements are bound into a coherent mass.

White's elements of memory can be helpful in describing learning and useful in deriving effective principles of instruction. Keeping these elements of memory in mind when planning a lecture can encourage the use of visualisation as a tool for promoting understanding. Visualisation can be linked with most, if not all, elements of memory. Aiding students to form images and episodes, however, offers fertile ground for the use of visualisation. White describes one of his elements, namely images, as mental representations of sensory perceptions. These are often visual but can be related to all five senses. Another of his elements, an episode, is described as the memory of an event that has happened. Using the PDEODE (see Fig. 3) worksheet and having the students make observations and discuss them helps them to construct, or reconstruct, their elements of memory. When discussing, the students have the opportunity to bring to the table their own images and episodes and learn from each other. White's elements of memory have been dealt with in more detail by Kolari and Savander-Ranne [15].

Constructivism

Some of the basic principles of constructivist learning theory have been used as guidelines for developing the PDEODE worksheet and working method described below. A constructivist view of learning and knowledge is that knowledge is not directly transmittable from lecturer to learner. Learning is a cognitive process and knowledge

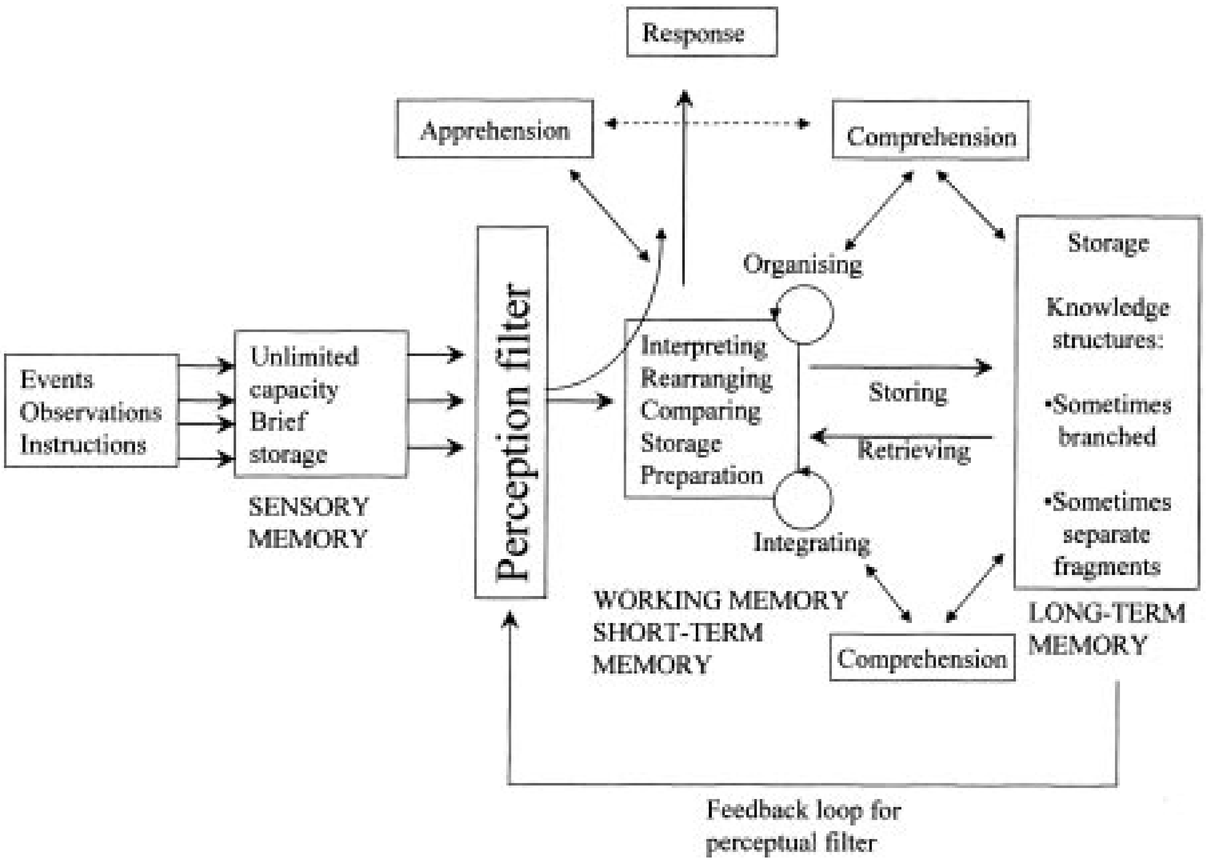


Fig. 1. The information-processing model [27–28], modified by the authors on the basis of Mayer [26] and Johnstone [29].

has to be constructed or reconstructed in the mind of the learner by him/herself through mental effort and activity [24].

Cognitive growth results from social interaction. Social interaction plays a crucial role in learning. Knowledge construction is primarily a social process in which meaning is constructed in the context of dialogue with others. Learning is aided by conversation that seeks and clarifies the ideas of learners. Learners should be encouraged to communicate with each other and the lecturer [24].

Concepts gain meaning and mental models and schemes are constructed on the basis of prior knowledge and what is perceived and experienced. Prior knowledge determines response to information, ideas and experiences. New knowledge must be related to the learner's earlier knowledge. Preconceptions and possible misconceptions have a significant impact on how new knowledge is constructed. The beliefs and attitudes of the learner should be considered [24, 25].

Information processing model

Mayer [26] proposes the model of the memory system shown in Fig. 1. The sense receptors accept new information, which is briefly held in the sensory memory. Relevant and irrelevant information are separated, and the relevant moves on to the working memory or short-term 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 retrieved from the long-term memory and subsequently transforms it.

The difficulties and importance of accomplishing conceptual change can well be understood on the basis of the information-processing model presented in Fig. 1 [26–29]. 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 that is present in the long-term memory and the learner's prior knowledge base. Misconceptions are also a part of the learner's cognitive structure and interfere with subsequent learning, so that the new information cannot be integrated appropriately and weak understandings and misunderstandings of new concepts are inevitable [26, 29, 30, 31].

In Fig. 1, 'apprehension' and 'comprehension' refer to two different 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 through a concrete experience [3]. For example, if you take a copper rod and bend it backwards and forwards several times, you will experience the rod becoming more and more stiff until it eventually breaks. This experience can lead to you apprehending that, if you are installing copper pipes, you can only bend it once.

Comprehension means understanding through reliance on conceptual interpretation and symbolic representation—conceptualisation [3]. In this case, you have a deeper understanding of concepts such as crystal structures, slip planes and dislocations and the theories related to these. Deeper understanding also includes being able to relate characteristics such as 'brittle', 'hard' and 'ductile' to the theories of deformation. Comprehension also leads to understanding why a mistake made when bending copper pipes cannot be corrected. The bending and correcting might have already caused slight cracks to form, and thus mistakes are rarely correctable. Comprehending gives a person a definite vision of the relation between the microscopic and symbolic levels of representation, and hopefully also the macroscopic level, and an ability to move between one level and another. Comprehension is needed when you design structures and choose materials, but so also is apprehension.

VISUALISATION

Visualisation is an efficient tool for helping students understand. Visualisation is a natural way to challenge the students to discuss and process the issues at hand and to engage actively in their learning process. This also gives the lecturer the opportunity to guide and assess, to give continuous feedback and to orient the students for future issues. Because every field of science has its own special features, it is up to the lecturer to guide the students to make observations and to focus on the right things. It is important that students learn to make observations and conclusions on their own during demonstrations, hands-on experiments and lab work, and in this way improve their life-long learning skills.

Questions to be reflected on

As teacher educators in the field of engineering education, the authors have guided lecturers to reflect on how to visualise phenomena and concepts when they are planning their lectures. The authors have challenged lecturers to use dialogue by setting tasks such as the following:

Explain <u>in your own</u> words

- what this concept means?
- what this phenomenon implies?
- what is the purpose of this quantity?

An example might be: *Why do we need a quantity such as diffusion flux?* In the authors' opinion, if somebody is unable to tell a story, to draw a picture or to demonstrate some quantity, it suggests that they have not sufficiently internalised the material themselves. Hence the conditions for successful teaching and learning are weak.

If a student knows the quantity diffusion flux (J), this can imply simply knowing the proposition $J = M/(A \cdot t)$, where M refers to mass or equivalently the number of atoms diffusing through and perpendicular to a unit cross-sectional area (A) of solid per unit time (t).

Knowing, however, should also include other elements of memory, such as images and episodes, as described by White [11]. Lecturers should be able to assist students in understanding the nature of a concept or quantity and develop a pattern of associations between the elements of memory. This means forming links between, for example, propositions, images and episodes.

The lecturer can practise visualisation by answering some simple questions:

- What do concepts such as dislocation, edge dislocation line, unit step and sheer stress mean?
- What is the purpose of these concepts?
- What images and episodes can be demonstrated when defining these concepts?
- What stories can be told?

Will the situation become more clear after these procedures?

Proceeding in this way gives the students the opportunity to give the concepts meaning, to bind them to each other, to hook them in their minds and to apply them. In this way, there is a good chance that mere rote learning can be avoided and true understanding can occur.

Skilful visualisation of quantities helps the student to move from a descriptive, less abstract level of understanding to a more complete and abstract one. An engineer and an educator should, of course, be able to use both means of expression: the descriptive, less abstract method when dealing with novices, and the abstract more integrated method in his profession and when dealing with experts.

Integration and visualisation meet the diversity of learning styles

The lecturers have diverse ways of constructing the learning environment so that they can take into account students' own knowledge base and guide them to views that are more compatible with those accepted by the scientific community. Visualising can be intensified by using, for example, hands-on experiments or demonstrations combined with Socratic dialogue [9, 32, 33]. An interactive and successful outcome needs an open and trusting atmosphere in the classroom. The lecturers must also be aware when communicating with the class that their own ability to listen is of significant importance. Listening is at least as important as speaking. Students should be encouraged to ask questions, discuss with their peers and to take an active role in finding answers and solutions.

TREATING Cu-RODS AND USING THE PDEODE METHOD

An efficient way to create interaction and a learning climate that supports understanding is to integrate lectures, class demonstrations and experiments, and/or laboratory work. This can be done, for example, by using demonstrations combined with the PDEODE (Predict-Discuss-Explain-Observe-Discuss-Explain) method.

Experiments with a copper rod can be undertaken in a course dealing with metals. This can be carried out so that students work in small groups. If this is not possible, the experiment can be carried out as a demonstration. The procedure can be as follows:

Phase 1	Bending and pondering	during the lecture
Phase 2	Cold hammering and pondering	during the lecture
Phase 3	Heat treatments	in the laboratory
Phase 4	Pondering–deducting	outside class
Phase 5	Conclusion	during the lecture

In phases 1 and 2, the students work in small groups during the lecture and the following steps and instructions are followed:

1. Fasten the Cu-rod ($l \cong 30$ cm, $\varnothing = 4$–6 mm, annealed) on the stand (see Fig. 2).
2. Measure the deflection when a weight (approx. 0.5 kg) is placed 5 cm from the free end of the rod.
3. Bend the rod slowly back to the horizontal position.
4. Measure the deflection again, as described in step 2.
5. Move the rod up and down 3–4 times with an amplitude of 3–5 cm.
6. Measure the deflection again, as described above.
7. Take a new rod and repeat the deflection measurement as in steps 1–2.
8. Release the rod and hammer it evenly.

After cold hammering and measuring the deflection, each student group will be given different instructions for heat treatment. After the heat treatment, the students measure the deflection again. They then ponder and seek more information so that they can explain their observations. All the results are summarised and discussed at the lecture. Such concepts, such as recovery, recrystallisation and grain growth, become more concrete when students can see, feel and discuss.

Using the PDEODE worksheet

After step 3, when the rod is bent back to the horizontal position, the following question can be presented to the students:

When the bending load is put back again, as described earlier, what do you think the deflection will be?

a) clearly more than before;
b) approximately the same as before; or
c) clearly less than before.

First, each student will individually fill in their thoughts using the space for predictions and

Fig. 2. The equipment for measuring the deflection of the Cu-rod.

reasoning on their PDEODE worksheet (Fig. 3). Next the students will discuss their ideas with their peers and try to find a mutual prediction and its explanation. At this stage the lecturer can interact with the groups. Then the observations at step 4 will be written down on the worksheet, after which the students will try to find explanations and reasons for their observations and write these on the worksheet. In the space for comments/questions, the students will explain what, in their view, has caused any differences between their predictions and observations. It is also helpful if the students note down any questions they still need explanations for.

The worksheet brings many benefits to the learning process. It helps the lecturer to discover any misconceptions which students may have, any problems they have in learning this concept and the students' level of understanding. The students' explanations and reasoning will help the lecturer to understand their ways of learning. This all improves the lecturer's pedagogical knowledge.

Using the PDEODE method, the students have opportunities to explore and articulate their ideas, to share them with others, to test those ideas through experimentation and conversation and to consider connections between phenomena and theories. During discussions and reasoning they learn important communication skills in their own professional field. When the students write down their comments, they have to practise their cognitive skills. Pondering in this way, step by step, provides stimuli to develop, modify and, where necessary, alter ideas. This will also promote conceptual change, as they are actively taking part in their learning process. The assignments and tasks should be prepared with some care. They must be relevant for the students [14] and should fit the their personal zone of development [34].

DISCUSSION

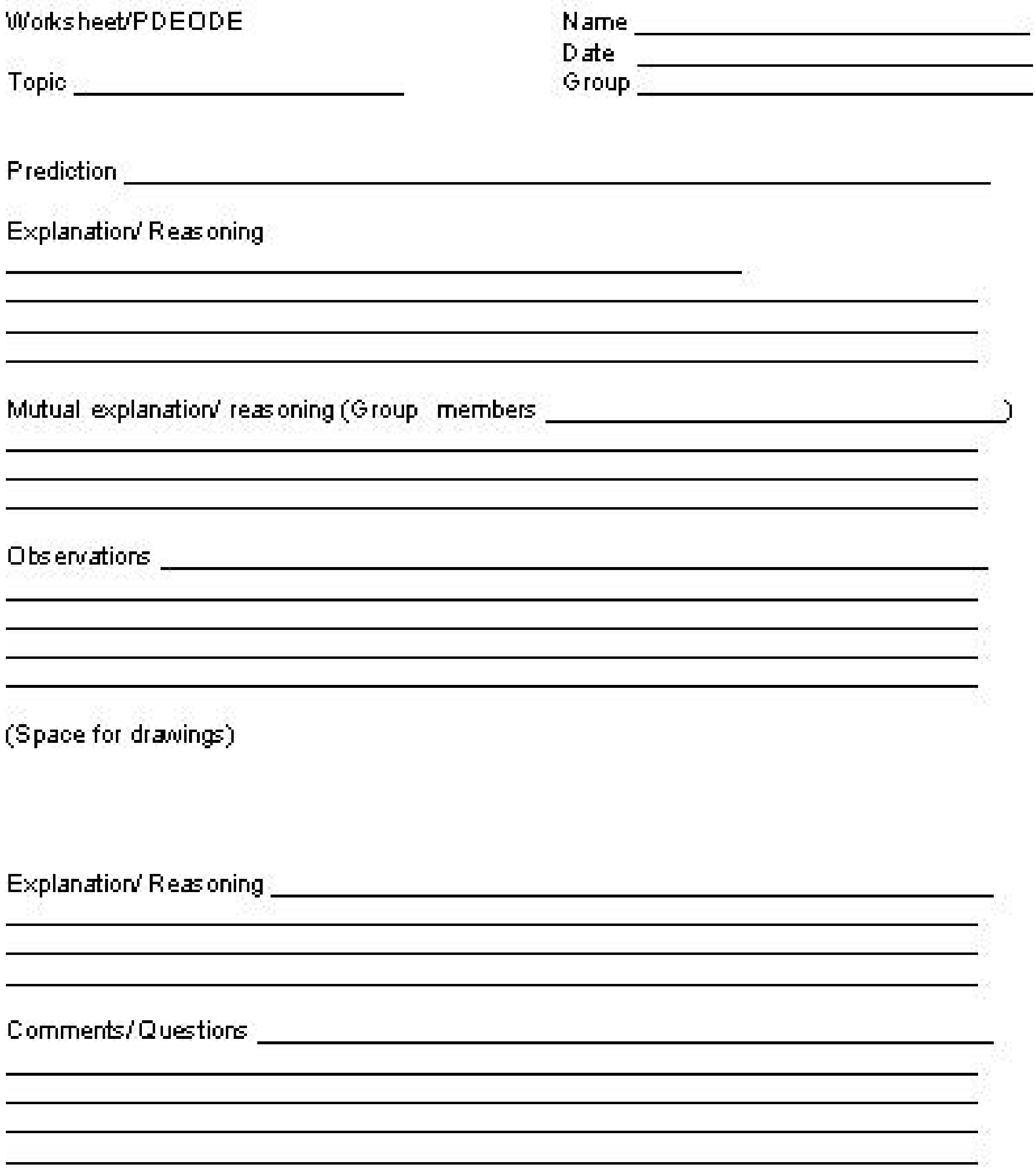
In the field of physical sciences and engineering subjects, there are many difficult and abstract topics. On the basis of the authors' own practical experiences and research studies in the field of engineering education, the authors believe that the use of visualisation and interaction, including the PDEODE method, have a positive impact on students' learning results and the learning atmosphere. Student motivation increases, learning improves, and deeper understanding is achieved. This also improves the students' self-confidence and enhances their self-directedness.

As a student in one of our studies on engineering education has expressed it [18]:

> *Such things are difficult where there is just lots of theory . . . when there are practical things, in the way we now have, it is always easier to understand.*

It is a well-known fact that we receive most information through our eyes. There are studies which have stated that the majority of engineering students are visual learners [18, 19, 22, 35]. This is important to acknowledge, but it is, however, important also to take account of the other senses when visualisation is pursued.

When proceeding as we suggest in our experiment on copper rods, we can create a learning environment that meets several learning styles and gives better opportunities for students to learn and understand. The demands of both active and reflective learners are met, as the mode of working includes phases of reflection, active discussion and doing. Watching, doing and discussing meet the needs of both visual and verbal learners. Writing out solutions, reasoning and justifying improve the students' cognitive skills and accommodate the verbal learner. How this mode of working suits sensitive and intuitive learners and sequential and global learners depends on a number of factors: the introduction and the presentation of the assignments; what procedures, such as measuring, searching data, calculating and deducting, are


Worksheet/PDEODE

Name ______
Date ______
Topic ______
Group ______

Prediction ______

Explanation/ Reasoning

______

Mutual explanation/ reasoning (Group members ______)

______

Observations ______

______

(Space for drawings)

Explanation/ Reasoning ______

______

Comments/ Questions ______

______

Fig. 3. Worksheet for the PDEODE assignment, modified by the authors on the basis of White and Gunstone [14].

expected of the students; and how the summing-up is done. Working in pairs and small groups, making predictions, discussing and justifying, making observations and giving explanations, enables students to link episodes and images to the issues concerned. Knowledge is hooked in a rational way to their knowledge structure (Fig. 1). By giving the students more responsibility, their commitment and active engagement in their learning process can be increased [27–28].

If a lecture is mainly a monologue from the lecturer, receiving information and processing it depends to a large extent on what is heard this one and only time. There may be no opportunity to rewind, and internalisation of the information may be virtually non-existent. Visualisation gives more opportunities to increase interaction and student engagement. The lecturer must use appropriate means to promote this, such as questions, problems and peer co-operation. The PDEODE worksheet (Fig. 3) brings more assertiveness to discussing and predicting. It also aids the students in practising their cognitive skills and developing their metacognition. The lecturer also obtains information about the students' level of comprehension. Observing, discussing and drawing conclusions deepens understanding, including both apprehension and comprehension [36–37].

Changing a traditional lecturing approach into an interactive approach has proven to be feasible in many studies in engineering education. This has a positive influence on students' motivation and learning [18, 19, 22, 35, 38]. However, there is no strong tradition in using interactive teaching methods in higher education, which means that we can expect some resistance when applying methods that entail students having a new, more active and responsible, role. All the relevant parties require a little time to practise and become accustomed to the new methods. Clear rules and careful planning are important if success is to be achieved [18–19].

IT technology has enabled us to use better means for visualising abstract issues, through the use of animations and three-dimensional models, amongst others. For example, atomic and molecular models, lattice defects, radiation and conduction are issues from an abstract micro-world [39–41], and there are numerous possibilities to be found over the Internet. Many applications allow the interactive use of animations, where the values of quantities can be changed and the response can be seen immediately. This can help the user to internalise and interconnect the relevant quantities.

Jean Piaget asserted that what we learn is dictated by two influences: the schemas that we already have in our heads and the information contained in the external stimuli to which we respond [24, 42]. John Dewey based his theory of education on experiential learning and the principle that all genuine learning comes about from experience [43]. Experiential learning models and their application in education are based on the works of Jean Piaget, John Dewey, Kurt Lewin and David Kolb. Thus, learning can be defined as the process whereby knowledge is created through transformation of experience: knowledge results from the combination of grasping experience and transforming it. The students must be actively engaged in the learning process. Through a variety of group activities, students can begin to acknowledge, gain appreciation of and criticise the views of others, accept and value criticism and recognise discrepancies, conflicts, contradictions and inconsistencies, as well as points of similarity and agreement. A necessary condition for cognitive restructuring is the opportunity for repeated, exploratory, enquiry-oriented behaviour in regard to an event or phenomenon in order to realise how a model or schema works or how it does not work. The cognitive structure is revised only when a reasonable option, consistent with one's experience, comes to hand [3, 44].

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