Assessing progression in engineering study programs

Anders Ahlberg
Academic Development
Faculty of Engineering (LTH)
Lund University, P.O. Box 118,
SE22100 Lund, Sweden
+46 46 2220000
anders.ahlberg@genombrottet.lth.se

Marie Wahlgren
Food Technology
Faculty of Engineering (LTH)
Lund University, P.O. Box 124,
22100 Lund, Sweden
+46 46 2220000
marie.wahlgren@food.lth.se

ABSTRACT

Swedish engineering education is organised as study programs consisting of intertwined chains of course units. Formal program objectives integrate skills, scientific attitudes and engineering knowledge. However, assessment of learning and educational quality typically focuses outcomes of individual course modules. It is our concern that study programme quality and student progression are hard to evaluate and stimulate in the prevailing modularised system. We have therefore investigated programme objectives and student progression and subsequently designed activities to evaluate and stimulate integrated engineering capacities and evaluate progression among freshmen and more senior students of chemical- and biotechnology engineering programmes. To make the aim of progression explicit we first interviewed students, alumni, teaching staff and senior industrial staff (engineer employers), thus elucidating core educational and professional values. Interviews indicate that students typically develop a sense of "becoming engineers" rather late in their training (6th semester). All interviewees emphasized problem-solving abilities as the most desirable competence. However, teaching staff focussed more on subject discipline content whereas students and industry employers go beyond subject discipline and request professional social skills. A real-world case was used to monitor (and stimulate) engineering programme progression in 1st and 3rd year student groups by means of qualitative assessment of engineering skills including critical problem-solving skills, appropriate use of technical and scientific language, knowledge of chemistry, biochemistry and engineering, statistical reasoning, team work behaviour, business-mindedness, delimitation of professional role, risk management, and work ethics. The student teams of both groups did well and solved the main aspects of the case although the senior student teams managed to do it on a more complex level. There were other clearly detectable aspects of progression among the 3rd years students, for instance problem solving strategies, team work behaviour, and independent use of available presentation materials. We conclude that observed case sessions can (1) be used confidently to assess progression of learning in engineering study programs (2) reveal students' abilities to combine knowledge from different fields and courses, and (3) demonstrate weaknesses in the progression. The method is however probably too complex to allow valid cross-institutional comparisons.

Keywords

Engineering, curriculum building, progress testing, learning progression, case methodology

1. INTRODUCTION

1.1 Background to our study

In line with the European Qualifications Framework, there is a political interest in Sweden to focus quality assurance of higher education on student learning outcomes. This is manifested in the new instruction for quality evaluation described by the Swedish National Agency for Higher Education [1]. Although this is legitimate and relevant, there is also a need for ways to assess entire study programs, curriculum building and assessment of student progression. In this paper we describe our work concerning student progression analysis in two engineering programs at Lund University; Chemical Engineering and Biotechnology (Figure 1). Three principal activities have been used in the overall project. Firstly, a comparison between course unit objectives and overall study program objectives (previously reported in in an interim report). Secondly (reported herein), focus group interviews with involved stakeholders to further assess the core objectives of the study programs, and views on student progression and how to monitor it. Thirdly (reported herein), we have developed and tried a qualitative method to assess complex professional abilities at different stages of the study programs.

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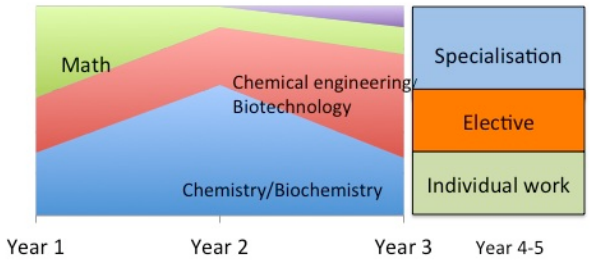

Figure 1. Study program scheme.

1.2 Quality assessment strategies

Swedish engineering education is organised as programs consisting of intertwined chains of course units. Formal study program objectives integrate skills, scientific attitudes and engineering knowledge. However, assessment of learning and educational quality mainly focuses outcomes of individual course units. It is in fact not allowed to assess curriculum beyond individual course modules in the Swedish system. It is our concern that study program quality and student progression are hard to evaluate and stimulate in the prevailing modularised system. We have therefore investigated progression and activities that could evaluate and stimulate integrated engineering capacities and evaluate progression among freshmen and more experienced students of Chemical and Biotechnology engineering programs at Lund University.

Quality assurance commonly serves multiple needs as it informs future students as well as detailed educational planning and resource allocation. It can also be deliberately designed for quality enhancement [2]. At our faculty (LTH) course modules are analysed and used for educational planning (annual course reports and the Course Experience Questionnaire evaluation system), e.g. the parts that form study programs. However there are currently few attempts to monitor student progression and overall study program qualities. Where such activities are in place they typically monitor curriculum (for example CDIO [3, 4], *core curriculum* [5] , or fulfilment of formal course objectives and learning outcomes such as the current focus on masters theses by the Swedish National Agency for Higher Education (HSV [6]).

Internationally, primarily in medicine education programs (recently also in Sweden), there are implemented ways to gauge student progression. In these instances annual *progress tests* are used [7-9], e.g., large sets of competence questions (knowledge items) repeatedly monitored at different stages of the study program that monitor progression and stimulate progression through individual student meta-cognition. Students thus experience, ideally, that they do fewer mistakes in these tests over time.

The curriculum monitoring strategy (CDIO) can expose discrepancies between overall goals of the program and the sum of goals in the course units of the study programs. However, the passing of a particular obligatory course unit does not guarantee that the expected quality of student learning has occurred. The benefit with the learning outcome strategy is that it focuses learning results. The problem here is that it is difficult to measure complex interdisciplinary and tacitly expressed knowledge and skills. A particular strength of item-based progress testing is the validity, e.g., the possibility to compare learning progression different schools of medicine. Again, this approach does probably not assess complex engineering capacities and is probably easier to adopt in professional training programmes with uniformly decided learning outcomes. We have therefore designed, and herein described, a more qualitative version of progress testing based on observations of student teams performances in case-based problem-solving situations.

2. METHODS AND INFORMANTS

In order to monitor students, industry employers and university teachers' views on study program objectives (e.g., views on aim of progression) and student learning progression we used semi-structured interviews [10] with a loose framework of questions. One randomly recruited student group from each of the two investigated study program and one group of mixed student representatives from both programs were recruited (totally 25 students; ca. 7% of all enrolled students. The three focus groups were interviewed and tape-recorded, and the tapes were subsequently transcribed. Two groups of teaching staff (totally 7 academics) were interviewed and recorded in a similar way, as well as two small groups of totally five relevant industry employers. Recent alumni, graduated from the investigated study programs within the past two years, are currently being interviewed individually via telephone (tape-recording replaced by note taking to optimize interview openness and informant integrity).

As complex problem solving is the very core of all interviewed stakeholders views of the aim of the study programs, we designed and tried progress tests using case methodology [11], with designated specialist observers of student groups action and interaction (rather than individually testing a vast range of professional knowledge items as is reported from progress testing in medical education [7-9]). The professional engineering capabilities of two student groups, 1st and 3rd year students, were monitored qualitatively, using a multi-stage near-real-life case designed to test

- Approaches to industrial problem solving
- Appropriate use of technical and scientific language
- Knowledge of chemistry, biochemistry and engineering
- Statistical reasoning
- A sense of economic consequences of ones actions
- Group behaviour, including project documentation
- Views on the professional engineering role in relation to other interacting professionals, companies and society (ethics & risk).

After a trial case lacking in engineering complexity we designed a new case that worked better (Figure 2), guided by the Leenders et al. [11] Case Difficulty Cube (Figure 3). Accordingly, we designed a case that is relatively simple in terms of the presentation material (limited info added at each of the four stages of the case) and analytical dimension (questions more or less openly provided), but advanced in terms of conceptual complexity (chemically and technically and professionally). Each case assessment sessions lasted for approximately two hours. The realistic case was set in the pharmaceutical industry and the students were given a role typical for newly graduated engineers. The emerging problem was presented as a report where one out of ten analytical tests on a

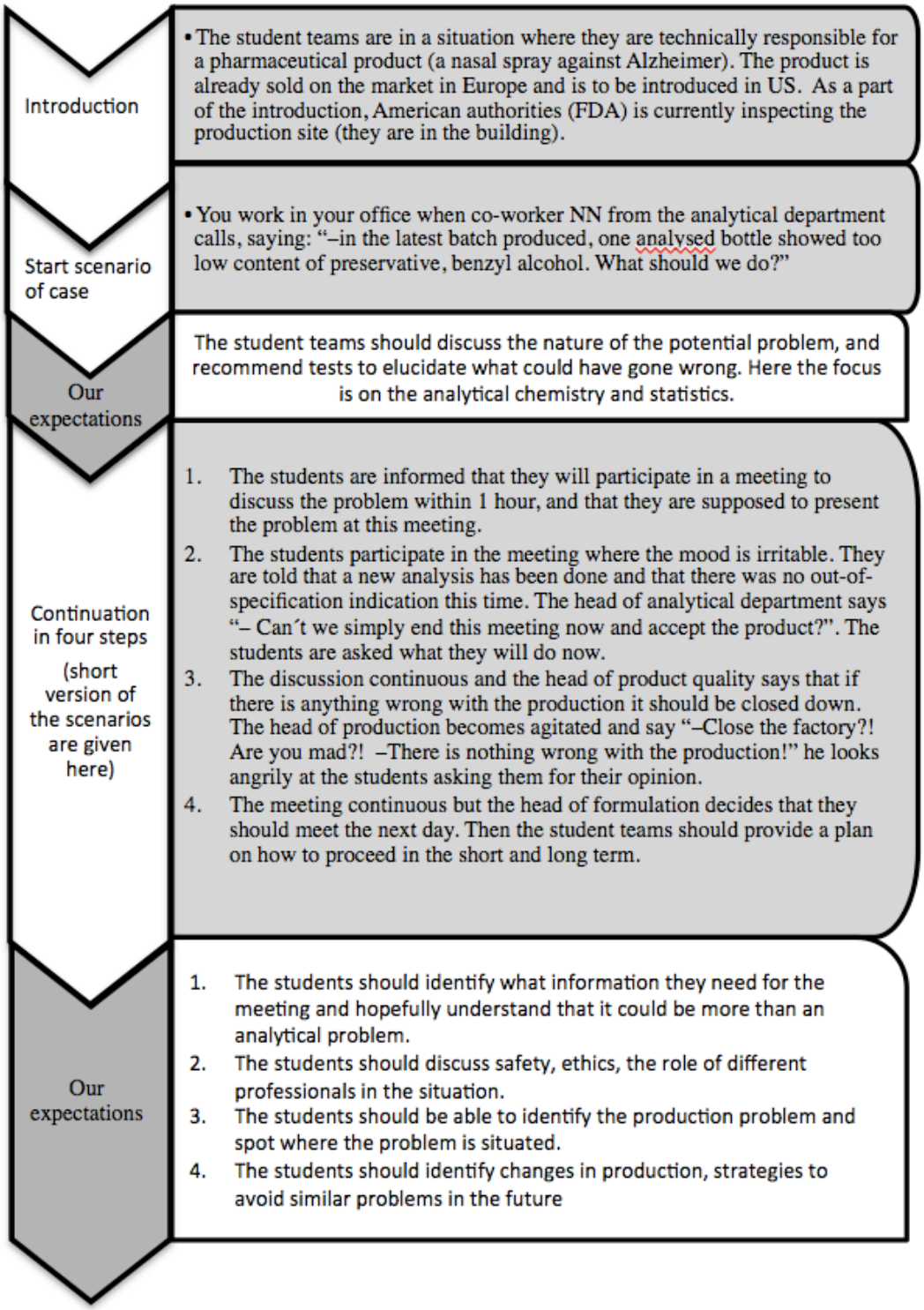

Figure 2. Outline of the case used to observe 1st and 3rd year student teams in problem-solving situations.

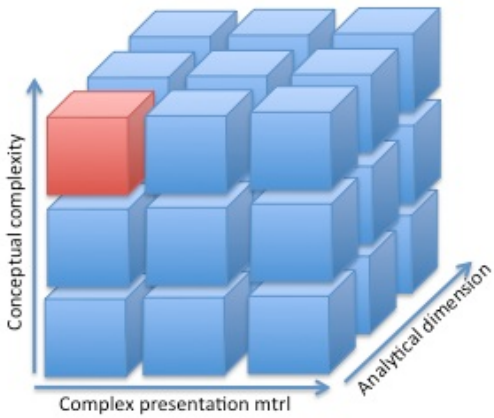

Figure 3. Our case design placed (red cube) in the Case Difficulty Cube of Leenders et al. [11].

produced batch of a new pharmaceutical product was out-of-specification for the product. Extra stress was inserted as the company was under investigation by legislative authorities. Key aspects to discern included the strategy of sampling, to exclude various faults in the production, to identify where and when in the production the error might have occurred, and the moral stamina to suggest that a production batch worth €10^5 should be discarded (Figure 2).

The 1st year students (20 students split into four working teams) and 3rd year students (8 students split into two teams) where tested on separate occasions. The students where observed by the case leader (program director, author MW) an independent observer (an academic developer, author AA), additional teachers from the study two programs and an alumni student. The students' conversations were monitored and the key discussion points (see above) were noted, compared and concluded by the observers.

3. RESULT AND DISCUSSION

To frame the core direction of progression, and views on progress test design, semi-structured interview were conducted with groups of 6-8 3rd-4th year students from each of the two study programs as well as teachers and middle management from chemical and pharmaceutical companies. Questions revolved around expectations of the professional engineering role and competences and views on future progress test focus. All citations below are translated from Swedish.

3.1.1 Expectations of the professional engineering role

Students from both investigated programmes consider problem solving abilities as the most prominent engineering asset, e.g.; *"to solve problems that emerge at work; to form new questions, to contribute with widely usable disciplinary width; clear presentation of results; deliver on time"* (4th year student of Chemical Engineering).

Whereas the discussion of the chemical engineering students remained within the technical realm, the biotechnology students widened their expectations to include project management and leadership. Both groups agreed (but were not particularly worried by) the fact that they internalise the "becoming an engineer perspective" rather late, in the 6th semester of studies. Prior to this the "coping of next course unit" remained in the foreground (overall study tempo is high and students attend parallel courses throughout the study programs). The interviewed students claimed that the maturity and confidence to solve complex problems emanates from working with open-ended projects in project-based courses, with no obvious correct answer. However, they didn´t think this was possible in the early part of their training due to lack of basic knowledge. Two interviewed students commented their gradually emerging engineer identity:

"For my part in the third and forth year, when you have more independent work and projects. Then you work in a complete different way. Before that, you read a lot of math. You are supposed to do a certain number of exercises, not at all project oriented"

"I think its good that one starts with more strict courses in the beginning with problems that has a wright answer. That is what you are used to so far, it is good with a slow transition to a more engineering-minded approach to problems like we have now in the third year where the answers are less exact and you can get different answers depending on how you approach the problem"

We conclude that the students seems to have a pronounced tolerance for the traditional teaching in their first years in the study programs, and that the open-ended problems play a considerable role in their maturation and confidence building when it comes to their view of them selves as professionals.

Teachers and middle management share the students' focus on problem solving as the key aspect of an engineering education. However, the teachers are much more focussed on disciplinary content (molecular understanding is in the foreground for some of the teachers while chemical engineering, masse balances and energy estimations were in the foreground for others). The teachers also showed considerable concerns around the students' ability to do laboratory work, progression in writing and capacity to evaluate scientific literature. Ironically, middle management in chemical and pharmaceutical industry observed improvements the past few years in newly employed chemical engineers ability to write technical reports. The teachers believe the students´ pronounced focus on problem-solving is a consequence of project oriented teaching design in the latter part of their training, and agree with students that this late maturation cannot be achieved in earlier semesters of the study programmes; *"They need the tools first"*. Students from newer, smaller study programmes have, according to teachers, a more developed meta-perspective on their educational journey at university.

The industry middle management informants agreed on a set of attractive capabilities and inclinations that they seek in their recruitment processes:

- Business-mindedness
- Realistic expectations on the first job
- Willingness to stay in the company for some time
- Added complementary competence (to the group)
- Project management capacities
- Professional social skills

In addition, there is a preconceived notion in this group that engineering knowledge of newly graduated engineering students meet the demands for jobs offered. Some industrial representatives identified a lack in self-confidence among Swedish students, in comparison to their non-Swedish employees. They also expressed an expectation to understand production and industrial issues. Some stressed the ability to sort and prioritise information. In general our informants were pleased with engineering education at Lund University.

It is gratifying that all three groups interviewed share the view on what is important in these engineering programs. It is also interesting to note that industry representatives and students express more similar views, than the academics, both focusing on more general skills than on specific areas of knowledge.

Partly, as a consequence of the obvious importance of projects shown in these interviews a stronger focus on project work and open-ended problems has been adopted into the curriculum of the programmes.

3.1.2 Informants' opinions on progress testing

Both students and teachers were positive to the concept of progress testing. However both groups had considerable problems to suggest good progress test questions (items).

Both student groups preferred any future progress tests to revolve around problem-solving strategies rather than detailed knowledge, and claimed that both work process and work result/product have to be included in the task. Suggestion for questions from the students where for example

"*–A scenario where a manager (who is not an engineer) tells you to do something you know is wrong how can you as a newly employed stand by your conclusion and show what they know and show that we should do like this instead*"

"*–You are manager for a process and something goes wrong in your process; what should you do?*"

The teachers saw progress testing as something positive, especially if these tests could strengthen student self-efficacy and show that they actually learned something during their education. The teachers also thought that the progress tests should enforce the students to think on their own. They did not want the question to be to specific and their suggestions were test questions that would need rather long answers that contained a discussion although their suggestion of questions were more specific than the students for example

"*–Describe the difference between a biofuel and fossil fuel or why should a molecule used for a drug not be to nonpolar!*"

Although there were an interest and a positive attitude towards progress tests, both in the student and the teacher group, traditional multiple-choice questions would not be suitable. Especially the students argued for more problem based questions that would take longer time to solve. Their suggestions for questions also had a striking resemblance to scenarios used in case teaching. Due to the interviews we abandoned the idea of traditional progress tests and decided to try to use observed case teaching to monitor student group progression.

3.2 Qualitative assessment of study program progression using case methodology

The 1st and 3rd year student teams were subject to the same multistage case in separate sessions. They all participated enthusiastically, and both groups analysed and suggested appropriate solutions regarding the critical aspects of the provided set of emerging industrial and professional problems. The case observers did however note a range of differences (representing progression) between the performance of the freshmen and the more experienced students:

Strategies used to address the problem: The 1st year students did not spontaneously use the available info handout on the case background to any large extent. Instead they quickly asked the case leader numerous questions and quickly got a superficial understanding of the problem. The 3rd year students initially read through the material, and subsequently asked a few questions to the case leader. They discussed details in the case with each other and it took them longer time to get into the problem. However, they did it on a deeper conceptual level compared to the freshmen. Some 3rd year students had however a tendency to get overly focused on details. This difference may be due to that the 3rd year students are more confident in their ability to understand the material, while 1st year students lack of professional confidence turns to the case leader as a strategy to faster understand the problem. It has been observed in PBL that students need some degree of structure either based internally due to prior knowledge or by a very structured material to attack the problem on their own [12]. If not, they sought help and direction from their tutors. It is likely that we see the same reaction here and that it is this lack of internal or external provided structure that causes the first year students to ask more questions.

Professional language: The 1st year students largely lack amounts technical terminology while the 3rd year students have a developed understanding of technical terminology. On the other hand both student groups have a developed language when it comes to fundamental chemistry and they all understood chemical formulas. This is not surprising since the study programs have their bulk of chemical engineering courses in the second and third year while the students have some of the key basic chemistry courses in the beginning of the first year. Furthermore, high school may already have provided some students parts of the necessary chemistry background.

Knowledge and use of statistics: The 1st year students quickly understood that the number of analytical tests was too low but did not have a terminology to discuss the results further. The 3rd year students discussed the analytical result using both statistical tools and tools used in analytical chemistry. However it took them longer to come to the conclusion that the sample is not representative for the whole production. They also showed a tendency to discuss statistical questions of limited relevance to the problem at hand, and were more frustrated by the fact that the

whole production batch has to be discarded due to the analytical fault (trying to find ways around it).

Knowledge in chemistry: Both student groups showed good conceptions of chemistry, discussing chemical degradation etc. However, some introduced concepts were unknown to the 1st year students. The 3rd year students discussed, with a higher degree of confidence, issues concerning analytical chemistry but did not discuss organic chemistry as much as the 1st year students did. This probably reflect that the 1st year students are currently studying organic chemistry while the third year students have taken analytical chemistry in the beginning of the fifth semester.

Knowledge in chemical engineering: The student groups differed considerably in their understanding in chemical engineering. The 1st year students did not recognise several of the concepts related to chemical engineering. However due to the use of general deduction they could still solve the overall technical issues, for example, where in the production process the error occur. The 3rd year students showed an excellent understanding of chemical engineering as well as aspects of analytical chemistry. They did identify problems of the industrial process and spontaneously discussed what they think are construction flaws. However, the process to identify *where* in the industrial process line the main error is situated took longer time for these students, mainly because they discussed the process in deeper detail than the 1st year students.

Ability to integrate knowledge: Both student groups showed appropriate abilities to integrate their previous knowledge with aspects of the case problem, although the 1st year students' used a substantial degree of common sense to solve the identified problems. Both groups showed abilities to suggest reasonable strategies to investigate the production problems. The 3rd year students showed more developed abilities and tendencies to suggest future improvements of the industrial process.

Group dynamics: The group dynamics were quite different between the 1st and 3rd year case sessions. The 3rd year students seemed to discuss more with each other, being less influenced by dominant person in their team. However, there were group size differences, and we are therefore not sure if the observed difference in behaviour representing cohort differences, progression in teamwork abilities.

View on professional role: The teams of the two main groups enthusiastically adopted the intended professional role in the case sessions. They were clearly able to distinguish and relate their own role from other agents.

Ethics and business-mindedness: Both groups showed solidarity with their inferred employer, worrying about economic loss as well as goodwill as flawed medical products reached the market. Surprisingly little discussion was aimed at the risks for third party (patients, society) although some general comments and questions around these issues were raised.

In general the observers were impressed by the ability of the 1st year students to quickly solve the situation and discuss it with a notable degree of scientific maturity. However it was also obvious that the case showed that the third year students had the ability to address the problem at a more advanced level.

3.3 Discussion

Our conclusion is that case observations

- can be used to assess progression of learning in engineering study programs
- can reveal students' abilities to combine knowledge from different fields , courses and experiences.
- can demonstrate weaknesses in progression (for example the insufficient ethical discussions in our study).

We further believe that recurring case teaching can be used to make students integrate knowledge from different courses of study programs, and that it can be used to integrate engineering studies with the engineering profession.

In comparison with item-based multiple-choice progress tests, our observed case sessions have some advantages. Case sessions enforce integration of knowledge and make some tacit professional skills more explicit, and students appreciate the training for future carriers. Observations are however time and resource consuming, and there is a risk that assessment is affected by the observers' preconceived views of the subject discipline. It is therefore important for observers to cross-compare and discus observations. Although our test design seem to work well for internal progression control in related study programs, there is probably a low degree of validity if one would attempt cross-institutional comparisons using observed case sessions.

The described sessions were our first attempts with observed case teaching for observation of student progression and we see several ways to improve our method. Although freedom of observation has benefits, stricter instructions to the observers could be useful. In our case the observations of an alumni student was especially helpful when it came to issues that had not been pre-considered during construction of the case. Further, the amount of presentation material available to the students where in our case perhaps too limited. It was therefore rather easy for students to both handle the material and identify the problem at hand. A case with more elaborate study material and a higher degree of disciplinary complexity could probably challenge the ability to handle and structure information better. However, the necessary session time would have to be extended.

We also consider limiting the availability of case leader supervision, so that the students have to consider the problem on their own. The drawback is that the amount of questions asked and the type of questions asked can be helpful in the observation of the student progression. Furthermore limiting the amount of question could make it more difficult for the same case to be used on several different student groups where some have limited background knowledge.

The case we used for observations could according to the Case Difficulty Cube Dimensions of Leenders et al. [11] be regarded intermediate to high in terms of disciplinary and professional complexity, simple to intermediate in terms of the analytical dimension (questions rather obvious), and simple in terms of presentation (a lean limited presentation material), see Figure 3. This choice of case difficulty suited us this first time to make observations comprehensible, but can of course be re-negotiated. It is of course possible to hand out a less adapted, more

voluminous "messy" presentation material, and to allow the teams to find and formulate their own questions to a larger degree. This would however require considerably longer observation sessions. We believe, based on our less successful trial case, disciplinary complexity should be high, to allow a range of learner qualities to observe. The ability to handle disciplinary complexity differed between freshmen and experienced students, as our 1st year students did not have the capacity to go in detail the way the third year students did. However, they could still "solve" the problem, on a more superficial level.

3.4 Further outcomes

As a part of this project we have decided to introduce case teaching as a way to introduce new freshmen to the study programs and the role as engineers. Cases that are "consumed" in progress tests will thus be re-used with novice students, under the supervision of us together with 3rd and 4th year students.

Further, the interview outcomes and the formal investigation of course objectives have lead to a mandatory longer project course (10 weeks) as a part of the master level of the investigated study programs. This course will include theory on group dynamics and theory for project management as well as practical project work.

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5. REFERENCES

[1] M. S. Magnus Hjort, "Högskoleverkets system för kvalitetsutvärdering 2011–2014," Swedish National Agency for Higher Education2010.

[2] S. M. Dinham and L. M. Evans, "The Unique Opportunities and Vexing Challenges of Undergraduate Program Assessment in Professional Fields.," in *Annual Meeting of the American Educational Research Association (San Francisco, CA, March 27-31, 1989)*, 1989.

[3] J. Malmqvist, K. Edström, S. Gunnarsson, and S. Östlund, "Use Of CDIO Standards in Swedish National Evaluation of Engineering Educational Programs " in *1st Annual CDIO Conference Queen's University Kingston, Ontario, Canada June 7 to 8, 2005.*

[4] J. Bankel, K.-F. Berggren, E. Crawley, M. Engström, K. El Gaidi, S. Östlund, D. Soderholm, and I. Wiklund, "Benchmarking Engineering Curricula with the CDIO Syllabus," *The International Journal of Engineering Education,* vol. 21, pp. 121-133, 2005.

[5] J. E. Gillett, "Chemical Engineering Education in the Next Century," *Chemical Engineering & Technology - CET,* vol. 24, pp. 561-570, 2001.

[6] Högskoleverket, "Kvalitetsutvärderingför lärande Högskoleverkets förslag till nya kvalitets- utvärderingar för högskoleutbildningar," 2008.

[7] A. Muijtjens, L. Schuwirth, J. Cohen-Schotanus, and C. van der Vleuten, "Differences in knowledge development exposed by multi-curricular progress test data. ," *Adv in health Sci Ed. ,* vol. 13, pp. 593-605, 2008.

[8] C. P. M. van der Vleuten, "Fifteen Years of Experience with Progress Testing in a Problem-Based Learning Curriculum. ," *Medical Teacher,* vol. 18, pp. 103–109, 1996.

[9] A. M. M. Muijtjens, L. W. T. Schuwirth, J. Cohen-Schotanus, and C. P. M. Vleuten, "Differences in knowledge development exposed by multi-curricular progress test data," *Advances in Health Sciences Education,* vol. 13, pp. 593-605, 2007.

[10] M. Bloor, J. Frankland, M. Thomas and K. Robson, "Focus Groups in Social Research" Sage Publications, London, 110pp.

[11] M. Leenders, Mauffette-Leenders, and J. Erskine, *Writing Cases*, 4th ed.: Ivey Publishing, Ontario, Canada, 2010.

[12] H. G. Schmidt, "Resolving Inconsistences in tutor expertise research: Does lack of structure cause students to seek tutor guidance," *Accademic Medicine,* vol. 69, pp. 656-662, 1994.