Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 00 (2015) 000–000

Procedia Computer Science

www.elsevier.com/locate/procedia

2015 Conference on Systems Engineering Research

Reflective Practice to Connect Theory and Practice; Working and Studying Concurrently

Gerrit Muller[a]*

[a]*HBV-NISE, Frogs vei 41, 3611 Kongsberg, Norway*

Abstract

Core challenge for educating systems engineers is the need for students to have a frame of reference of practice to appreciate the theory they learn. In this paper, we report on the use of reflective practice to connect theory and practice. Since 2008, our master education mandates a special course Reflective Practice. The course gradually evolves, based on observations and feedback. Appreciation of the course is high, however, students still perceive applying of systems engineering in practice as difficult.

Peer-review under responsibility of the scientific committee of Stevens Institute of Technology.

Keywords: Reflectvie practice, competence development, expereince, theory, practice

1. Introduction

Donald Schon laid the foundation for Reflective Practice as competence development approach [1]. Reflective Practice builds on Kolb's Learning Cycle [2], see Figure 1. The learning cycle captures how learners apply knowledge and skills in practice and reflect to increase their understanding. The increased understanding is tested in practice again to continue learning.

In 2008, Buskerud University College (BUC) in cooperation with the Norwegian Center of Expertise (NCE) in systems engineering developed a systems engineering master curriculum. Starting point for the curriculum was the master program from Stevens Institute of Technology. However, the BUC curriculum builds on the close

* Gerrit Muller. Tel.: +4732869594.
E-mail address: gerrit.muller@hbv.no

Peer-review under responsibility of the scientific committee of Stevens Institute of Technology.

cooperation with local industry in NCE. This cooperation resulted in the Industry Master (IM) model where students need an industrial position of three years in industry while studying. The idea behind this model is that systems engineering education requires practical experience. The initiators of the program introduced a special course Reflective Practice to ensure that work and study are connected.

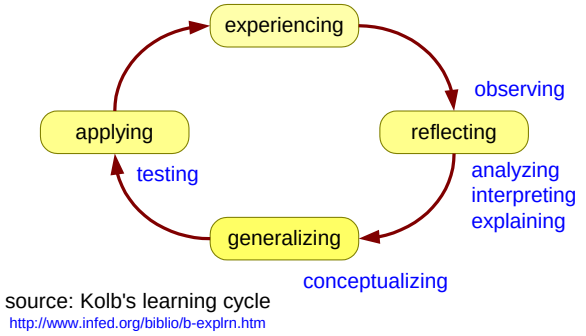

Figure 1 Kolb's learning cycle is the foundation for reflection.

The systems engineering curriculum consists of 5 mandatory courses, 3 elective courses, an international semester, and a half year full-time master project. The total study load is 120 ECTS[†]. Students entering the program must have a bachelor degree in science or engineering. Students in the IM program have little or no working experience. The school offers the same courses in an experience-based master with a study load of 90 ECTS. Reflective Practice is a mandatory 7.5 ECTS course for IM students.

Merete Faanes, one of the initiators of the systems engineering curriculum, researched the effectiveness of the Reflective Practice model during the first 3 years. This resulted in a PhD thesis [3] documenting Reflective Practice.

2. Didactic Model

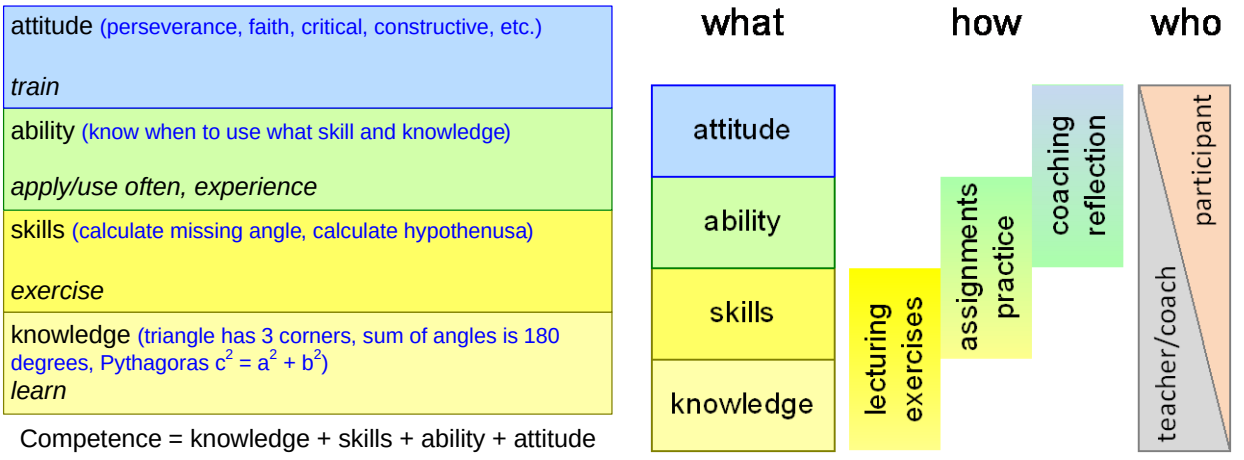

Figure 2. Competence consists of 4 elements each requiring a specific didactic approach

[†] European Credit Transfer and Accumulation System (ECTS) defines one ECTS as a study load for a nominal student of 28 hours. A study year for a nominal full-time student is 60 ECTS.

The left-hand side of Figure 2 shows four elements that together form competence. The European Quality Framework (EQF) [4] defines learning outcome in terms of knowledge, skills, and competence to apply them properly. We use the word ability (to use knowledge and skills), so that we can use the term competence for the combination of these 4 elements. We add attitude explicitly to this model, since effectiveness in practice depends on attitude. The right-hand side of Figure 2 shows the typical learning forms. Traditionally, universities offer lecturing and exercises to develop knowledge and skills. However, the educational challenge starts at the transition from skills into ability. Ability requires experience. To develop the ability we need students to follow Kolb's learning cycle. The last step, acquiring attitude requires critical thinking about personal behavior and performance in the actual organizational context. At the ultimate right-hand side, we visualize the influence of external providers and the individual. Low in this stack, teachers may contribute a lot by lecturing and exercise feedback, while higher in this stack more action and drive from the individual is essential. The role of the teacher or coach is reduced to inspiratory and catalyst.

3. Cooperative Model between Educational Institute and Industry Partners

The educational model requires a close cooperation between the educational institute and its industry partners. A partnership model formalizes this cooperation. Industrial partners and the institute have three boards to set the strategy, determine the tactics, and run the operation:

- Industrial Advisory Board (top management, strategic)
- Reference Group (systems engineering or engineering management line managers, tactical)
- Human Resources (operational)

4. Structure of Reflective Practice

The courses in the systems engineering program are condensed one-week courses, followed by a homework project. This format fits well with working in a company, since employees are away a limited number of weeks throughout the year. Reflective Practice is spread out over 3 years in 9 half-day workshops. In this way, we have regular interaction moments with the students.

Each workshop addresses a specific topic. The students make a pre-assignment before the workshop, to initiate an awareness process. After the workshop, the students make a post-assignment. At the start of the workshop, the facilitator initiates a brief discussion to refresh the previous topic. During the workshops, the students work in small breakout teams in three steps: an awareness discussion, analysis of the topic, and a forward oriented discussion (what can and will we do with new insights). After the breakout session, a plenary wrap-up finishes each step.

5. Content of Reflective Practice

The workshops are set-up in such way that the topics make sense in the phase at their development. All workshops provide some means to cope with the topic of interest. The sequence of workshops is (course material is available at http://www.gaudisite.nl/BUCmasterSE.html#BUCmasterSERP):

- Reflection and Learning
- My Role and Style
- Critical Thinking
- Domain knowledge
- How to apply SE in my daily work?
- Cultural Differences
- Communication
- From Student to Systems Engineer
- Academic Writing

The first workshop, *Reflection and Learning*, explains the ideas behind the IM model and Reflective Practice. The workshops *My Role and Style*, *Domain Knowledge*, and *How to apply SE in my daily work*? try to increase their

scope and awareness of their role in a broader context. The intermediate workshop *Critical Thinking* builds further on *Reflection and Learning* to make them aware of the necessity to be sharp in reflection.

Cultural Differences proceeds the international semester. Objective of this workshop is to make students aware of cultural differences and their impact on their work. This workshop is also the preparation of a small project during the international semester to study these differences abroad.

Most companies indicate the need for soft skills, when asked for input to a systems engineering curriculum. Some of the courses in the program touch upon soft skills. However, in general, we recommend students to invest in further development of soft skills. The workshop *Communication* is the only workshop that explicitly addresses the most central soft skill: interpersonal communication.

The last workshop before the master project, *From Student to Systems Engineer*, prepares the student for their lifelong learning journey, where they themselves have to take the lead. Topics here include the transition from supervision to peer interaction, and the role of professional societies.

Finally, when they work on their master project, *Academic Writing* helps them to write an academic paper about the practical application of systems engineering in industry.

6. Evolution of Reflective Practice over time

In 2009, the sequence of 9 workshops started to run repeatedly. We collect feedback every workshop, and at the end of all workshops. Both topic and form was new for the teachers. The teachers had a significant challenge: can we engage young, technical-oriented students in the "fuzzy and vague" topic of reflection? In several workshops, we hit engagement/motivation problems, forcing us to rethink the workshop, its form, and its timing. Since 2011, we made several changes:

- Schedule *Domain Knowledge* earlier
- Reduce workshop duration from 6 hours to 4 hours
- Add a review by company supervisor to the *My Role assignment*
- Add a review by company supervisor to the *Critical Thinking* assignment
- Add a review by company supervisor to the *Domain Knowledge* assignment
- Schedule *My Role* one month later
- Add various interaction models for plenary sessions
- Replace post questionnaire of *How to apply SE in my daily work?* by an assignment to actually apply architecture and design on own system
- Add a 5 to 10 year preview of own career to the *My Role* post-assignment

We discovered in the *How to apply SE in my daily work?* workshop that lack of domain knowledge was one of the blocking factors. At the same time, the idea behind the IM model is that students should build up domain knowledge during their work. An early workshop *Domain Knowledge* should stimulate students to pursue domain knowledge during their work actively.

A combination of factors triggered the reduction of the workshop duration. One factor is that 4 hours of this type of interaction saturates the students; continuing longer does not add value.

A clear improvement was the idea to have some assignments reviewed by the company supervisor. This construction has multiple benefits: it stimulates the student to discuss specific topics with the company supervisor and it engages the company supervisor with the educational program. The assignments stimulate students to talk to more stakeholders in their context.

Timing of the *My Role* workshop is critical. The workshop should be early enough to make them perceptive for their role in their organizational context. However, when we arranged the workshop in October, several students were still involved in a series of introductory courses (ranging from technology and process to obligatory courses like safety). At that moment, the students have insufficient framework to appreciate the role awareness. However, in some cases the workshop uncovered some poor positioned tasks in the company. Early detecting such poor tasks enables discussion with the company supervisor and a repositioning of tasks. Students should not lose too much time with poor task allocation, since they need the 3 years to grow in all directions.

One of the challenges of this course is to keep students engaged throughout all workshop sessions. In the group discussions, they produce flips that teacher and students later discuss plenary. Over time, we developed several

active models for reading all flips and doing something with the flips to motivate students to read them really. We started with asking students to provide balanced feedback to other posters, by writing comments on yellow stickers. Later we added stealing of ideas from other flips, formulating a question for later discussion, and formulating a guideline for later personal use. Another form that we added is redistributing the teams to make sure that students work in a fresh consternation. The redistributed teams get the task to analyze the flips, capture the most relevant findings, and explain their relevance. By alternating these interaction forms, the students do not fallback in a routine.

We have used the new assignment for the *How to apply SE in my daily work?* workshop only once so far. In this first round, students struggle to define designs beyond static views, such as physical diagrams and product break down. Capturing dynamic behavior was after a first round of feedback insufficient for half of the assignments. Relating static and dynamic views to quantified key performance parameters is in most assignments missing. The reflection reports of this cohort show a wide variation in lessons learned. A number of students grasped then opportunity to go out and learn more about their system. A number of students concluded that they do know too little about dynamic behavior and key performance parameters. Some students complained that the assignment did not give them enough guidance. This last point deserves more interaction: after one year of courses, we expect from students that they can select methods, tools, and representations at own initiative. As part of the intermediate feedback, the students got a pallet of examples; our expectation is that they select a format that suits their case.

One of the students suggested, after the post-assignment of the workshop *From Student to Systems Engineer*, to ask for the long-term career view early during the study. The idea is that such question will trigger a thinking process that students revisit in this workshop. We have followed this suggestion, by extending the *My Role* post-assignment.

7. Data collection from the workshop *How to apply SE in my daily work*

The students answer a questionnaire as preparation of the workshop. The questionnaire has a number of open and closed questions, see Table 1 with all questions. All closed questions use a 5-point scale. The form uses 2 pages for these questions to allow for sufficient space for answers to the open questions.

0	What kind of engineering do you practice in your company?					
1	How often can you use SE techniques and methods in your daily work?	never	now and then	regular	frequent	very frequent
2	Try to describe (briefly) in which situations you use SE techniques and methods.					
3	How many different SE techniques and methods can you use?	1..4	4..8	8..12	12..16	more than 16
4	What SE methods and techniques can you use?					
5	If you apply them, how helpful are they for you personally?	not at all	a little bit	moderate	much	quite a lot
6	If you apply them, how valuable are they for your colleagues?	not at all	a little bit	moderate	much	quite a lot
7	How do you rate your own skill level in SE techniques?	very low	low	moderate	high	very high
8	How do you rate your industrial domain knowledge?	very low	low	moderate	high	very high
9	How do you rate SE awareness of your colleagues?	very low	low	moderate	high	very high
10	How do you rate the average industrial domain knowledge of your colleagues?	very low	low	moderate	high	very high
11	What limits you in applying SE methods and techniques?					
12	Comments (anything you want to add?)					

Table 1. Students answer this questionnaire as preparation for the workshop

Figures 3, 4, and 5 show the results of the closed questions from the cohorts that started the study in 2012 or 2013. The cohort of 2012 has 27 students and 2013 has 18 students; all 45 answered the questionnaire, except one student, who did answer never on the first question and hence did not answer questions 5 and 6.

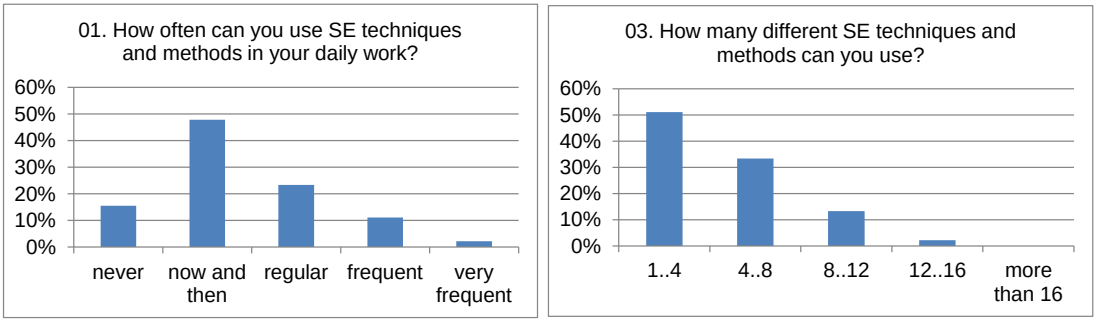

Figure 3. Results from questions 1 and 3, about frequency and number of systems engineering methods and techniques that students use in daily work.

The majority of the students indicate that they barely use systems engineering techniques and methods (16% never, 48% now and then). 23% uses them regularly, 11% frequently, and 2% very frequently. The answers on the amount of methods that they use (question 3) reflect this too: 51% uses 1 to 4 methods, 33% uses between 4 and 8 methods. When they fill in the questionnaire, they have followed 3 courses: *Fundamentals of Systems Engineering*, *Systems Architecture and Design,* and *Project Management for Complex Systems*. These three courses teach tens of methods and techniques that apply to nearly all domains and systems.

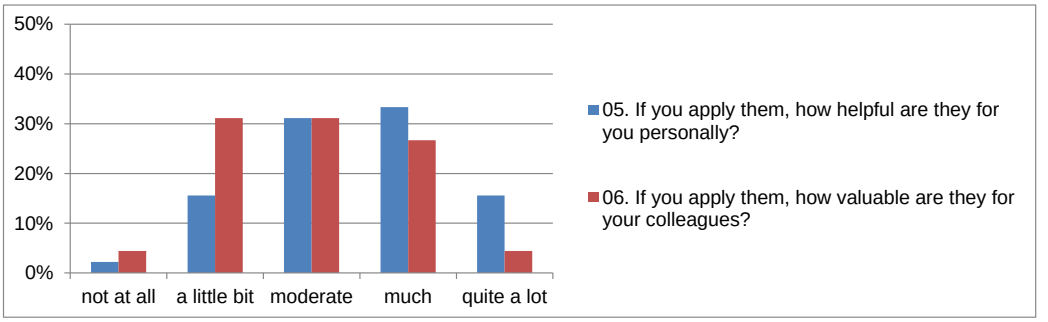

Figure 4. Results from questions 5 and 6, value of applying systems engineering methods and techniques .

Questions 5 and 6 ask for the value when applying these methods for the person applying it and for their colleagues. Here half of the students are positive (33% answer *much*, 16% *quite a lot*), 31% sees *moderate* value for themselves. The value for their colleagues shows an interesting spread: 31% sees only *a little bit* of value, 31% sees *moderate* value, and 27% sees *much* value for their colleagues. We can only speculate about the cause of this variation: some tools may be mostly useful to gain individual understanding (for example by analysis), or it may relate to the students attitude (focus on own performance or focus on serving colleagues).

Figure 5 shows how the students rank their own systems engineering skills and domain knowledge and the same for their colleagues. Only 4% of the students feel highly skilled in systems engineering, all others score lower (47% *moderate*, 38% *low*, and 11% *very low*). Their opinion of the systems engineering skills of their colleagues is painfully low (40% *moderate*, 38% *low*, and 13% *very low*); only 9% scores *high*.

Domain knowledge scores (still) low for the students (23% *low*, 58% *moderate*, and 19% *high*). Since they work for only a year (part-time) at their company, we consider this reasonable. The students have a high opinion of the domain knowledge of their colleagues (13% *moderate*, 62% *high*, and 20% *very high*).

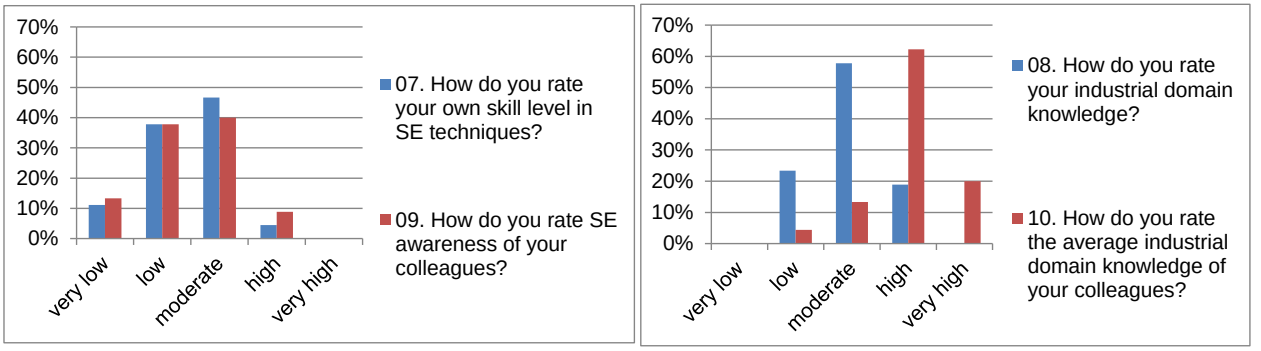

Figure 5. Results from questions 7 to 10 skill and domain knowledge of students and their colleagues.

8. Challenges for connecting work and study

Current feedback on individual workshops and the course as a whole are positive. However, especially the questionnaire used in the pre-assignment of *How to apply SE in my daily work?* shows that most students in their second year feel that they can barely apply systems engineering methods and techniques in practice. Typically, students apply project management tools such as GANTT charts, requirements tracing, the concept of the V-model, testing, and some mention systems thinking (the holistic approach). The students mention the limiting factors for applying systems engineering methods and techniques:

- Mindset and experience of the company and colleagues.
  - Lack of systems engineering knowledge in the company and colleagues
  - Difficult to change the way it always has been done.
  - No pull from the company
  - Systems engineering perceived to be time consuming
  - strict deadlines, amount of work, and pressure
  - project management focus
- Personal factors:
  - Complex to map on own working situation
  - Methods and techniques are not applicable on my work
  - Limitations of my own competence and experience
  - The need to acquire domain knowledge first
  - Own lack of awareness
  - Systems engineering perceived to be time consuming
  - Working “too low” in the system, e.g. engineering mono-disciplinary components
  - Working in a late phase of a project

9. How do students experience Reflective Practice?

We did send a brief survey to all students from cohorts 2010 to 2014. We used three questions with a fixed scale (1=very little, 2 = little, 3 = moderate, 4 = much, 5 = very much):

- How much did Reflective Practice have impact on your work?
- How much did Reflective Practice have impact on your learning?
- How do you appreciate Reflective Practice?

In addition, we asked 3 open questions: *Benefits of Reflective Practice as mandatory course*, *Concerns of Reflective Practice as mandatory course*, and *Any other feedback.* The survey was send to 98 students, working at 15 companies. We got 65 responses (61% response rate). Figure 6 shows how the students perceive the impact of Reflective Practice on their work and on learning. Students see some impact on their work (32.3% answers *very*

little or *little*, 67.7% answers *moderate* or more). The impact on their learning is clearly higher, 46.2% answers *much*, and 6.2% answers *very much*.

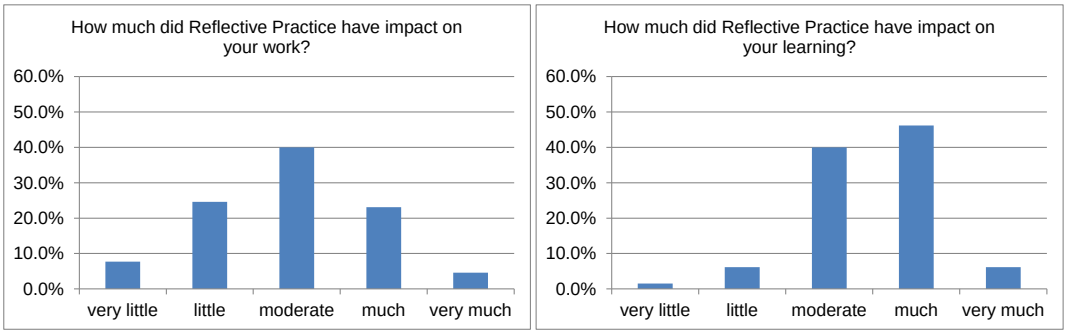

Figure 6. The students' response on the impact of Reflective Practice on their work and learning.

The closing question, how do you appreciate Reflective Practice, shows a somewhat negative Net Promoter Score (NPS)[5, 6] of -13.1% (16.9% scores *very much*, the so-called promoters, minus 30% score for *moderate* and lower, the so-called complainers). The negative NPS requires attention; although the course is mandatory, so we do not have to sell it, we speculate that a positive NPS correlates with higher motivation and participation that is more active. Figure 7 shows the distribution of answers for the appreciation question.

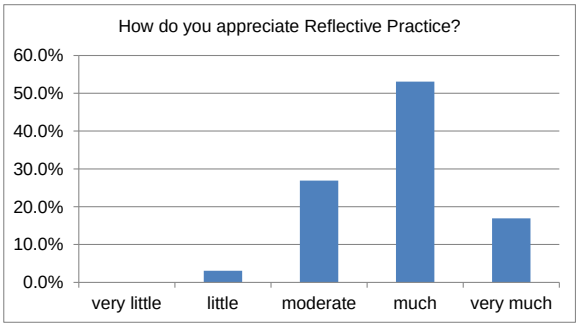

Figure 7. The students' response to the appreciation question.

A positive impact that students repeatedly report is that the course stimulates them to contact more people in the organization. A few quotes illustrating this point are:

- *"My impression is that since I have included my superior(s) and work colleagues, we have gotten a relationship as a result."*
- *"This has made me more open for discussions with both my co-students and co-workers."*
- *"Brought up interesting subjects not covered by other engineering courses, which have a positive impact on my relationship with my working colleagues."*

The mandatory nature pops-up several times in the open questions. Especially the fact thatstudents would not have chosen such course by themselves. However, in retrospect they see the value. Some examples:

- *"If it was not a mandatory course I think many would just do the exercise without any real reflections."*
- *"If it was not mandatory, I doubt that many people would have attended, based on the first impression of the course and the course-description. However, after talking with co-students, this is a highly appreciated course."*
- *"Allthough I was quite opposed to this course, and did not appreciate it much the first year, I look at it as a very useful course in retrospect, and I've appreciated the RP sessions and homework greatly."*

One of the challenges for the students is the half day workshop format, especially for students living outside Kongsberg. Some partner companieshave their offices close to Oslo, which is more than 1 hour traveling from

Kongsberg. We also have students in Kristiansand (3 to 4 hours traveling), and Bergen (7 to 8 hours traveling). Hence the traveling overhead for these students is large. In exceptional cases, we allow students to make an alternate assignment replacing the workshop. However, since all interaction is lost in such alternate assignment, we expect that the learning benefits are less. Some comments from students on the trade-off between traveling and following the workshops:

- *"In my work situation it is a long time of travel for a small time of lecture. It helps when some subjects can be done from home, but that again remove some of the benefits. It might help if the course had fewer, larger modules. (with the downside of less frequency thinking about these issues)"*
- *"For us who lived in Oslo, and had to commute, it was somewhat of a hassle to spend one day travelling to Kongsberg. Maybe not academically relevant, but it affects the motivation of the student."*

Many students struggle(d) with the intangible nature of the course, however, see clear benefits. Similarly for the assignments; takes a lot of time, immediate value not clear, however, in retrospect quite useful.

- *"RP gets me thinking on the important surrounding issues of the master-program and my work situation. The other topics on the master and at work are very specific. RP leads to me reflecting over my own situation on if I am doing the right things, in the right way and if it is taking me where I want to go. It has not had a direct impact on my situation as per today, but it makes me think more on the issues mentioned, rather than only focusing on the work. In that sense it might influence my future."*
- *"Seen in retrospect there is a consistence in the course that may be difficult to grasp during the couple of first years in the program."*
- *"The course made me change behavior without thinking about it. Through the course we were forced to ask ourselves questions that I haven`t thought of earlier. In the start it was not totally clear what the course was about, an how we would gain anything from it. But after every workshop, I had the questions and the subject in the back of my head, and this automatically changed the way I worked."*
- *"Even though it is difficult to measure, and even be aware yourself, I believe it has great effect for most people in the way we reflect. Very often subconsciously. Disruption causes new patterns to emerge ;-)"*
- *"When the group is less outgoing, it is a bit hard to activate the group. (I was not very outgoing the first year and a half, and definitely felt that if we had managed to be more active, we could have gotten better discussions.)"*
- *"it can be hard to relate the topics to our daily work sometimes."*
- *"Occasionally, a bit too abstract, a bit hard to identify the true value and intent of the course. "How will this benefit me?"*
- *"The stickers and the flip-overs have been widely used. Even when we have got the time to sit down and discuss the topics, it is not always that easy to come up with individual comments on the stickers. Hence, it is more easy to look into what other students write and copy it. But that may be some of the point, to just get our minds working"*

An interesting topic popped-up in the concerns and free comments: does Reflective Practice have value for more experienced students? Some argue that more expereinced students have less need for such course, while others observe that expereinced employees also may benefit from reflective capabilities. Here are some of the quotes:

- *"Maybe this is not as valuable for everybody, people with a lot of work experience for example. Sometimes it might be going too slow for people."*
- *"Some of the subjects are already well known for most people at a certain age, and it generates time consuming work which often do not reflect the value of doing it."*
- *"I would even recommend the reflective practice (or a tailored version of it) to be set up for the part-time, fully employed students. "Are we doing high quality system engineering at my company? Why/why not?" "How is my role as system engineer in the real world, compared to how it is described by INCOSE or other instances' definition?""*

The open feedback question results in several suggestions for improvement, such as:

- *"it would be nice to have a visiting experienced SE practitioner for some of the workshops"*
- *"It will be a good idea if we arrange 5 hour-session and fewer sessions."*
- *"I propose to have this courses in classrooms with a «round» table. This could bring more of the student in to a better discussion together."*

10. How to proceed?

Both educational institute and industrial partners need intensive cooperation to tackle the challenges of applying systems engineering in practice. The mindset and experience of the company and the colleagues are a typical example of a change management challenge, with industry partners as prime owners; the educational institute can offer support, however, the change has to happen in industry itself. The educational institute can work on most personal factors (with the students as main owner). Designated individuals from industry partners can offer mentoring and support to enhance effectiveness of the educational effort significant.

The first step to improvement is to understand the current situation. The data collected for this paper and its analysis is covering this step. Now we have to share this information with the main stakeholders: industry partners, educational staff, and students. Prerequisite for an effective follow-up is to allocate clear and specific owners.

11. Conclusions

Experiential learning is a natural approach for systems engineering, since systems engineering is heavily experience based. A significant challenge is that the distance between the state-of-practice in industrial companies and the theory taught in education is significant. Reflective practice is a didactic approach targeted at bridging this distance. Reflective practice is, despite its "soft" image appreciated by the students. We went ourselves through a learning cycle, resulting in an evolution of the course. Feedback from the students shows that educational institute and industrial partners still need to work on the distance between theory and practice. Limited skills in systems engineering and the mindset of colleagues form one of the obstacles that industry and school need to resolve. Industrial and educational owners have to define an improvement plan to overcome these obstacles, with the Reference Group as sounding board.

12. Future work

The past assignments of Reflective Practice contain more valuable information that needs analysis. Future research can monitor the further development of Reflective Practice, the improvement process of the systems engineering program, and especially the effects of the improvements.

Acknowledgements

The reviewers demanded analysis of students' appreciation and the impact on their work and learning. This provided a stimulant to collect and analyze such data; section 9 shows the result. Past and current students responded quickly and openly to the survey. Their responses helped to shape this paper and facilitate future evolution of Reflective Practice.

References

1. Schon, D.A., *The Reflective Practitioner: How Professionals Think in Action*, Ashgate Publishing Limited, 1984
2. Kolb, D.A, *Experiential learning: Experience as the Source of Learning and Development*, Englewood Cliffs, NJ: Prentice-Hall, 1984.
3. Faanes, M.R., *Developing Reflective Engineers Including work practice in the curriculum*, PhD thesis, NTNU Trondheim, 2014
4. European Commission, Education and Culture, *Explaining the European Qualifications Framework for Lifelong Learning*, Luxembourg: Office for Official Publications of the European Communities, https://ec.europa.eu/ploteus/sites/eac-eqf/files/brochexp_en.pdf, 2008
5. Reichheld, F. The One Number You Need to Grow, Harvard Business Review 2003
6. Keiningham, T, L. Aksoy, L. Cooil, B. Andreassen, T, W. (2008). Net Promoter, Recommendations, and Business Performance: A Clarification on Morgan and Rego. Marketing Science.Vol.27, No. 3, May-June 2008, pp. 531-532.