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Developing metacognition: a basis for active learning

HENK VOS[†]* and E. DE GRAAFF[‡]

The reasons to introduce formats of active learning in engineering (ALE) such as project work, problem-based learning, use of cases, etc. are mostly based on practical experience, and sometimes from applied research on teaching and learning. Such research shows that students learn more and different abilities than in traditional formats of teaching. These abilities are often required by the employers of the alumni and are therefore included in the curricula to educate competent practitioners. A major problem is, however, that a coherent theoretical background explaining the mechanisms underlying ALE is all but lacking. Therefore, it is not clear what the developmental objectives of ALE are. A theoretical basis embedded in learning psychology is needed. A promising concept to fill this gap seems to be the construct of metacognition (Vos 2001, *Metacognition in Higher Education*, PhD thesis (Enschede: Twente University Press)) as distinct from cognition. Cognition is concerned with *what* someone knows, metacognition with what people know *about* their knowledge (Flavell 1979, *American Psychologist*, **34**, 906–911, Metcalfe and Shimamura (eds) 1994, *On Knowing what we Know: Review of Metacognition* (Cambridge, MA: MIT Press)). Our proposal is that ALE is focused on developing metacognition above or more than cognition. This foundation is important because education for cognitive objectives differs from that for metacognitive ones. Also, metacognitive objectives are more difficult to obtain. The use of founding ALE in the development of metacognition is that knowledge about metacognition serves to formulate clear goals of ALE. From knowledge about metacognitive development, hints can also be derived to raise the effectiveness of ALE.

1. Conceptual background

In order to demonstrate the connection between active learning in engineering (ALE) and cognition, let us first describe the terms used. In ALE the student is an active participant. The activity of the students is not restricted to using their ears and hands for writing notes, their tongues for answering questions and their eyes for looking at the teacher and the blackboard, or storing away what the teacher tells or shows. ALE requires a lot of activity, both mental and physical. The activity is encouraged by the instructional environment: the students are, to a certain extent, free to choose what they like to do, they may use advanced tools and concepts, attack real problems, work together with experts and teachers, and co-operate in a team. Several educational models apply to one or another form of active learning.

[†]Department of Electrical Engineering, University of Twente, Enschede, The Netherlands.
[‡]Faculty TBM, Delft University of Technology, The Netherlands.
* To whom correspondence should be addressed. e-mail: h.vos@utwente.nl

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Well-known models are problem-based learning (PBL) and project-organized learning (POL) (de Graaff and Kolmos 2003). Both models rely on didactic principles such as *discovery learning, learning-by-doing* (Jerôme Bruner), *experiential learning* (Kolb) and *student-centred learning* (Carl Rogers). The most important difference between PBL and POL seems to be the resemblance to reality of the treatment of the 'problems'. In a PBL setting students analyse an ill-defined problem in order to define their own learning goals. Solving the problem is a means, not the goal. It simply has to fulfil the function of setting of the learning process. In POL students are expected to learn from solving a problem in a realistic setting. The project is defined by a clear start and a deadline. The subject matter is usually rather well described, as are the goal (the problem to be solved) and the time to be spent on the project.

If the goal and the product to be delivered are defined, as well as the method to produce the product, one speaks of a skills training project (e.g. 'Measure the voltage of various electrical signals with a storage oscilloscope'). If the method can be chosen freely, one speaks of a subject project (e.g. 'Measure the voltage of lightning'). In this case, sometimes heuristics can be used (Mettes and Pilot 1980).

Sometimes the goal is given but the specific end-product is not as in design projects (e.g. 'Design a flexible route information system for blind people'). If the problem to be solved is not given, but vaguely formulated, ill-defined, or even has to be formulated by the students themselves, one speaks of a problem project (e.g. 'Is metacognition a psychological phenomenon?' or 'What research do you want to do as an exercise and preparation for your final thesis in this field of study?').

Solving a problem does not necessarily involve learning as learning involves a generalization to future, different situations and contexts. Separate attention has to be given to learning goals, from the viewpoint of both the teachers (learning objectives) and the students (learning goals). Being able to specify yourself an ill-defined problem could be such a learning objective. By formulating the specific problem to be solved themselves, the students attribute meaning to the problem, its solution and their learning. They determine the cognitive learning goals themselves (self-regulated learning).

In both PBL and in POL, learning is sustained by reflection on the processes, or on the approach to the solution, that took place. Comparing the results with the initial learning objectives and learning goals enhances the learning process (e.g. Cowan 1998). Sometimes it is helpful to formulate explicit rules for generalization, as in experiential learning according to the learning circle of Kolb (1976, 1984). Such techniques can also be applied in learning from case studies and other forms of ALE. In this way, the students execute higher level cognitive activities of several types.

Cognition includes knowledge, skills, experiences and the information in symbolic form that goes with them. Cognition is the faculty of knowing, including being able to write, read, measure, construct, observe and understand instructions for tasks and information. Cognition is related to material objects, to spoken information and/or written material. That is to say, field oriented—in the sense that it relates to observations of phenomena, human signs and artefacts.

In classical teaching as well as in ALE, concepts, skills, exercises and information are used on a cognitive level. For that, ALE is not needed. Classical teaching is based on the required reproduction of cognitive knowledge, skills, etc. In ALE there is an extra dimension: doing the things that are described yourself, giving meaning to what you do and finding sense in it; asking yourself how and why you do things, and what your motivation is. These aspects include metacognition.

In traditional engineering education, the engineer develops a functional way of thinking, a reduction of reality. By giving meaning yourself to what you do, or by changing the meaning, reductionism is broken through. The objects, products, or concepts, acquire multi-functional elements. The engineers are set free to reconstruct reality, matter and technology. They experience a free constructivism. It is important for engineers to make the real world itself tangible, comprehensible and meaningful, to be able to give it (another) meaning or to perceive reality in a different way and change it. Developing metacognition is a conceptual tool for this.

The difference between metacognition and cognition can be expressed as follows. *Metacognition* can be considered as the faculty of knowing *about* cognition. It includes: knowledge of the structure of knowledge, information or tasks; comprehension of text; knowledge about self or others; self-regulation; the feeling of knowing; the use of reflection, etc. Tasks on a metacognitive level are, for example, to check whether you understand information, or to find the information you need for a cognitive task by yourself. Metacognition is related to observation of your own mental states and processes. Learning goals on this level are therefore difficult to formulate.

2. Metacognitive learning objectives and goals

Metacognition involves "active monitoring and consequent regulation and orchestration" of cognitive processes to achieve cognitive goals (Flavell 1976). Metacognition is oriented on the mental processes that occur with cognition. Therefore, learning objectives on a metacognitive level as formulated by teachers refer to mental states and processes. Since these are very personal and not easily accessible to the teachers, the personal learning goals of the students can differ from the intentions of the teacher. Also, extra learning goals emerge, such as determining your cognitive learning goals yourself and reducing the real world by yourself to attain these goals.

Some examples of cognitive objectives in education are the following. The student must be able: to define the concept of 'function'; to understand the written information about the forces on a bridge; to apply the concept of electrical power to lightning; to calculate the acceleration of an object from given positions and times; or to use a computer, a multimeter, etc. for a specified purpose.

Examples of metacognitive objectives are, for example, being able: to define a newly developed concept; to find structure in some given information; to model reality; to solve real-world problems; to design a new product; or to regulate your learning yourself. Problems related to these objectives lie on the three higher levels of the Bloom's taxonomy of problems: analysis, synthesis and evaluation. Such tasks can be executed in several alternative ways, which give some choice and freedom to the students.

Other such metacognitive developmental objectives are that students are able: to pursue their curiosity with respect to nature, technology, human dynamics and/or society; to find a way to understand a phenomenon that is in conflict with what they learned before; to distinguish between what they already know and what they do not yet know; to develop alternative ways to solve a given problem, compare these and/or choose the best; and to keep the goal in mind during problem-solving.

Such objectives require flexibility of the teachers. There is no one good answer in tasks designed to develop metacognition. It is also more difficult deliberately to design instruction for these objectives. Since there is freedom in learning there is also freedom in teaching. This is reflected in different formats for ALE. Nevertheless, some hints for the design (Dijkstra 1997) of ALE instruction can be got from a comparison of teaching for cognitive objectives and metacognitive ones (Brown *et al.* 1979, Forrest-Pressley *et al.* 1985, Garner 1987, Weinert and Kluwe 1987, Elshout-Mohr 1992, Nelson 1996, Hacker *et al.* 1998).

3. Design rules for ALE instruction

The difference between working for cognitive goals or metacognitive ones will be clarified with the aid of so-called 'educational functions', functions that have to be fulfilled in the processes of teaching and learning by the interaction between the teacher and the student (see table 1). In this view the teacher and the student form a system for the development of the student. The responsibility to fulfil each of these functions can be either the teacher's (teacher-guided learning, facilitation, coaching), or the student's (self-regulated learning), or a co-operative one (e.g. reciprocal teaching).

From table 1 some hints can be derived to help in raising the effectiveness of various formats of ALE, for example:

- Intentionally include cognitive conflicts in the subject matter and the assignments.
- Let the students formulate their own learning objectives within the scope of the course (to be distinguished from the teaching objectives of the course or the curriculum).
- Do not give them all information they ask for without consideration but point out possible sources of the information needed, in the beginning (and check beforehand whether the information really can be found there!).
- Give feedback just before an opportunity to apply this feedback and to improve their next work.
- Do not give the students traditional 'cookbook' labs but let the students compose their own 'cookbook' to carry out an assignment.
- Let the students work together, give them the opportunity to discuss among each other and also with other groups, but require an individual report (and/or log-book) about what they did and learnt.

Educational functions	Implementation for cognitive objectives	Implementation for metacognitive objectives
Motivation	Appreciating the sense and the use of the subject matter	Having the will to solve cognitive conflicts
Setting objectives	Explicit objectives	Open objectives
Support	Just-in-time information	Just-in-time feedback
Executing assignments	Doing what is required	Choosing the best way to do it
Evaluation	Checking what has been done	Checking whether the direction is right
Development	Practising individually	Practising together
Reporting	Co-operative formulation	Individual description

Table 1. The implementation of some educational functions for cognitive and metacognitive teaching objectives.

4. Discussion and conclusion

In learning for cognitive objectives the teacher provides certainty. The teacher or an assistant provides, for example, the information needed. Metacognitive learning objectives involve a higher level of uncertainty (cf. Vos 2001: chapter 3). The student has to be able to handle this uncertainty: acquire the information yourself; get feedback after the use of this information; do not avoid discussions or cognitive conflicts; and practise together but learn individually. These are typical aspects of ALE. So students are trained to accept uncertainty and to keep an open mind; but there are also consequences for teachers.

In classical teaching the learning is teacher-guided and cognitive objectives are learned, since personal cognitive goals usually do not differ much from the curricular cognitive objectives. The metacognitive objectives in ALE involve two varieties. The first one is self-regulated learning for cognitive objectives. Here the metacognitive aspect is the regulation of learning. The other is learning for metacognitive objectives. Both require self-control, to let go of the hand of the teacher.

Having nothing to lean on might be frightening at first for the student, but is also unusual for the teacher. It requires a certain form of controlled letting go from the teacher, a state of trust in the student's abilities, that has to be distinguished from and should not to be confused with throwing the students in at the deep end. This is not an easy process, especially for those who feel themselves more at home in the teacher-guided cognitive domain. ALE requires either special training or a selection of teachers.

The relation between ALE and the development of metacognition is new, challenging, promising and needs further elaboration.

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About the authors

Henk Vos has been working in the Department of Electrical Engineering at the University of Twente, Enschede, the Netherlands, as Assistant Professor in Methodology, and as an Educational Consultant from 1985 until 2001. He was a Staff Trainer at the Gadjah Mada University, Yogyakarta, Indonesia, from 1979 until 1983. From 1973 to 1979 he participated in building up the Physics Department of the Teacher Training College connected to the Free University. He holds a Ph.D. degree in Educational Science from the University of Twente, 2001, and a Ph.D. degree in Physics, from the Free University in Amsterdam, 1972. In 1972 he also received his Teaching License in Physics and Mathematics.

Erik de Graaff (Dr) trained as a psychologist and holds a PhD in social sciences. He is attached to Delft University of Technology in the Netherlands as associate professor in the field of educational innovation. Since 2001 he has headed the faculty development unit of Delft University of Technology at the Faculty of Technology Policy and Management.