Paper ID #23641

Work in Progress: Projects in Engineering Education – Cross-fertilization Between Communication and Situated Learning

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Introduction

Engineering education has been regularly reformed a number of times the last decades [1], and continues to develop. Along this track the role of the engineer has also developed. As Cohen and colleagues [2] describe it, the development has *"... sought to enlarge the core identity of the engineer from a technician skilled at calculation and fabrication to a professional member of the wider culture"*. This is probably true now more than ever, as we face global challenges of climate change, large migration streams and an overall focus on economic, social and ecological sustainable development. The engineer's role in society has been emphasized the last decades as expressed by e.g. National Academy of Engineering's *Engineer of 2020* [3], and new quite "non-engineering" skills and competencies have been showed to be crucial for engineers to become employed [4].

Today, most engineering communities agree that communication is of utmost importance, both as an integrated part of the engineering education and as a necessary competence in work life. How to best achieve this competence, however, is still an open question. In this paper the authors focus on written communication, and illustrate writing not only as a professional skill but also as a cognitive process that can fertilize situated learning in project-based courses. This approach is applied in two such courses given at several five-year integrated Master's programs at Linköping University in Sweden. The first course, Engineering thermodynamics, is given for first or second year students at several programs. The second course is a Bachelor's (cap-stone) project course given at the end of the third year. There are substantial differences between the courses in terms of e.g. learning objectives, project extent and in the students prior writing experience. However, an imperative cornerstone of the pedagogical approach is shared, namely the importance of designing the courses/projects in such a way that the students are very much in charge of their work. The students are free within the project boundary to decide what should be done, how it should be done (e.g. what methods should be used), and when the different project tasks should be carried out. They are continually being supervised and coached by both engineering and communication faculty, but in such a way that the students always are in charge of their project and drives it forward in accordance with one of the key components of the situated learning model [5]. The underlaying idea is to promote a dynamic learning environment based on a social constructionist view of knowledge and how it is acquired, and thereby to facilitate an active and situated learning.

The two aims of this "work in progress" are to investigate: 1. How students and teachers perceive

the education and learning of written communication in the courses; what is good/what should be improved. 2. cross-fertilization between writing process and active/situated learning. Investigations are carried out using questionnaires for students in combination with semi-structured interviews, and in-depth discussions with the teachers. The teachers were also encouraged to specifically observe how the students make use of the writing process and how it is changed along the course of the projects. Based on the results, the two projects/courses will be developed, and a subsequent study will be carried out in order to assess improvements in learning outcomes. The results will also be used in a larger framework at the university to develop other existing and new courses, in order to stimulate both improved communication skills and engineering.

Background and motivation

The importance of writing and other forms of communication in higher education cannot be overstated. The significance is stated both in the national degree regulation and the CDIO framework (Conceive, Design, Implement, Operate) adopted by Linköping University [6]. The regulation says among other things that the student should *"... demonstrate ability in communication, both in national and international contexts, in oral and written form, in dialogue with different groups clearly explain and discuss their conclusions, knowledge and arguments on which they are based."* CDIO complements and significantly expands on Accreditation Board for Engineering and Technology, ABET's criteria [7]. Both personal and professional skills are highlighted, but also interpersonal skills such as teamwork and communication. Examples are problem formulation, metacognition and knowledge integration, communication strategy, communication structure, written and oral communication [8].

Communication in engineering curricula is nothing new. From the Writing Across the Curriculum (WAC) movement in the 1970s [9], many approaches has been developed and used in order to include communication in engineering education. The last decades, courses has been presented in which engineering and communication has been combined. A notable area where this approach has been successful is engineering design. There are many good examples globally where this has been applied also in freshmen cornerstone courses, for example in Portugal [10] and in the US [11].

A similar approach was used also at Linköping University during a few years, until about ten years ago. At that time, students in the five-year integrated Master's program in Mechanical Engineering started their education with a broad introductory engineering course. This course covered a lot of different subjects as for example design, production technology, written and oral communication and ecological sustainability. The course unfortunately gained a bad reputation among both students and teachers for being too vague, to lack clear focus and objectives, and for bad integration between the subjects. This ultimately led to a discontinuation of the course.

Since then, there has been a quite compact resistance against new courses of this type at Linköping University. How to teach student communication has however been continuously discussed among faculty, encouraged by decreasing writing skills among students entering the university and increasing demand on communication from e.g. national regulation documents.

This has led to the adoption of a strategy for communication development. The strategy is supported by most of the faculty, and aims to integrate communication throughout the curriculum in order to achieve a clear progress in communication skills. The direction and controlling of the strategy implementation and integration has however been weak, more or less leaving the implementation to enthusiastic teachers that try to ”wrench” writing education into already crowded course syllabi. This approach has its advantages (e.g. that teachers that chose to do this by their own will are more motivated to succeed), but also risks to end up with an un-sufficient progress over the entire curriculum. There is also an always present debate over *how* important e.g. written communication is compared to typical engineering subjects – if more writing education is to be included, what should then be excluded? In that perspective it is clear danger that even teachers who acknowledge the importance of communication education, and argue in favor of it in general terms, still reason *”not in my course”*. However, if it can be shown that education in writing/communication not only takes time from other subjects, but in fact can fertilize the learning of these subjects as well as engineering in general, the inclusion of writing/communication in the curriculum should become easier.

Writing as a cognitive process

In order to write about something, we need to understand in depth what we write about - writing is therefore a learning strategy for reaching deeper knowledge and new insights. The writing process has been shown to have positive aspects besides that writing itself, for example to improve student reflection [12, 13], and to improve critical thinking skills [14]. As noted earlier, both integration in regular courses and progression over the entire curriculum is important. Towards this aim, it is beneficial to break down ”writing” to units that can be distinguished and described while keeping the overview and context clear. A good example of this is the VaNTH model applied to biomedical engineering [15] in which writing is divided into modules based on how people learn and work together in problem- and case-based situations. Another example is the cornerstone class model outlined in [16].

Writing is a way to make ideas visible both to ourselves and to others. It is also a way to take care of, use and develop thoughts and knowledge, expressed in [14] as: *”Simply put, when students are asked to write, they grasp subject matter more thoroughly and more deeply. They are then able to use this understanding to transport knowledge across disciplinary boundaries.”*

The writing process has often been shown to have similarities with other creative processes, for example engineering design [17] and product development [10]. Similar to the end product of a design or development project, the final version of the text is in focus throughout the writing process. As pointed out by [13], writing and engineering are often closely related in engineering practice. By continuously and concurrently present both the technical project and the documentation adherent to it for other students and teachers, the students get feedback on what they have come up with so far. In this way, they get valuable knowledge that leads to a refined technical solution but also a clearer and more distinct documentation. As concluded in [11], *”Both design and communication are iterative, multi-stage processes. Both require creative problem solving... Design and communication are mutually beneficial: just as reports and*

presentations must be well designed to achieve their goals, so must designs be clearly communicated to be understood."

Writing as a professional skill

From both academy and industry perspectives, communication skills remains a top priority. The demand of writing skills seem to increase, especially in working life but also in general. You have to be able to express yourself in writing in more, as well as different, situations and for more heterogeneous recipients than before. Despite this, there is strikingly little collaboration and integration between engineering and communication faculty [18]. Thus, expertise in and research on communication pedagogy tends not to be exploited.

At the beginning of their training, students' difficulties can of course be due to lack of writing experience in general. Text knowledge, such as genre, structure of the text, what belongs to the introduction and conclusion, differences between description and interpretation, strengthens the formal writing skills and can be considered unrelated to the subject. Lack of knowledge of the subject is of course a complicating factor, but also that the students do not know what is demanded in the subject genre in terms of e.g. linguistic form and structure. This is an important factor to take into account by trying to find a natural progression throughout communication training. A complicating factor here is that it is often "someone else" that teaches communication [18], but who "someone" is or what he/she teaches seems in general to be unknown. From that perspective it is often very difficult to achieve proper integration and propagation of writing training. In a recent study, it was furthermore shown that engineering faculty who is teaching communication, in general seems not to be updated on the comprehensive literature on communication in engineering [19]. It has also become more and more obvious that just writing a lot is not sufficient – writing must be taught, integrated and tied to course aims and grades. The risk is otherwise that writing is only seen as "busy work" by the students [15] which limits the learning outcome.

Writing texts as a part of their professions is a way to be part of, and to manifest, their group membership. It is not enough to have writing skills, but the student has to know how texts should be structured and formulated for the profession a canonical way. Writing in education can be an individual activity, but most often it is a group and social activity as well. Writing is also culturally conditioned and therefore must always be considered in relation to the cultural, social and specific contexts in which it is included.The Russian philosopher Bakhtin [20] argued that as a writer you are engaged in a dialogue that goes forward in time but also backwards because you build on a common knowledge base of society. In short, writing is an important part of the cognitive process as well as an important professional skill.

Situated learning model

The model of situated cognition and learning is based upon the notion that knowledge is contextually situated and is influenced by activity, context and culture in which it is used [5]. The activity involves both the individual person as well as the community in which the individual is a

part. The model contains eight key components of which some is very much related to writing, both as a cognitive process and as a professional skill.

One of the key component is reflection. It is necessary to take a step backwards, to stand apart from ones writing to evoke new insights and make revisions for the better. Situated learning can meet the demands for both the experiential and reflective dimensions of cognition. Another component is collaboration, which enables collective problem-solving and makes it easier to confront ineffective strategies and get rid of misconceptions. The students also learn to take on different roles and acquire cooperation skills.

As recently pointed out in [21], a critical aspect of the situated learning model is the notion of the apprentice observing the ”community of practice”. Brown et al. [22] describes cognitive apprenticeship as: *”Cognitive apprenticeship supports learning in a domain by enabling students to acquire, develop and use cognitive tools in authentic domain activity.”* This implies a multiple practice or appropriating which can be seen as a process where the students gradually acquaint themselves with, and learns to use tools from different practices. As the students gain increased knowledge and experience the tools can be used more effectively [23]. Lave and Wenger [24] describes this process in the way that the student starts as a legitimate participant in the periphery and little by little work her/his way to the center in order to become a central actors who support the activity .

An important similarity between the active and situated learning models is that they focus on both the student and learning process. The underlaying idea, which the author tries to explore in the projects and communication education, follows the phenomenological approach [25]. This stimulates a deep-level instead of a surface-level approach to learning, and is thereby closely related to student-centered, active and sociocultural learning strategies. This shifts focus away from the teacher, but also changes the role of the teacher – the teacher becomes more of a ”coach” or mentor, and the old-fashioned way of teaching based on knowledge transfer is clearly obsolete. Although most teachers agree that students must be ”active” to learn, active in a general sense is however not enough [25] – *”When using active learning students are engaged in more activities than just listening. They are involved in dialog, debate, writing, and problem solving, as well as higher-order thinking, e.g., analysis, synthesis and evaluation.”*

Context of the study

In this study three integrated five-year Master’s programs given at Linköping University in Sweden are investigated. The university has some 25,000 students of which about 50% study engineering. The three master programs consists of Mechanical engineering (ME), Design and product development (DPD) and Industrial engineering and management (IEM) which respectively enrolls approximately 140, 70 and 200 new students each year, respectively. Approximately 50% of the students at the IEM and DPD program are females, but only 20% at the ME program. All three programs have a traditional curriculum for the first 2 years, including courses in mathematics, mechanics, computer programming, engineering thermodynamics etc. The respective program has also introductory courses in mechanical engineering, design and product development and industrial engineering.

Teaching in the programs are mainly carried out as lectures, lessons, and laboratory sessions. In a typical engineering course, 30−40% of the education is carried out as lectures, 30−40% as lessons and 20−40% as laboratory experiments. In addition, case studies and project works are used in about half of the courses. Some projects are small (down to 15% of the course workload) and some may make up the whole course.

In the present study, two courses are of interest. One is a course in Engineering thermodynamics which both the ME, DPD and IEM students take; the ME students as the very first course of the program, and the PDP and IEM students at the middle of the second year. The other is a bachelor (capstone) project course that the IEM students take as their final course at the end of the third year, and if passed fulfills the requirements for a bachelor's thesis project.

Engineering thermodynamics - Course Content and Syllabus

The engineering thermodynamics course follows the content of courses at other universities as well as standard textbooks in the field , and can thus be considered a traditional course. In short the course focus on properties, states and processes of pure substances, and much time is spent on the first law of thermodynamics and its applications to processes and cycles of open and closed systems.

The course is given during 10 weeks, and make up about 40% of the workload for the students during this period (the students take 2,5 four week courses in parallel). The course content is presented at 12 lectures, 13 lessons and 2 labs. The course also includes a relatively large project work (approximately 40% of the course/the student workload is dedicated to the project). The project is carried out in groups of 5 students and focus on the compressor cycle. One aim is to determine the efficiency (coefficient of performance) for a traditional kitchen refrigerator. A method to carry out this is proposed to the students, but they need to plan, carry out, analyze and present all measurements and calculations by themselves. There is continuous supervision, but only when the students ask for it. Care is taken to let the students be in charge of their own work.

Apart from the engineering thermodynamics objectives, the project aims to give the students training in project work and communication, which can be divided into three learning areas: 1. How to plan and carry out projects that are not structured in detail from the beginning. 2. Use of measurement equipment and analysis and presentation of data. 3. Report writing supported by education and training.

The students start writing the reports quite early during the project. As a support, they got a briefly described report structure (that is however not mandatory to follow), and also supportive documents for form, structure and formatting. The project and report writing are discussed during all lectures held under the project time. In addition to that, a professional communication teacher gives a lecture on communication and report writing, and supports the students as a coach during their report writing together with the thermodynamics teacher. Towards the end of the course, all groups hand in a preliminary report to the both the communication and thermodynamics teachers and to another group of students that serves as opponents. Each group then have a meeting with the communications teacher to discuss the report and possible improvements. Based on all

comments the students achieved they update the report and hand it in for examination. The report often contains 12−20 pages.

Energy engineering bachelor project course - Course Content and Syllabus

At the end of the third year the students at the program in industrial engineering and management (IEM) take a energy engineering bachelor project course. The project follows in general the purpose of a capstone project outlined in [13]: *"The purpose of a senior capstone design course is to provide students a situated learning experience that is relevant to their future professions as engineers. "* The course run over two quarters and equals 12 weeks of full time work. The students included in this study consists of the about 40 students (of the 200 at the IEM program) that have chosen to specialize in energy engineering. The project is carried out in groups of 5 persons. Before this course, they have in addition to math, general engineering and industrial engineering also studied energy engineering courses equivalent to half a year of full time studies. The course in engineering thermodynamics described above is mandatory as prior knowledge.

The course has 4 overall course aims: 1. Subject specific (e.g. application of methods, analysis and evaluation of technical solutions in energy engineering), 2. Individual and professional (e.g. planning), 3. Group work and communication (e.g. professional oral and written communication), and finally 4. Engineering application (e.g. create technical solutions). Aims 1 and 4 complement each other and are the main focus during the project. Aims 2 and 3 can be seen as supportive to the process of solving the engineering problem (e.g. planning and report writing).

The project work has been to design, build and test a portable solar heating system. All groups have got a pump and about 1 square meter of high performance solar thermal panels and $200 to spend on whatever material they want to build the most effective solar system. The project is carried out as a competition between the groups. The goal is to obtain points by maximizing a "goal function". Points are given for the amount of energy stored, the time a certain amount of energy can be stored, build quality, innovative solutions, saved money (and a penalty for exceeding budget).

The project is documented in a report (often about 120 pages), and is considered a quite difficult report to write. Several different methods (e.g. measurements and simulations/calculations) are used in combination, both in parallel and consecutive, and results from one method can serve as input to another. Along the course, the students got seminars, lectures and supervision related to report writing and communication, both from energy engineering teachers and from professional communication teachers. This education covers many aspects of writing, e.g. disposition, format, referencing, clarity of writing and plagiarism. Since the students have studied for 2.5 years prior to this course, they have written quite a lot of shorter reports earlier, but their actual education in report writing and communication is far from extensive – many has not got any additional communication education in addition to that given in the engineering thermodynamics course. Since several teachers from both engineering and communication faculty is involved in both the courses, there is relatively straight-forward to design the education in order to obtain progression. Care is taken to let the students be totally in charge of their projects, including what to do, when

to do it, who does what etc. The role of all teachers are more or less only as coaches, especially regarding project planning, teamwork and communication/report writing. In this respect, the teaching follows the recently developed ”Matrix classroom” model described in [21].

Methods - investigation of students and teachers experience

In order to investigate the communicative learning in the courses and how it is related to the situated learning model, an investigation of both students and teachers experiences were carried out. All students got a questionnaire, 10 % of the students were subject to semi-structured interviews, and the teachers had several in-depth discussions directed to communication education in general and questions related to the situated learning model in particular.

An anonymous survey in form of a questionnaire was sent out by e-mail to all students who had taken the two courses during 2016 and 2017. The students come from three different programs (ME, DPD and IEM) of which all has taken the engineering thermodynamics course. The 40 IEM students that had the engineering thermodynamics course in 2016 also took the energy engineering bachelor's course in 2017, and was asked to answer the questionnaire twice. The ME students took the thermodynamics course as the very first university course, and the DPD and IEM students at the middle of the second year. The total number of questionnaires, which was sent out through email, was 220 and the answer rate was 43%.

The questionnaire consisted of nine questions and if the alternatives given was not suitable there was an option for the student to formulate his or her own answer. The last question gave the student opportunity to add something that was not includes in the previous questions. Three of the nine questions were considered most important for this study and is described in the results section. The questions were:

1. Is it good to practice your writing skills in the context of engineering education?
2. Why is it, in your opinion, important to practice your writing skills? More options can be specified but max 3.
3. How do you want the teaching organized?

For most of the questions the students could choose one or several answers from a number of alternative answers as described below.

Results and Discussion

The student interest in their communication education is encouraging based on the numerous discussions during the two years of the study. It is clear that almost all students agree on the importance of communication as an important professional skill, and many has also worked hard to improve themselves in this respect. Furthermore, many students have shown interest in this study and the on-going work at the university to develop the communication education.

The answer rate of 43 % is considered sufficient for the objectives of the study. Roughly 18% of the students answered that they were unfamiliar with professional writing (most of them ME students that took the course as their first university course) and 33% that they were used to write technical or scientific text. Although 82% of students rates themselves as experienced writers, all students answered that learning how to write in a professional style should be a part of their training to become engineers, see Figure 1.

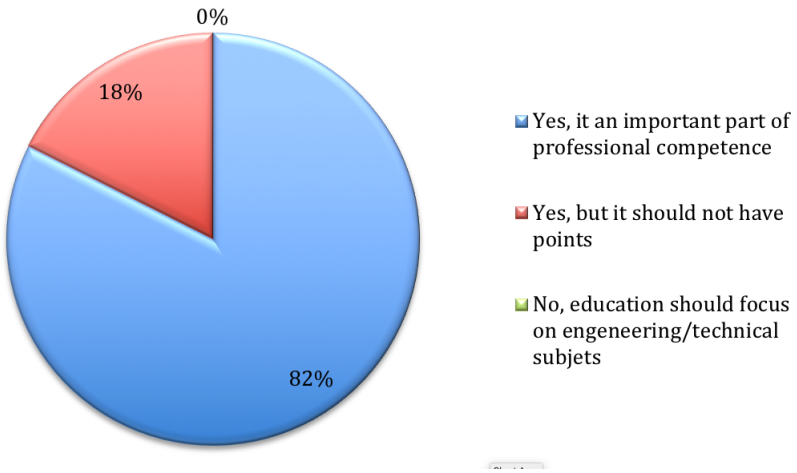

Figure 1: Is it good to practice your writing skills in the context of engineering education?

In order to learn more about how the students view various aspects of communication in relation to situated learning, seven additional questions were asked, see Figure 2. Another reason for these questions was to get insight in the *student* perspective of communication that according to [18] can differ from faculty beliefs. The students were only allowed to make three choices out of the seven possible. In addition to the choices made, many students answered with additional text to motivate their answers. How the students want communication education to be organized is shown in Figure 3.

According to Figure 2, most students agree that it is important to be able to document and communicate in a professional way, although they state various arguments why it is important. Question 2 and 4 were chosen to directly get a connection to the key components of the situated learning model. Approximately one third of the students chose these answers.

The remaining answers are split equally between having instruction in writing either at the beginning of the program, or in connection with the Bachelor thesis. Two students suggest that one part should be in the beginning of the program but then a second part in connection with a Bachelor thesis.

Students would primarily like to see teaching of disposition for various genres of text, and how these should be appropriated to the content as clearly as possible. Language correctness and formalities such as layout and reference management is also considered important. Thematic conventions and terminology is not considered to be as important, but it may be because this knowledge is acquired through learning the subject, i.e. thermodynamics.

The students believe that the best way to develop writing skills is through individual writing

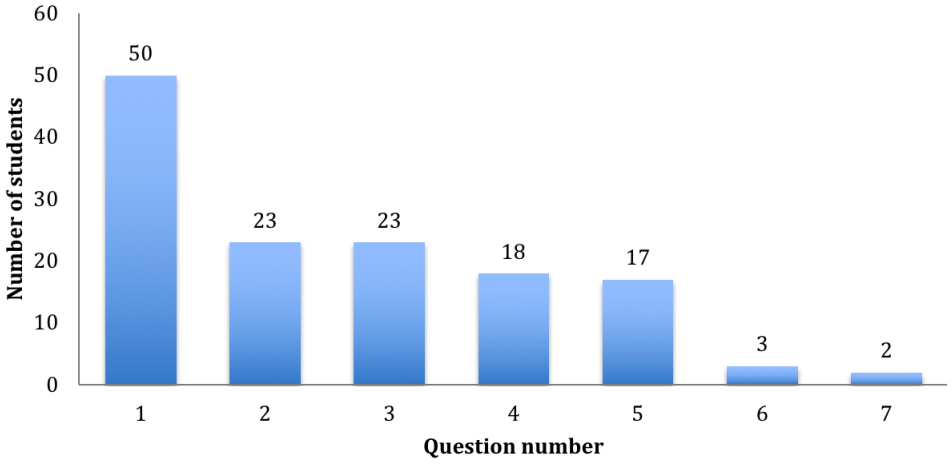

Figure 2: Why is it, in your opinion, important to practice your writing skills? More options can be specified but max 3. Questions from 1-7 follow. 1. It is important to be able to document and communicate in a professional way. 2. I am learning to understand the topic better by writing about it. 3. I will more easily remember what I have learned if I write. 4. It develops my critical thinking. 5. It will help me to solve problems, to see connections and patterns. 6. I do not think it is important to practice writing skills. 7. It is not important that I write totally right as long as the facts are correct.

assignments commented on by a teacher. This result is not aligned with situated learning of writing, and communication and other workplace skills as described in [18]. Writing together with other students as well as to read and discuss others students' texts are also considered to contribute to strengthen writing ability. Only 3% see a strict peer-to-peer-review as way to improve writing skills. Based on the teacher-student discussions and the discussions among teachers, the author expected the students to be more positive to the cooperation within and between student groups. The reason for this will be investigated further.

When the students' responses are linked to the theories initially presented, concordance appears. Although the survey is limited, certain things are highlighted. It is valid for, among other things, the students' awareness of need for this kind of teaching despite most perceive themselves to be experienced writers. Although many students realize the importance of mastering the ability to express themselves in writing, they still need some motivation which increases when teaching is incorporated into a context that reflects what is expected of them in their future profession.

By integrating the communication element in engineering courses (instead of in communication courses), the students get concepts and appropriate terminology by the subject teacher. At the same time, this has been shown to have positive effects on student motivation [11]. The communication teacher can then focus on what the students in the survey request, e.g. how facts should be presented with respect to the target group.

"I mean not only cosmetically unsightly grammatical errors but the parts where it is genuinely difficult to understand a text because of its poor structure. Grammatical errors can also be discussed; just to show how much less serious text feels if it is grammatically wrong." – Student no. 17, semester 6

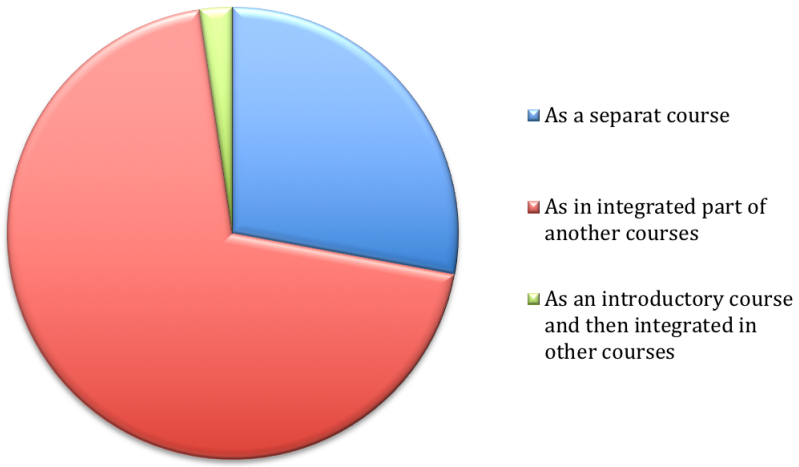

Figure 3: How do you want the teaching organized?

”Ignorance [about proper language] is so unattractive that it is sad.” – Student no. 43, semester 3

Even those students who consider themselves experienced writers say they are unused to writing, especially longer, technical texts. They need more knowledge of work-related genres. To achieve this a close cooperation between the various teachers is required for the students to perceive the course as seamless. If the actual writing process is compared with the agile development methodology that is familiar to the students, the situated learning is amplified. The different text versions can be considered as a prototype that will be improved with each iteration.

The study reflects that students are aware that writing is not only a skill, but also an important component in their own learning process. Walter Ong wrote that the human brain would not think in the way it does without the art of writing. The thinking process is structured indirectly or directly by the technology of writing [26]. Writing about something complex and complicated required deep learning and not just knowledge on the surface.

”It is important to learn to communicate in a way that is unambiguous, but also easy to understand.” – Student no. 44, semester 6

”I learned a lot of writing already in the thermodynamics course, both the importance of context and the importance of clarity of writing. I really wonder why we did not get the first writing education before the third semester - all writing in other courses would have been both easier and better” – Student no. 4, semester 3.

Not surprisingly, the students will preferably have their texts commented on by a teacher. If the comments are given verbally, as they are in the presented case, it will be natural to have a discussion with students. The discussion will then be about how they thought when writing the assignment, not only about the ”words on the paper”. Since there is often not only one correct answer, but various alternative solutions, the knowledge can be deepened by the reflection during discussion. This approach turns the teacher into a coach which stimulates students to take a greater responsibility for their own learning, compared with if only written comments are given.

This is emphasized by the fact that the students rather discuss their text with other students than obtaining written comments from them. Both cases could be seen in the light of Bakhtin´s concepts of dialogue in the cognitive process [20].

Conclusion

The students agree that communication is an important professional skill that is best learned as an integrated part of engineering courses. A majority (80%) prefers writing education to be organized within regular engineering courses instead of as separate ones. Most students acknowledge both the importance of writing as a professional skill and to some extent also as a way of learning. The students were satisfied with the communication parts of the projects, especially the role of the communication faculty, and the general opinion is that the education is needed despite many see themselves as experienced writers. Faculty are convinced that the students really need the writing education given in the courses, and that more and progressive education is needed already at the first semester and then continually throughout the education.

If the results are interpreted in light of the situated learning model, the collective student and faculty comprehension is that collaborative learning, reflection and ”cognitive apprenticeship” are present in the writing process – especially in the bachelor’s project. Many students recognize writing as an important cognitive tool, but the reasons differ between the students. The teachers opinion is that the situated learning within each groups is adequate, but there is significant room for improvement of the cooperation and interaction between groups. An improved description and motivation of the various aspects of writing as a way of learning might be needed to further facilitate and improve the situated learning experience.

Acknowlegements

The author wish to gratefully acknowledge Dr. Eva Törnqvist for initiating this work, for indispensable ideas and support during the work, and for performing parts of the investigation.

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