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Improving Student Learning in an Environmental Engineering Program with a Research Study Project*

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The suitability of constructivist teaching strategies was studied in the context of environmental engineering education. The object of this study was a course called Water and Soil Analyses, which is taught to third- and fourth-year environmental engineering students. Using pre-lecture assignments, focusing on peer interaction, having the students take responsibility for making their own research plans, taking advantage of the PDEODE method, doing fieldwork and laboratory analysis, and producing a report and presenting the results in a seminar, were all tools for motivating and engaging students to take responsibility for their learning. In addition, assessment of the course was spread throughout the course, without a traditional exam. When assessing the students' learning it was clear that the learning results were excellent. This includes both subject matter and other skills, such as social, teamwork and communication skills. The students' feedback was also mainly positive. The students found the course laborious and sometimes also difficult, but very rewarding. Taking responsibility for their own learning motivated them to work hard and thus gave excellent learning results. Also, seeing their work in a real-world context improved their engagement and learning. From the lecturer's point of view there is no turning back, even though some work modes need adjustment and focusing.

INTRODUCTION

THE AUTHORS HAVE studied the suitability of contructivist learning theories and teaching strategies when teaching engineering subjects. Researchers studying learning in higher education have established that students develop complex reasoning skills effectively when actively engaged in the material they are studying. Cooperative learning, peer instruction and demonstrations including the PDEODE (Predict—Discuss—Explain—Observe—Discuss—Explain) method or Socratic dialogue are all means to get students more involved in their own learning process [1–7]. Discussion in cooperative groups has been found to promote the use of high-quality cognitive strategies during learning. It has also been documented that oral rehearsal of information increases the use of high-quality learning strategies. Thus understanding and long-term retention can be promoted. Versatile associated skills can also be incorporated into the students' skill set [8–10].

The object of this study was a course on Water and Soil Analyses included in the program of Environmental Engineering at Tampere Polytechnic, Finland [11, 12]. Using pre-lecture assignments [1, 13, 14], focusing on peer interaction and cooperating in small groups [1, 2, 15, 16], having the students take responsibility for making their own research plans, taking advantage of the PDEODE method (Fig. 1) [6 ,7], doing fieldwork and laboratory analysis, and summing up results in a report and presenting them in a seminar [9], were all tools which helped achieve an excellent learning outcome. One essential feature was also spreading the assessment throughout the course and giving up the traditional final exam. This was done in order to get better variability in the issues being assessed and to be able to evaluate the whole learning process. The program of the course was planned on the basis of the needs set by the students' future working life as environmental engineers. Knowledge and practice were integrated.

Most engineering students start their studies without having any preceding work practice relating to their forthcoming studies and future occupations. This makes demands on the education process, as the students need to be provided with practical exercises in order to give them some hooks whereby they can attach their theoretical knowledge. Students often express a wish to have theoretical and practical issues well integrated. There have also been several studies which show that student motivation and commitment is much better after alternating the teaching methods and strategies in this direction [13, 14, 17–19].

In chemistry studies, for example, at advanced

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level, students often have difficulty seeing the connection between real-life applications or situations and the theory [20]. A good understanding of chemistry, and an ability to apply chemical knowledge to practice, demands a command of all three levels of representation: the macroscopic, microscopic and symbolic [21, 22]. Moving from one level to another is not easy for students to do on their own. Chemistry is usually taught at an abstract level, which does not enable the students to see what the symbolic representation means in practice. As a solution to this dilemma, integrating the different subjects [17] and using cooperative and project-based learning approaches [18–21] have achieved good learning results. When students see their work in the real-world context, and when they work in groups and have to be responsible for their achievements, their learning increases, as does their commitment, motivation and engagement with their coursework [9, 17–19, 21].

According to contructivist learning theories, learning is a process of adjusting our mental models to accommodate experiences. The constructivist learning theory assumes that learning is a result of mental construction, construction of knowledge, where learners individually and socially construct meaning as they learn. Constructivists emphasize student-centred approaches, high levels of student engagement and active participation in learning activities. The purpose of these activities is to provide experiences, multiple means for social interaction and the possibility for learners to construct and test their knowledge. The constructivist approach to teaching includes designing a learning environment where students are given the opportunity to become actively involved in their learning process and to apply their knowledge to practice, where students are guided to build their knowledge starting from their own experiences, and are encouraged to observe and discuss and reason in order to attain meaning and understanding. The constructivist approach to teaching encourages students to use higher-order, critical thinking skills, to understand the causes and effects of ideas and actions, and to become fully engaged in their own learning [24–27].

The aim of this research was to study how the applied teaching methods and arrangements based on constructivist learning theories benefit student learning and how these methods and arrangements meet the learning goals set in environmental engineering education. This study is part of an ongoing project in which the aim is to improve learning results in engineering education by pedagogical means.

SUBJECTS AND WORKING MODE

The target of this research was a two-credit unit course (=3 ECTS; approx. 80 hours student work) on Water and Soil Analyses at Tampere Polytechnic and the subject group of this research represented a combination of two separate student groups. The one group included fourth-year environmental management students from an English degree program on Environmental Management and the other group included third-year Chemical Engineering students from a Finnish degree program who had chosen environmental engineering as their major subject. Sixteen students were female and nine were male.

Learning goals

The aim of the course was to acquaint the students with methods of water and soil analysis and to give the students a holistic view of how to master the planning and execution of an environmental study. This included water and soil sampling and physical and chemical methods of water and soil analysis. The course consisted of lectures, field and laboratory work, analyzing research results, making a report on the results and presenting them at a seminar.

The course was compiled so that the first five lectures (3 hours each) dealt with the basic theories of water and soil analysis, how to take water and soil samples and prepare them, how to do the required analysis and how to use the analysis equipment. After having made their research plans and familiarized themselves with all necessary methods in taking and preparing samples and doing analyses, the students moved on to the fieldwork and the laboratory work according to their research plans. Seven lectures (3–4 hours) were reserved for field and lab work. Having completed these stages, the students started reflecting on their results, working on their reports and preparing for their seminar presentations. Table 1 summarizes some of the special features of the studied course and outlines the timetable.

Learning styles and self-directed learning readiness

In order to get students to reflect on their own actions as learners and to guide them towards lifelong learning, a learning styles test and a self-directed learning readiness test were introduced at the first lecture. The Felder-Soloman ILS test [28] on learning styles was chosen and the students were given the opportunity to do the test after class using the website. The aim was to get an idea of students' learning preferences and to assess individual strengths, tendencies and habits that might affect learning. It was also envisaged that students would become more aware of their own preferences and that the lecturer would become aware of the preference profile of the class. Guglielmino's Self-Directive Learning Readiness Scale (SDLRS) [29] was used to show students that personal responsibility and activity play an essential role in igniting a lifelong learning process. In addition, these tests were considered a means of enhancing study motivation. Also the lecturer did the tests. All parties got both collective and personal feedback on their test results. The students were given guidance on how best to plan and

Table 1. Timetable and special features of the teaching arrangements. One lecture is 3×45 minutes

	Teaching and Learning
1st lecture	Motivation and commitment Introducing the lecturer, students and researchers Curriculum Introducing and agreeing on teaching arrangements and methods Discussing goals and assessment Demonstrating and elucidating Working in groups and pairs Tests and questionnaires: Introductory questionnaire, concept test, learning styles and self-directed readiness tests
2nd lecture	Motivation and commitment Feedback on concept test and introductory questionnaire Final setting of mutual goals, rules and responsibilities Final agreement on student assessment Lecturing: Teaching methods and arrangements applied as agreed
3rd–7th lectures	Lecturing: Teaching methods and arrangements applied as agreed Pre-lecture assignments Peer interaction PDEODE method applied Students' research plan Mini-seminar
8th lecture	Fieldwork: Collection of water and soil samples, preserving samples
9th–14th lectures	Laboratory work: Preparing and analyzing water and soil samples
15th lecture	Presenting and discussing results of the research project in the form of seminars Feedback questionnaire

execute their studies so that they would be able to use their full potential. The lecturer got a good insight into the students' preferences and readiness as learners. Understanding and accepting that there are dissimilarities within the student groups is important for all parties when good cooperation and results are pursued.

Concept test

The students were also asked to do a diagnostic concept test during the first lecture. The test was compiled to show the students' level of knowledge in the basic terms and in methods commonly used in environmental analysis of water and soil. In addition the test gave information both for the lecturer and the students themselves about the students' skills in deduction and mathematical calculations of chemical problems. The aim of the test was to motivate the students to revisit topics that they were uncertain about and, in this way, allow them to take responsibility for ensuring that they had sufficient relevant knowledge in order to cope with the challenges of the course. In general the test went well and showed that most of the basic terms had been adopted and were used in a professional manner. The test showed, however, in two of the questions that, on the one hand, the students had understood inadequately two basic terms of chemistry—organic and inorganic—and, on the other hand, that the students were clearly reluctant to try to do simple computational operations without a calculator. The lecturer was inclined to believe that the latter was simply due to unwillingness rather than inability.

Mutual agreements

At the beginning of the course the lecturer introduced the objectives of the course as well as the teaching methods and arrangements she had planned. On this basis the lecturer and students mutually agreed to the responsibilities, rules and timetables. They also mutually compiled and wrote down a description of student assessment and a description of what knowledge and skill requirements are needed both for an excellent grade and for merely passing the course. Student assessment was spread throughout the course and the lecturer evaluated the whole learning process. The evaluation included the pre-lecture assignments, making the research plan and presenting it, the fieldwork and laboratory work, and analyzing, reporting and presenting the results. Some student self-evaluation was also required. The students were individually responsible for completing and handing in their pre-lecture assignments on time, they were responsible as a group for the fieldwork, laboratory work, analyzing and reporting. When presenting the results, everybody had to do their share. The presentation was evaluated as an entity but also on the basis of everybody's individual performance and ability to answer questions asked.

It was decided that the target for the students' study project was a very small lake and its surrounding area. The students were to familiarize themselves with the activities at the lake and its surroundings and, on this basis, to decide what water and soil analyses were relevant when studying the environmental quality of the lake and its surroundings. The students' assignment was to make a realistic research plan that they could execute. There was a road with heavy traffic, a golf course, a pier for washing carpets, a riding school and stables, etc., in the vicinity of the small lake. There had also formerly been a gasoline pumping station, which needed to be taken into account when studying the environmental quality of the lake and its environs.

Pre-lecture assignments and research plans

The time available for lecturing and thus for teaching the theory of water and soil analysis was limited. Pre-lecture assignments were included in the working mode, so that the time available could be used efficiently. The pre-lecture assignments were compiled so that they aided the students in following the instructions and allowed the lecturer to focus on the more difficult topics, without having to deal with all the basics. The use of pre-lecture assignments also made it possible, within the limited time available, to make better use of collaborative working, peer interaction and student–teacher dialog. The pre-lecture assignments required the students to familiarize themselves with the target of the study, the basic analysis methods, and the basic analysis equipment, and to practice some numerical calculations such as diluting solutions. All pre-lecture assignments were handed in and evaluated. This enabled the lecturer to ascertain the students' preconceptions and thus adapt her lectures accordingly.

The first pre-lecture assignment was for the students to get acquainted with their environmental study object and obtain as much information as possible about the lake and its surroundings. Everybody worked individually on the pre-lecture assignments. The students could use any resources available. After this they were to make plans on how to conduct their study, what things were relevant and interesting to analyze and, all in all, what they wanted to find out about the lake and its surroundings' environmental status. The students came to class with this information and knowledge and started working on their research plan. They used the PDEODE [6, 7] working mode, which had been tailored for making a research plan and included individual work phases and group work phases (see Fig. 1). The students first reflected individually on the data they had gathered, with the assistance of the lecturer, and subsequently formed into small groups, typically three persons per group, and continued their discussion. Working in a group was mandatory but the students could form the groups as they saw fit. This did not seem to be a problem for anybody. The power of working in groups, discussing and developing the plan could be seen. After class the groups that were formed continued developing their mutual research plans. The groups worked together throughout the course. The research plans were introduced to the other groups during the lecture a few weeks later. They could learn from each other, get advice from each other and in this way polish up their research plans and make them as good as possible. This working mode had a positive impact on the students' motivation and commitment and they were enthusiastic to get on to the next stage.

PDEODE-worksheet

Course: Water and soil analysis
Topic: Making a research plan

Name:
Date:
Group:

Research idea (individually):

Justification/ Explanation (individually):

Justification/ Explanation (results of group work):

What preliminary studies are necessary (group work)?

Space for drawings and sketches:

Resources for information and references (group work):

Comments & questions:

Fig. 1. PDEODE (Predict—Discuss—Explain—Observe—Discuss—Explain) worksheet for developing a research plan.

RESULTS AND DISCUSSION

The following results are based on questionnaires, tests and observations. The introductory questionnaire asked the students about their motivation, their readiness to work on the course assignments and how much time they planned to use on the course. The feedback questionnaire asked the students to estimate their own contribution and learning during the course, their use of time, their evaluation of the course, grading, and the lecturer's skills, including pedagogical content knowledge and subject matter knowledge, and in addition to give suggestions for improving the course. Also the observations of the lecturer and the authors, both in class and during field and lab work, contributed further information. The authors analyzed the written tests, such as the concept test and the ILS and SDLRS tests, and the lecturer evaluated the pre-lecture assignments, reports and seminars. The students' and the lecturer's self-assessments have also been taken into account.

Pre-lecture assignments

Student feedback on the pre-lecture assignments was very positive. The students considered that the pre-lecture assignments had had a very good impact on their learning. The assignments had made learning easier, as the subjects covered did not come up for the first time in class. The students had been able to do some preparation and this had resulted in better understanding. The students did find the assignments difficult and time-consuming, requiring them to do a lot of work, searching for answers and solutions which were not always obvious or easy to find. This had caused some students some minor frustration, but, nevertheless, they were satisfied with their learning outcome. Most students appreciated that they were, in a positive atmosphere, forced to work hard and that the work had led to excellent results. There were, however, some students, who gave either neutral or slightly critical feedback on matters concerning the pre-lecture assignments. They did not feel that these assignments had had a major influence on their learning and they did not appreciate the work that was included in doing these assignments. They could not see the correlation between the learning results and the pre-lecture assignments. These students, however, were a clear minority, and they were all male students.

The lecturer was somewhat disappointed that the thorough preparation during the lectures, including the pre-lecture assignments, nevertheless resulted in some students experiencing chaos at the beginning of the laboratory-working period. She says this will necessitate some adjustments before the implementation of the next course. These adjustments include substituting a few hours of lecturing time with a tutoring session in the laboratory. This will hopefully enable the students to get a better grip on their work in the lab right from the start and thus the stress and chaos that some students felt at the beginning of the lab work could hopefully be avoided. Some re-focusing in the pre-lecture assignments is also needed. Some of the assignments could be even more purpose-oriented. A still more clear connection between the laboratory instructions and the actual work in the laboratory is needed. The students who were a bit lost at the beginning of the laboratory work did, however, admit that they could have done their own share of the preparatory work better.

Research plans

The students' assignment had been to make a realistic research plan for studying the target lake and its surroundings. They had been enthusiastic about making plans of their own and being able to execute them. After finishing their research project, many of the students said in the feedback questionnaire that they would do some things differently. This we can take as a positive sign of learning. Nobody had experienced any big failures, but some students said that if they were to start again they would make slight adjustments in their plans and analysis. This included being more careful when taking samples, taking triple samples or getting better acquainted with the environment and its specific circumstances.

Students' opinions on the amount of instruction given varied. On the one hand, more instructions were required for planning and writing the research plan. On the other hand, some students felt that planning the study was a good experience, regardless of the fact that no exact instructions were given. The lecturer experienced one big disappointment when reading a couple of students' research plans. The plans showed that not every student had understood the meaning of doing the first phase of their preparations independently and in a responsible manner. The ideas were good, but were marred by plagiarism, which unfortunately was obvious in the plans of two groups. This gave the lecturer reason to discuss these issues again in class and to warn students not to plagiarize information straight from the internet or from each other.

Reports and seminars

Instructions for reporting and presenting results in a seminar had been provided in handouts and to some extent dealt with in class. The students gave many positive comments on having to work on their reports and seminars. They found the work troublesome and laborious but nevertheless challenging and educational. They liked doing their reports. It made them search for information and reflect on their results, including wondering what the results actually signify. It was beneficial to compare their own results to those of others and those found in the literature. Some students had difficulty finding suitable references and making comparisons. However, this process had helped students to internalize things and achieve lasting learning results. Some students commented that they had been able to get a good grasp of a complex situation and that this was learning at its best. In spite of this positive feedback, the study project will probably be split into two separate parts in future courses: water analysis and soil analysis. The reason for this is simply practical; it is difficult to find contaminated soil areas and eutrophicated lakes in the same area. The real-life context and study of a specific entity will still remain. Dividing the project will hopefully help the students digest the large content and thus make it easier for them.

The students found that seminar presentations based on their reports deepened their knowledge and their awareness of how to make a research plan and fulfil it. This working mode helped in analyzing the results and gave a more complete and holistic overview of the subject. Some new points of view were also attained. The students said that the seminars had helped them to understand the subject better and realize what improvements they could make in any future water and soil research project. Both writing their reports and delivering and listening to seminar presentations were seen as beneficial for their future working life. One of the students, though, said that he was so experienced in writing reports and presenting them that this type of approach had not afforded him any benefit.

The students presented their results and analysis of their results in a seminar. Each group gave a 10–15 minute presentation on their results, after which a short discussion was held. The lecturer assessed the seminar presentations. Most groups delivered excellent presentations, although it was obvious that a few of the groups did not have very much experience in giving oral presentations. When assessing the reports it could be seen that some students lacked experience. The fourth-year environmental management students were more prepared and confident in their presentations and their reports were more thorough. They had also put more effort into searching for references in the literature than the third-year environmental engineering students. The students appreciated that their lecturer had given them comprehensive feedback in written form on their learning process, including their reports and seminar presentations.

Learning

When assessing the students' learning, it became clear that they had learned a lot. This included both knowledge of the subject matter and generic skills such as social, teamwork and communication skills. The students learned different ways to take water and soil samples and analyze them for the most common parameters. This included both fieldwork and many different kinds of analyses in the laboratory. For determining the water quality of the lake, the students analyzed it for such parameters as suspended solids, total organic carbon, pH, electrical conductivity; ions such as chloride, nitrate and sulphate, and metals. For soil analysis the students learned how to pretreat and analyze the samples for metal concentrations, they learned the procedure of wet digestion for measuring heavy metals, how to determine dry matter and loss-on-ignition, and how to determine the pH and electrical conductivity. They learned that samples need to be taken in appropriate containers and, depending on the sample and what was to be analyzed, pre-treated in different ways. They learned that some analyses need to be done immediately and that, for some parameters, the sample can be preserved and the analyzing can be done later. The equipment that the students used included pH meters, conductivity meters, an AAS, a total organic carbon analyzer and an ion chromatograph. In fact, it is little wonder that the students felt that the course was useful and that the learning outcome was excellent. This was enhanced by the students' own input and the good atmosphere in the class, which resulted in cooperation amongst students and between students and lecturer. In addition, the students were happy to be able to do this kind of a study project in practice.

In addition to the subject matter, many generic skills and issues were emphasized during the course. These included honesty and critical use of cited literature, planning and keeping a timetable for carrying out the analyses, writing a report and presenting the results orally. The applied mode of working supported the development of various skills, including metacognitive skills and generic skills that are important in the engineering profession. Since the course was advanced and aimed at third- and fourth-year students, some basic teamwork and communication skills had already been acquired during their previous study years. Thus the lecturer was entitled to expect that these basic skills had already to some extent been assimilated by the students. During this process the students' self-confidence (I can; I know) was strengthened, especially those students who obviously lacked confidence in their work but received encouragement when presenting their results.

Grading and evaluation

Figure 2 shows the grades that the students achieved in this course. When the course began there were 25 entries. Five of these, all male students, failed, because they did not follow the mutually agreed rules and did not fulfil the requirement of the independent work phases and thus did not have an adequate amount (60 %) of prelecture assignments handed in. Twenty students completed the course successfully. When comparing the grades with previous equivalent courses, a clear improvement can be seen. The average of grades was now 3.9 out of 5. In two previous courses the averages had been 2.7 and 3.4. The grades were now better, although the number of students was bigger. There were no poor grades (1 and 2). This means that all those students, who finished the course achieved at least grade 'good' (= 3). This result supports such studies in engineering education [13, 14, 30] and on cooperative learning [16], which say that interactive teaching methods and teaching arrangements result in better learning outcomes and are suitable for most students.

In general, the students thought that the course was rather demanding. The authors agree on this point. However, the authors feel that the workload was appropriate, as 80 hours covers a sufficient amount of student work to get a grade in a two-credit-unit course. The average workload that the

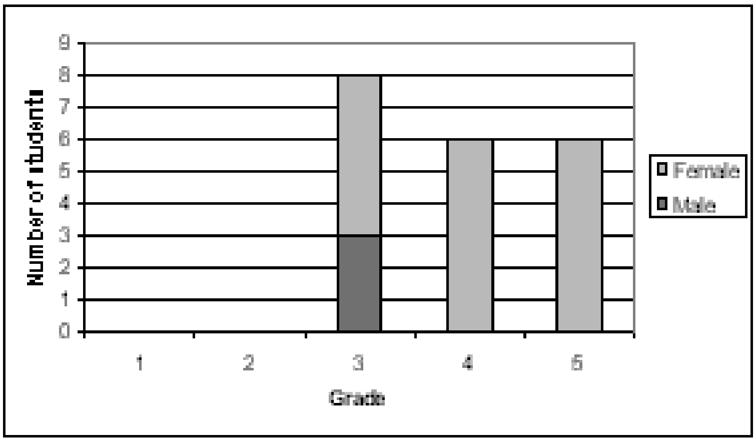

Fig. 2. The grades of the 20 students who finished the course. The grading scale goes from 1 (adequate) to 5 (excellent). Five students failed.

students reported having used was 79.5 hours. The course was demanding because the students had to handle a large amount of material, and their success was up to them. The grading and evaluation of the lecturer was consistent with the students' self-evaluation, with the exception of one group, which thought that the workload was a too great and thus that they should have earned more credits, or at least a better grade. In this case the student group would have given themselves grade 4, while the lecturer gave them grade 3. After a recap of and short discussion on the mutually agreed assessment criteria, they did not oppose the grade they had received.

The most important reasons for these good results were the students' motivation and willingness to work hard from beginning to end. The students had found the course interesting. The average score for motivation in the feedback questionnaire was 4, the scale being from 1 (= very poor/very little) to 5 (= very good/very much). There were slight changes in motivation during the course. Some students were a bit confused at the beginning of the laboratory work, as they were not very experienced in this field of working. This caused, momentarily, a slight decline in their motivation. In general, however, the laboratory work inspired and motivated the students. They enjoyed being able to do things actively and taking responsibility.

The lecturer felt that grading which included the whole learning process was more difficult than before. Formerly, 50% of the grade was based on the report and 50% on a written exam. The previous grading was primarily simple mathematics and calculation of given points on exam answers. This new, more holistic, way of grading required more work and was more demanding, being based on so many different parameters. In addition, planning the course and pre-lecture assignments took approximately three times more time and effort in advance than carrying out the course in the conventional way. This time, however, is saved in subsequent courses, since the basic work has been done and the working mode and content simply needs some adjustments. All in all, learning was better than before and thus the results were better and the grades were higher. The students were satisfied with the way their knowledge and skills was assessed. They did not see any major discrepancies or criticize the applied mode of assessment. It is, however, safe to say that the good students get the best grades no matter how the mode of assessment is constructed.

CONCLUSIONS

The students identified several reasons for the good motivation that helped them to achieve their excellent learning results. They felt that the course was useful for their future work and they were able to influence the content of the course. They had the feeling that everything had been planned carefully and that their learning was important to all parties. Also, they could experience the success of learning, which improved their self-confidence. The authors felt that the working mode was such that the students' initial knowledge was taken into account but also that the students were forced to provide themselves with sufficient relevant knowledge when doing the pre-lecture assignments, so that group work could be successful. In this way equality could be very profitable and the students' theoretical knowledge could be taken advantage of. Thus far better results could be achieved in group work.

The mutually made agreements on rules, mutually compiled criteria for assessment and the possibility of influencing the course content no doubt increased the students' commitment and their active role in studying. They were attentive and far more active than ever before. They took responsibility for their own learning as well as their peers' learning. It took some time for a few students to realize that they should be using their own initiative. They did not necessarily like it, but, after getting tired of waiting for the lecturer's instructions or being dissatisfied with the advice they got, they eventually started to find out things for themselves. This process builds self-confidence. Taking responsibility was extended to all the work they did in this course. Figure 3 shows, on the basis of five questions in the feedback questionnaire,

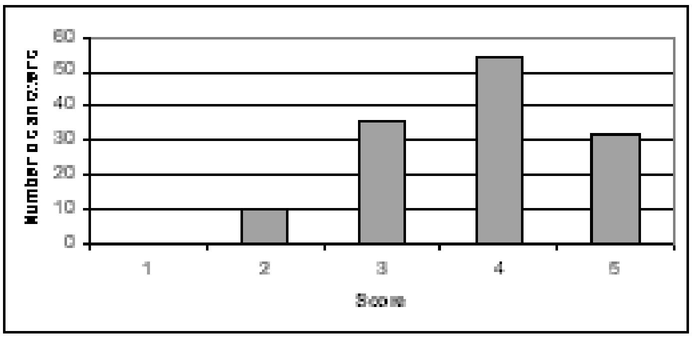

Fig. 3. Students' active role as they assessed it in the feedback questionnaire. The scale goes from 1 (= very poor/very little) to 5 (= very good/very much).

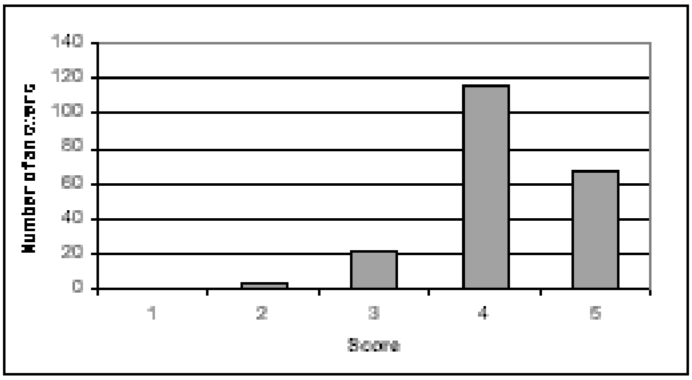

Fig. 4. The evaluation of the lecturer's pedagogical content knowledge made by 19 students at the end of the course at their last meeting. The scale goes from 1 (= very poor/very little) to 5 (= very good/very much).

how students assessed their own activity. This assessment is very much in line with the general observations of the lecturer and the authors and with the actual activity that could be seen in the pre-lecture assignments that were handed in.

The importance of good planning and a clear start cannot be overestimated. Here the lecturer is the key person. In this case the lecturer's professional skills and enthusiasm influenced the students. This could clearly be seen in the students' evaluation when they assessed the lecturer's subject matter knowledge and pedagogical skills, and her ability to make a realistic curriculum and choose suitable and efficient teaching methods and arrangements. The scores of altogether eleven questions in the feedback questionnaire are summarized and presented in Fig. 4. One of the most important lessons learned during this course was that the rules and agreements concerning the work format, grading and evaluation must be unambiguous, clear and in a written form. When these are done carefully in advance, the lecturer can carry out the course as planned and agreed, thus reducing the lecturer's workload during the course and increasing students' commitment and motivation.

On the basis of the good learning results in terms of subject matter and the positive feeling of success, on which all parties agree, we can clearly see that the students had learned a lot by making their own research plan and executing it. With cooperative working the students were able to get a more holistic picture of their study project. The lecturer said that there will be no going back to old habits. To some extent, everybody did more work than usual, but it was rewarding for all parties and they are certainly kean to continue in this way. Some things need re-thinking, reforming and focusing. It seems that the connection between theory lessons, pre-lecture assignments and laboratory assignments needs to improve. The results are, however, encouraging and the lecturer has now introduced this approach into three other laboratory courses.

On the basis of the students' self-evaluations we learned that for many students this was an opportunity to overcome a fear or dislike of everything related to chemistry. This, the lecturer felt, was a big victory. Working in the laboratory was seen as both fun and educational. Seeing the connection between their earlier theoretical chemical studies and real-life situations, and applying their knowledge to a real study on water and soil chemistry motivated the students to work. This could be seen in many of the reports, where a significant amount of student work went into independent searching of the literature and comparing results with previous studies. This is in accordance with earlier findings which found that introducing the real-world context into chemistry studies improves learning and increases engagement with the subject [17–19, 31]. This connection also seemed to remove dislike of chemistry among some of the students of the fourth-year environmental management group.

John Dewey, a pragmatist, views humans as naturally active and curious. He based his theory of education on experiential learning and the principle that 'all genuine learning comes about from experience'. New situations stimulate expectations and hypotheses based on earlier experiences in the learners' minds, which they then test. On the basis of their own actions and reflection, learners reconstruct their own impressions and ideas. This reconstruction process is the core of learning [32]. Dewey's ideas on methods of education transfer well to science and engineering education. It is not just important that we give our students the opportunity to experience, but students should also be supported in developing their understanding. Developing understanding requires that students have opportunities to articulate their ideas, to test those ideas through experimentation and conversation, and to consider connections between the phenomena that they are examining and other aspects of their lives.

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