Can computer-based systems be adapted to the particular questions and concerns of self-directed learners? According to this paper, the answer is yes. It considers theories on self-directed learning and the use of critiquing systems. Critiquing systems are expert systems with another approach to advice-giving than mainstream expert systems. Instead of initially telling the user what to do, critiquing systems use the student's problem-solving approach as a starting point. This mode of critiquing focuses the analysis of the system around the student's thinking in a very natural and direct way. The paper presents research evidence indicating that the critiquing approach can foster independent problem solving and encourage students to become self-directed, autonomous learners.

INTRODUCTION
Adults spend about 500 hours a year each at major learning efforts, according to research in nine countries (Husen & Postlethwaite 1975, p. 4511). The teachers themselves plan about 75 percent of these highly deliberate learning projects. Therefore, self-directed learning skills are very useful. Acquisition of these skills can begin at an early age.

At schools, the teacher directs the learning process to some extent. At one extreme the teacher has 100 percent control. He or she has total responsibility for choosing the learning goals and planning the strategy for learning. The opposite end of the continuum has been called 100 percent freedom and autonomy. The learner retains full control and turns none of it over to the teacher. For a given teacher, learner, and content, there will be an optimum or ideal range of the continuum. If the teacher and learner stay within this range, the learning will be facilitated more effectively than if they move higher or lower on the continuum (cf. Husen & Postlethwaite 1975, p. 4513). This raises important questions: Will the application of computers into the classroom change the optimum amount of teacher control? Do the computer-based systems offer support which allows the teacher to turn more control over to the students than usual?

Studies on computers and learning show several ways in which one can use computers to encourage students to become self-directed learners. Many current ways of using intelligent systems can be categorised as either delivery or support of learning. In the first class of applications, computers substitute for the human teacher and deliver learning. The teacher turns the control of the learning process over to the students and the computer. In the second class the systems support students when they apply concepts and practise skills, i.e. after they have been taught a subject matter by the human teacher.

This paper deals with the second class of applications. It addresses the question of support of self-directed learners, and it presents a promising way to supply appropriate feedback during independent problem solving.

FEEDBACK GENERATED BY CRITIQUING SYSTEMS
This section explores the premise that critiquing systems can facilitate independent problem solving and encourage students to become self-directed, autonomous learners. The systems are not replacements for human teachers. They support students who have already been taught a subject matter by a teacher. They are means for the students for self-monitoring of their learning after the lessons with the teacher. The section considers two scenarios in which this takes place. The first one deals with the teaching of ideas and concepts, the second one deals with the teaching of skills.

The teaching of ideas and concepts often goes on like this: at first, the teacher presents new ideas and concepts. Then, the students discuss these, and contrast them with alternative ideas and concepts. Finally, they apply them in various ways. The purpose of this is to give the students opportunities to understand the new ideas and concepts. This cannot be done by heart. We have various approaches to ease understanding (cf. Sparkes 1984). One often used strategy is to teach new ideas and concepts in more than one way.

Another basic strategy is to apply the concepts and ideas considered in different contexts. The goal is to put them to practical use in a setting where close, individual attention can be paid to each step. At this stage the students benefit from feedback. The feedback makes them sure that progress is being made in the desired direction. Students' prior understanding usually varies so some of them misunderstand or forget previous presentations and explanations. The feedback is supplied in various ways (cf. Sparkes 1984). The students can receive feedback from question and answer sessions with the teacher, through peer-group discussions, and by use of more or less standardised test procedures.

The students can also receive feedback by a critiquing system. Critiquing systems are expert systems tailored to support students when they need feedback to be able to evaluate and refine their problem solving by showing mistakes, offering suggestions, alternatives, improvements etc.

Expert systems usually contain an explanation capability. This capability allows the advice of the system to be adapted to the particular questions and concerns of the students, using the recommendations of the system as a starting point. There is, however, a much more direct way to adapt the analysis of the computer to the user's thinking. It is to use a different approach to advice-giving: the critiquing approach. Here, instead of initially telling the students what to do, the system asks what approach they are...
contemplating and then criticises that plan. This mode of advice immediately focuses the analysis of the system around the particular concerns of the students (Miller 1984).

The students have a much more active role in comparison with the use of a main stream expert system. They must provide a plan of their own before they can get advice. The advice supplied by the system is a critique of the students' suggestions and hypotheses. The advice can take the form of suggestions of corrections, extensions, critique of the students' perspectives, etc. This feedback, when appropriate, confirms the students' expectancy, directs attention to relevant factors, etc.

Often the feedback from critiquing systems is accompanied by verbal advice from the teacher. The relationship between the two kinds of feedback requires research. Apparently, the two kinds of feedback are supplementary. Teachers almost never offer detailed analysis and explicit diagnosis of students' (mis)understandings (Cox & Cummings 1990) as critiquing systems and other intelligent systems do.

The learning of skills is somewhat different from the acquisition of concepts and ideas. Students do not learn skills by watching the teacher or others doing what has to be learned. Therefore, the teaching of skills consists of two parts. The first part is instruction and demonstration. The second part is practice (cf. Sparkes 1984). The students must have opportunities to practice any new skill to acquire it. During the practice the students need feedback.

There are many ways in which one can monitor the students' steps and give appropriate feedback. Feedback can be given through supervision and through self-checking of skills by use of more or less standardised test procedures.

If students' performance is sufficiently well codified, it can also be tirelessly monitored through critiquing systems. Critiquing systems can provide a non-threatening means to generate feedback. They can help students focus on details performed successfully as well as negative details. Other sources of feedback might tend to concentrate on failures of problem-solving activities.

**CLASSROOM EXPERIENCES WITH THE USE OF A CRITIQUING SYSTEM**

This section presents findings from research now in progress. The research explores the pedagogical potentials of critiquing systems. Therefore, it is called 'The Critiquing Project'. A prototype critiquing system, Vandvid, has been built to be used in environmental education. Vandvid embodies the expertise needed to point out areas with ongoing pollution in streams and rivers. Details of the function of the system can be found in Andresen 1990.

Vandvid helps students in judging the quality of the water and identifying sources of pollution. The problem is to judge whether, and eventually where, the stream or river investigated is polluted. The procedure is the following. First, students go to the stream or river considered and collect data about the quality of the water. This is done at several places. Second, the students analyse this data. Third, they judge about the quality of the water and eventually sources of pollution. Fourth, they use the detailed critiquing system to evaluate their hypotheses about the pollution. Figure 1 illustrates the consultative session.

In the years 1989-91 several hundred students in Danish primary and lower secondary schools have used Vandvid. Findings include that Vandvid has introduced an unprecedented level of autonomy into environmental education. The feedback of the system motivates students to become self-directed learners inside as well outside the structured classroom environment.

The students learn procedural skills. Procedural skills are essential in self-directed learning, according to previous research (Linn & Linn 1991). The study shows that the students acquire abilities to analyse, plan, synthesise, and evaluate. They learn to organise their approach to a problem in a systematic way, to handle important variables involved in the solution and to recognise interrelationships among them.

Previous research show that another important skill of self-directed learning is the ability to gather information (cf. Lieberman & Linn 1991). The study shows that the students learn to retrieve topic knowledge they might lack from sources outside the classroom, and they learn to apply the topic knowledge to the problem-solving task.

The students also learn self-monitoring skills. They learn how to evaluate their progress. The use of the critiquing system is an iterating process. After the first trip to the stream or river considered, the students analyse the data and plan the next step. They plan new measurements to investigate suspected areas of the stream/river in greater detail. This bracketing method can be used as many times as needed. Each time the students go to the stream or river and investigate new places, the average distance between the places decreases. After two or three steps, the students usually have discovered the source of pollution. Between each step,
another element should be added: the students’ ability to formulate and evaluate hypotheses. The learning process requires hypotheses about what is going on in the domain considered. The students formulate a position on the quality of water, the amount and sources of pollution, etc. and receive feedback supplied by other students or the teacher. Last, but not least, they receive feedback from the critiquing system. The ability to formulate guiding hypotheses for one’s own work is an important, sixth element in self-directed learning.

CONCLUSION
This paper considers self-directed learning and critiquing systems. Critiquing systems are expert systems that embody knowledge about a subject matter and about a way to evaluate the students’ problem solving. They augment and do not replace previous channels to expertise. The teacher’s knowledge and skills are still available.

Critiquing systems supply feedback to confirm the students’ expectancy, direct attention to relevant factors, and stimulate recall of ideas, concepts and skills. They assemble the feedback dynamically and tailor it to the particular data and hypothesis of the students. The aim is to elicit the introspective participation of the students showing their mistakes and offering suggestions and improvements.

Feedback generated by a critiquing system is timely. Students use the system at a time where corrective feedback is most valuable.

This paper reports on research evidence showing that a critiquing system provides a non-threatening means to generate feedback and helps students focus on details performed successfully as well as negative details. Other sources of feedback might tend to concentrate on failures of problem-solving activities.

The critiquing can be repeated several times. The students take the critique into consideration, generate new hypotheses until finally, the students end the session and take the proper action.

During this process the students gain topic knowledge and develop procedural skills, self-monitoring skills, and communication skills. They learn by doing.

The important point is that the use of critiquing systems provides an instructional method that places the responsibility for learning on the student.

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